CHAPTER VII

The lake

CHAPTER VII

7.1 Introduction

India is endowed with a large number of fresh water lakes (4290 large lakes) that are in use for centuries by the mankind (Sugunan 1995; Suryanaryana 1996). Natural fresh water lakes are also prevalent up to 5000 m elevation in the Himalaya that has cold arid climate in the west to humid in the east (Fernando 1984; Gopal and Krishnamurthy 1993). Origin of such natural lakes are diverse that could be related to geological factors such as glaciation, land-mass movement, thrusts and wind actions. These natural lakes are located at various elevations in the entire length of the Himalaya from Kashmir in the west to Arunachal Pradesh in the east. The lakes of the western and central Himalaya have been studied by various workers (Zutshi *et al.* 1972; Kaul 1977; Sharma and Pant 1979; Zutshi *et al.*1980; Purohit and Singh 1981; Kaul and Handoo 1987; Pant and Joshi 1987; Wanganeo and Wanganeo 1991; Khulbe 1993; Joshi and Sundriyal 1995) for their structure, limnology, history and functioning. However, the study on lakes in the eastern Himalaya have largely remained ignored and are not comparable to the central and western Himalayan lakes for many reasons most significantly because of contrasting environmental set up and climate.

Varieties of environmental impact can occur when the land use is disturbed affecting the total volume and rate of stream flow, overland flow and nutrients outflow (Loshali 1989; Singh and Das 1995). It causes harmful impacts more on the standing body of water which is exceedingly complex physico-chemical-biological entity balanced by nature and ready to explode on slight interference. Vulnerability to such a trauma is more for smaller water bodies (Welch 1952). The suspended microscopic plants and animal life of the lake are of prime importance in the study of lake ecosystem as they interact with each other and the physical environment and give a clue of eutrophication thus predicts the health of the lake (Ohle 1956; Goldman 1968).

The ecosystem approach of lake basin study has been lacking in the mountain regions and considered mostly the limnological aspect and the drainage part as different entities. Sedimentation and nutrient flow in relation to lake longevity has not been assessed yet in lakes of the Sikkim Himalaya. The present study involves a nested watershed lake basin and details on hydrologic process and sediment concentration, seasonal nutrient dynamics of lake and bog, plankton composition and productivity of a closed basin.

7.2 Materials and methods

The present investigation was undertaken in Khecheopalri lake area which showed two distinct environments viz. the lake (3.8 ha) and the bog (7 ha). The hydro-ecological studies were carried out at six sites, four in the lake periphery as Site-I (South-East), Site-II (North-East), Site-III (North-West), Site-IV (South-West) and one each in the perennial inlet sources (North-West) and outlet (South-West). Site-I and Site-II were considered as the disturbed sites which received pressures of pilgrimage, tourism and livestock grazing in the bog and watershed area that comprised mostly of agricultural lands and settlement. In contrary, Site-III and Site-IV were considered as relatively undisturbed sites which were not accessible by tourists and pilgrims, and the watershed area is covered by dense forest (Fig. 7.1) Water samples were collected from all the six sites comprising four from the lake periphery and rest two from the inlet and the outlet sources for the detailed physicochemical analysis. Besides, the physico-chemical analysis of bog water from Site I and Site III considering the bog disturbed (BD) and bog undisturbed (BUD), respectively was also performed (Fig. 7.1).

7.2.1 Precipitation, discharge and sedimentation

Precipitation was measured by using rain-gauze for a period of two years (1997-1998). The discharge was measured at the inlets and outlets with the help of wooden rectangular weirs installed at the site. The height of the water was measured daily twice a day and the values were pooled together on monthly basis. Discharge from the seasonal inlets were measured in the rainy season only. Sediment concentration was estimated by collecting water samples on monthly basis and filtering it with Whatman filters paper no 42. The filter paper was air-dried and the sediment concentration was weighed in the electronic balance.

Samples of inlets, outlets and the lake water were collected bimonthly for major chemical analysis and values were pooled for three seasons. The samples were transported to the laboratory within 24 hours of collection. The temperature and transparency was measured in the noon time (12 to 1 p.m.) on each sampling day at all the sites of the lake.

7.2.2 Physico-chemical analysis of water

The water samples for chemical analysis were collected between 9 to 11 h in 1.5 litre polythene bottles at the depth of 5 to 10 cm by hand and at the surface on the bog. The pH values and conductivity were determined in the non-filtered samples and remaining samples were filtered and stored in the refrigerator for analyses within seven days.

Temperature was measured with the help of a good quality mercury thermometer having the range up to 50 °C. The pH of water samples was measured using digital systronics pH meter. Conductivity was measured by the systronics conductivity meter and the values were computed in μS. Transparency was measured by the Secchi disk of 20 cm diameter, having alternate white and black bands and attached to a string.

Dissolved oxygen (DO) of water was estimated by the Azide modification method (Eaton *et al.* 1995). The sample was fixed at the site with 2ml each of $MnSO_4$ and alkaline iodide azide solution in 300 ml BOD bottles and later the precipitate formed was dissolved with H_2SO_4 in the laboratory and titrated against 0.025 N sodium thiosulphate solution using starch as an indicator until the blue color disappeared. DO was calculated as

$$DO\ (mg/1) = \frac{V \times N \times 8 \times 1000}{\text{ml of sample}}$$

where V = ml of sodium thiosulphate used

N = normality of sodium thiosulphate

8 = equivalent weight of the oxygen.

Total alkalinity as $CaCO_3$ was estimated by titrating the sample with 0.1 N HCl using phenolphthalein and methyl orange as indicators.

$$\text{Total Alkalinity as } CaCO_3\ (mg/1) = \frac{X \times N \times 1000 \times 50}{\text{ml of sample}}$$

where X = ml of total HCl used for titration

N = normality of HCl

Total acidity as $CaCO_3$ was estimated by titrating the sample with 0.05N NaOH using methyl orange and phenolphthalein as indicators.

$$\text{Total Acidity as } CaCO_3 \text{ (mg/l)} = \frac{Y \times N \times 1000 \times 50}{\text{ml of sample}}$$

where Y = ml of NaOH used for titration

N = normality of NaOH.

Free carbon dioxide was determined by titrating the sample with NaOH using phenolphthalein as an indicator.

$$CO_2 \text{ (mg/l)} = \frac{V \times N \times 1000 \times 44}{\text{ml of sample}}$$

where V = ml of NaOH solution used

N = mormality of NaOH solution

Chloride was estimated by Argentometric method (Eaton *et al.* 1995) by titrating the samples with 0.014 N silver nitrate solution using potassium chromate as an indicator.

$$\text{Chloride (mg/l)} = \frac{V \times N \times 1000 \times 35.5}{\text{ml of sample}}$$

where V = ml of silver nitrate solution used

N = Normality of silver nitrate solution.

Total nitrogen was determined by Kjeldhal method (Cunniff 1995) by the digestion of the sample with sulfuric acid and potassium sulfate which converts all the organic nitrogen and ammonia into ammonium sulfate. NaCl is added to prevent the partial reduction of nitrate to ammonia, which converts NO_3 into NaOCl. The nitrogen in the form of ammonium sulfate can be determined by distillation and titrating it with HCl

$$\text{Kjeldahl N (mg/1)} = \frac{(a-b) \times 0.01 \times 1000 \times 14 \times D}{\text{ml of sample distilled}}$$

where a = ml of HCl used with sample

b = ml of HCl used with blank

D = dilution factor (2.5) where the original sample has been made to 100 ml after digestion.

Ammonium nitrogen was estimated by Kjeldhal method (Allen 1989) using magnesium oxide and titrated with M/140 HCl in the presence of boric acid indicator.

$$\text{Ammonium nitrogen (mg/1)} = \frac{(a-b) \times 100}{\text{ml of sample}}$$

where a = ml of HCl used with sample

b = ml of HCl used with blank

Phosphate phosphorus was estimated by stannous chloride method (Eaton *et al.* 1995) using molybdate reagent and stannous chloride and absorbance was read at 690 nm in spectrophotometer.

$$\text{Phosphate phosphorus (mg/1)} = \frac{\mu g\ P \times 1000}{\text{ml of sample} \times 1000}$$

Biological Oxygen Demand (BOD) was estimated by titration method (Eaton *et al.* 1995) measuring the differences of oxygen concentration by azide modification method between the initial sample and incubating the sample for 5 days at 20 ^{o}C in dark.

BOD (mg/l) = $(D_O - D_5)$

where D_O= Initial dissolved oxygen in the sample

D_5 = Dissolved oxygen after 5 days of incubation

7.2.3 Plankton analysis

Water samples of known volume were filtered through a silk net (50 μ mesh) and preserved with Lugol's solution. The Plankton assessed using this method appeared low, therefore water samples were centrifuged at 1500 rpm for 20 minutes and estimated the plankton. Calculation of plankton was based on concentration factor resulting from centrifugation of the samples (Trivedy and Goel 1986). Plankton counting was done in Sedgewick rafter counting cell having dimension of 50 mm long, 20 mm wide and 1 mm deep (Eaton *et al.* 1995). Plankton identification was made with the help of standard books (Edmondson 1962; Prescott 1978; Eaton *et al.* 1995). Members of the phytoplankton community either single celled (*Ankitrodesmus* sp. and *Chlorella* sp.) or colonial forms (*Microcystis* sp. and *Coelastrum* sp.) or filamentous forms (*Oedogonium* sp. and *Spirogyra* sp.) were counted as single units/individual. This census of the phytoplankton is described as 'density'. Per cent composition of plankton were calculated based on bio-volume.

As the number of individuals do not give true picture of actual biomass, the number was multiplied by the average cell volume. The volume is calculated from the mean dimension of the cell assuming that their form roughly corresponds to simple geometric solids [Sphere: $(4r^3\pi)/3$; Cone: $(r^2\pi h)/3)$; Cylinder: $(r^2\pi h)$] following Vollenweider (1969) and Sarkar and Jana (1985) to compute in μm^3/ml. The cell volume was converted to biomass (g/m^3) assuming that the specific gravity to be 1.0 (Willen 1959; Nauwerck 1963). Distribution pattern of different species was determined following Pandey *et al.* (1995). The maximum value of occurrence at the site was considered to be hundred per cent and species were divided into three classes i.e. 0-25 (species just present), 26-50 (species commonly present) and 51-100 (dominant species).

Similarity index was calculated for plankton considering both sites and conditions in relation to its seasonal dynamics. It was calculated with the formula 2C/A+B (Sorensen 1948), where A and B were number of species present in two different sites or conditions and C is the species common to both the sites or conditions. Species indices of plankton were calculated on seasonal basis at two sites and conditions using Margalef's (1957) for richness (d)=(S-1/*ln*(N); Pielou's (1966) for evenness (e)=*H*/*ln*S; Shannon (1948) for diversity (H)=-$\sum$ pi *ln* a(pi) and Simpson (1949) for dominance (cd)= $\sum(Pi)^2$ where, S= total number of species, N=total number of individuals of all the species, Pi= Proportion value of *i* species. Analysis of variance (ANOVA) was done for nutrients following Systat (1996).

7.2.4 Productivity of the Lake

Gross primary productivity, respiration and net primary productivity was estimated by the light and dark bottle method. (Gaarder and Gran 1917). The water of the initial bottle was fixed with 2 ml each of $MnSO_4$ and alkaline iodide azide solution in 300 ml BOD bottles and rest two bottles light and dark were filled with water and suspended them in same water for two hours. Then the water of the light and dark bottles were fixed. The oxygen content of the water of the three bottles were measured.

$$\text{Gross primary productivity } (O_2 \text{ mg/l/hr}) = \frac{Dl - Dd}{h}$$

$$\text{Respiration } (O_2 \text{ mg/l/hr}) = \frac{Di - Dd}{h}$$

$$\text{Net primary productivity } (O_2 \text{ mg/l/hr}) = \frac{Dl - Di}{h}$$

where Di = Dissolved oxygen in initial bottle

Dl = Dissolved oxygen in light bottle

Dd = Dissolved oxygen in dark bottle

h = Duration of exposure in hours.

The values are then converted in mgC/m^2/day by multiplying with a factor 0.375 and the daily sunshine values with 9 hours in spring and 7 hours in winter for gross primary productivity and 24 hours for respiration.

The other biological component as fishes, aquatic birds and aquatic insects could not be studied in detail as the lake is considered sacred and local communities restricted the collection of living organisms from the lake.

7.3 Results

7.3.1 Hydrology

The Ramam watershed with an area of 12 km^2 is the catchment of "Rathong Chu" river whose water is drained by the Ramam Khola. The area that drains into the lake is 91 ha whose 68 ha area drains through two perennial and five seasonal inlets, and remaining 23 ha drains through overland flow directly into the lake (see Chapter V). There is one major perennial outlet through which the water movements out of the lake. Besides, the lake is fed with subsurface flow, seepage from the watershed and the direct precipitation over the lake and bog area, which could not be measured in the present study.

7.3.1.1 Precipitation, discharge and sedimentation

The total precipitation was recorded 3899 mm in 1997 and 3776 mm in 1998 (Figs. 7.2 & 7.3). The highest rainfall recorded in the month of July was 1262 mm in 1997 and 1279 mm in the month of August in 1998. The highest rainfall (around 85%) was recorded during the rainy season and remaining 15% during winter and spring seasons.

The inflow of water from all the seven points, which included 5 seasonal and 2 perennial inlets was monitored for a two year period. The five-rainfed inlets showed water flow between May to November. The annual inflows of water recorded in the inlet sources were 1103 $x10^6$l and 1174 $x10^6$l in 1997 and 1998, respectively (Figs. 7.2 & 7.3). The outlet discharge was recorded 4279 $x10^6$ l in 1997 and 4072 $x10^6$ l in 1998. The highest outlet discharge was recorded in the month of August (2775 $x10^6$l in 1997 and 2795 $x10^6$l in 1998). The lowest discharge was recorded in the month of March (7.36 $x10^6$l in 1997 and 7.8 $x10^6$ l in 1998). About 74% excess discharge was recorded at the outlet compared to inlet discharge.

The sediment movement across the inlet and outlet sources also showed the seasonal pattern along with water flows and accounted to be highest (164 Mg in 1997 and 366 Mg in 1998) in the month of August at the inlet sources. At the outlet 252 Mg of sediment was recorded in 1997 and 330 Mg in 1998 (Figs. 7.2 & 7.3). Sediment concentration of discharge at the inlets and outlet was highest in the rainy season. It was much higher at the inlets compared to outlet, however outflow was far greater contributing to substantial sediment exit. The total annual inflow of sediment was 346 Mg in 1997 and 599 Mg in 1998 from the inlet sources. The exit from outlet showed 316 Mg in 1997 and 380 Mg in 1998. Around 29 Mg of silt deposition was recorded in 1997 and 219 Mg in 1998. High sediment in 1998 was caused as a result of landslide in one side of the lake.

7.3.2 Nutrient dynamics

7.3.2.1 Lake

pH: It was observed that the water from all the sites was circum-neutral to alkaline. It was highest in the rainy season and lowest in winter season except at the outlet. The pH ranged from 6.7 to 7.8 in 1997 and 6.6 to 8.6 in 1998 at various sites in the lake (Tables 7.1 & 7.2). Mean pH ranged from 7.8 in winter to 8.2 in rainy seasons in the lake (Fig. 7.4). Analysis of variance showed that the pH varied significantly between sites and seasons (Fig. 7.4).

Temperature: The temperature varied between 8.7 °C to 20.0 °C in 1997 and 8.9 °C to 19.2 °C in 1998 during winter and rainy seasons, respectively (Tables 7.1 & 7.2). Mean value of 8.8 °C in winter and 19.6 °C in rainy season was recorded. It was lower in the spring season at the inlet during both the years of the study. Variation in temperature was recorded significant between sites and seasons (Fig. 7.4). Since their recorded significant between sites and seasons (Fig. 7.4). Since their interaction was also significant, LSD value difference between the means showed that site to site variation was not apparent except for the inlet water with other sites.

Transparency: The transparency in 1997 was recorded 75 cm in the rainy season and 138 cm in winter. In 1998 the values were recorded still lower with 65 cm and 130 cm in rainy season and winter, respectively (Tables 7.1 & 7.2). Transparency was recorded lower at site I compared to the other sites. Average transparency for all the sites was 104 cm. It varied significantly with sites and seasons, and their interaction was also found to be significant (Fig. 7.4).

Acidity: Acidity of the lake varied between 3 to 15.8 mg/l in 1997 and 5 to 12.5 mg/l in 1998 at various sites in the lake (Tables 7.1 & 7.2). It was recorded higher in the rainy season at the inlet compared to other sites during both the years of study. It showed significant variation between sites and seasons, and their interaction was also significant. LSD value difference showed that mostly the means varied significantly except between some sites (Fig. 7.4).

Alkalinity: Alkalinity ranged from 13.3 to 36.6 mg/l in 1997 and 16.7 to 32.6 mg/l in 1998 (Tables 7.1 & 7.2). It was recorded highest in the spring season followed by winter and least in the rainy season. The total alkalinity varied significantly between sites and seasons, and their interaction was significant (Fig. 7.4).

Electrical conductivity: Conductivity values ranged from 13 to 65 μS in 1997 and 15 to 133 μS in 1998 at various sites of the lake during spring and rainy months, respectively (Tables 7.1 & 7.2). The highest electrical showed higher conductivity during both the years in the spring season. It varied significantly between sites and seasons, and their interactions was significant (Fig. 7.4).

Free carbon dioxide: Free carbon dioxide ranged from 4.1 mg/l to 6.95 mg/l in 1997 and 4.46 mg/l to 6.6 mg/l in 1998 at various sites of the lake. It was recorded higher during the winter season. It varied significantly between sites and seasons, and their interactions was significant (Fig. 7.5).

Dissolved oxygen: Dissolved oxygen ranged from 1.96 to 10.09 mg/l in 1997 and 0.98 to 9.76 mg/l in 1998 at various sites (Tables 7.1 & 7.2). The highest values were recorded during the rainy season followed by spring and least during the winter season (Fig. 7.5). It was higher in all the seasons at the inlet and varied significantly between sites and seasons (Fig. 7.5).

Ammonium nitrogen: Ammonium nitrogen ranged from 0.5 mg/l to 2.6 mg/l in 1997 and 1.14 mg/l to 3.25 mg/l in 1998 at various sites (Tables 7.1 & 7.2). The NH_4-N varied significantly between sites and seasons (Fig. 7.5).

Total nitrogen: Total nitrogen of the lake, inlet and outlet waters varied significantly among sites and seasons. It ranged from 2.56 mg/l to 6.9 mg/l in 1997 and 4.3 mg/l to 10.6 mg/l in 1998 (Tables 7.1 & 7.2). The mean total nitrogen of two years ranged from 3.7 to 9.7 mg/l showing higher values at the outlet in all the seasons (Fig. 7.5).

Chloride: Mean chloride concentration was highest in the winter season reducing in rainy and the lowest in spring. Chloride concentration ranged from 2.65 to 9.47 mg/l in 1997 and 4.79 to 10.49 mg/l in 1998 at different lake sites. It varied significantly between sites and seasons and their interaction was significant (Fig. 7.5).

Phosphate phosphorus: Phosphate phosphorus ranged from 0.1 mg/l to 0.16 mg/l in 1997 to 0.05 mg/l to 0.21 mg/l in 1998 at various sites of the lake (Tables 7.1 & 7.2). It is recorded higher at all the sites during the rainy season (Fig. 7.5). It varied significantly between sites and seasons, and their interaction was also significant (Fig. 7.5).

7.3.2.2 Bog

The pH of the water of the bog was acidic with 3.8 to 4.4 at both the sites during the rainy season. It varied significantly with the sites but not with seasons. Alkalinity was recorded higher (26.66 mg/l) in the winter season and lower in the rainy season (16.66 mg/l) at the disturbed site (Table 7.3). Conductivity was recorded higher in the rainy season and ranged from 26 to 28 µS at undisturbed and disturbed sites, respectively. Alkalinity and conductivity varied significantly with sites and seasons but their LSD difference between means do not show significant variation during the rainy season. Dissolved oxygen peaked in the rainy season with 4.11 mg/l and carbon dioxide in the winter season with 4.93 mg/l (Table 7.3). The dissolved oxygen varied significantly only with the seasons, but the carbon dioxide showed significant variation between both the sites and seasons. Ammonium nitrogen ranged from 0.16 to 0.73 mg/l during the winter and rainy seasons, respectively. Total nitrogen ranged from 4.2 to 7.6 mg/l (Table 7.3). Ammonium nitrogen and total nitrogen did not show significant variation between sites, but varied significantly with seasons. The chloride concentration was higher in the winter season (9.45 mg/l) at the undisturbed site of the bog. The phosphate-phosphorus was recorded higher during the rainy season (0.281 mg/l) and lower (0.24 mg/l) in the winter season. It did not show significant variation with sites, but was significant between seasons (Table 7.3).

7.3.3 Plankton composition and seasonal dynamics

7.3.3.1 Seasonal distribution and the similarity index of plankton

The detailed systematic list of the species of phytoplankton and zooplankton identified in the Khecheopalri lake and bog are given in Appendix 3. A total of 48 species of phytoplantkon were collected and identified during the study period. Phytoplankton species composition belonging to different families showed chlorophyceae (18) to be the most dominant group, followed by chrysophyceae (15), cyanophyceae (11), and one species each of charophyceae, euglenophyceae, dinophyceae and cryptophyceae. These species were confined to water either in the lake or bog. Cyanophycean group was higher in the lake compared to the bog. Some of the species such as *Ankistrodesmus* sp., *Gloeocapsa* sp., *Lyngbya* sp. and *Microcystis* sp. were found to be dominant in the lake water whereas they had mere presence in the bog. The most common species shared by both the lake and the bog water were *Nitella* sp., *Mougeotia* sp., *Oedogonium* sp., *Bulbochaete* sp., *Euastrum* sp. and *Cosmarium* sp. (Table 7.4). Species like *Synendra* sp., *Asterionella* sp., *Terpsinoe* sp., *Cymbella* sp., *Characium* sp., *Penium* sp., *Aphanizomenon* sp., *Oscillatoria* sp., *Fragilaria* sp., *Anabaena* sp., *Spirulina* sp., *Lyngbya* sp., *Colacium* sp. and *Cryptomonas* sp. were confined to the lake and absent in the bog (Table 7.4).

A total of 18 species of zooplankton from the lake and bog were recorded that comprised of 7 rotifers, 5 protozoans, 2 each of copepods and cladocerans, and 1 each of ostracods and isopods (Table 7.4). *Asplanchna* sp. and *Notholoca* sp. were absent in the bog, whereas both the lake and bog shared the protozoans and other groups. *Difflugia* sp. was dominant in the lake water while it was just present in the bog (Table 7.4).

The lake conditions (disturbed and undisturbed sites) showed more similarity in species composition than the bog during rainy season. Among the lake conditions the similarity index was highest (0.59) with eighteen common species of phytoplankton. *Cosmarium* sp., *Euastrum* sp., *Nostoc* sp., and a few filamentous algae such as *Oedogonium* sp. and *Phymatodocis* sp. were dominant common species. Similarity decreased in winter (0.375) in the lake site conditions where only six species were found common (Table 7.5). It was almost similar in the rainy and winter seasons in the bog when compared among disturbed and undisturbed conditions where ten species were found common during the rainy season. Mostly filamentous forms such as *Spirogyra* sp., *Oedogonium* sp., *Mougeotia* sp. and *Uronema* sp. with a few other forms such as *Gleocapsa* sp. and *Nitella* sp. were recorded in the bog. In the winter season only four species shared both the site conditions and they were *Nitella* sp., *Cymbella* sp., *Mougeotia* sp. and *Peridinium* sp. Comparatively, disturbed site conditions were found to have greater similarity of species than the undisturbed site conditions in both the sites during rainy and winter seasons (Table 7.5). Comparison of both the sites and conditions showed that the species were highly dissimilar (0.811) during rainy and no similarity of species during winter indicating that most of the species were site specific.

Zooplankton also showed the similarity to be higher in the lake site conditions during the rainy season (0.833) followed by spring (0.700) and least in winter (0.615). In the bog, higher similarity (0.526) was recorded among both the two conditions in the rainy season. Phytoplankton at the disturbed conditions of the lake and the bog were more similar than undisturbed conditions, whereas in the case of zoolpankton the disturbed condition had slightly less similarity (0.430) than the undisturbed condition (0.471) in the rainy season. The undisturbed sites were dominated by copepods and ostracods. In the winter season at the disturbed condition similar trend as that of phytoplankton showing more similarity of species with complete absence of copepods and ostracods was recorded (Table 7.5). Taking into consideration for all the sites and conditions, zooplankton showed slightly more dissimilarity in the winter (0.9) than in the rainy season (0.81).

7.3.3.2 Plankton bio-volume

Chlorophyceae was dominant group with respect to bio-volumes at all the seasons and site conditions. It's contribution ranged from 60 to 90% during spring season in the lake, which is mostly attributed to filamentous form such as *Uronema*, *Spirogyra* and *Bulbochaete* species (Fig. 7.6). The other species group contributed 27% at the disturbed condition of the lake which was mainly influenced by *Cryptomonas* and *Colacium* species.

Rainy season showed well mix of all the groups, however the greater bio-volume was contributed by chlorophycean group with 67 to 73% in the lake, and 95 to 96% in the bog. Cyanophycean algae contributed 19% of the bio-volume at the lake disturbed condition dominated by *Oscillatoria*, *Gleocapsa*, *Nostoc* and *Synechoccus*. Other species group contributed only 0.2 to 3% and was mainly represented by *Nitella*, *Colacium*, *Peridinium* and *Cryptomonas* species at both the conditions of the lake, while by *Nitella* only in the bog (Fig. 7.6).

Winter season was well represented by the dominance of chrysophycean group in number. However, its bio-volume contribution was only 22 to 29% in the lake, and 6 to 10% in the bog (Fig. 7.6). The chlorophycean group in terms of bio-volume contributed 66 to 94% at both the sites and conditions.

The zooplankton number varied with seasons and their per cent contribution revealed that rotifers and protozoans were present throughout the year. During the spring season, zooplankton numbered around 22/ml being higher at the disturbed site of the lake. The rotifers were dominant during this period with 12 individuals mostly represented by *Asplanchana* and *Notholoca* species but contributing only 1% of bio-volume. In terms of bio-volume "other species group" contributed 77% at the disturbed site and 98% at the undisturbed site of the lake (Fig. 7.6).

During the rainy season number of zooplankton varied between 7 to 10/ml in the lake water and 11 to 14/ml in the bog with higher number at the disturbed condition in the lake and undisturbed condition in the bog. Protozoans and copepods were well represented groups in both the sites. However the higher bio-volume was contributed by the other species group which contributed around 97% and was mostly represented by *Cypriodopsis, Sida* and *Gammurus* species (Fig. 7.6). Copepods contributed around 3% biomass being highest in disturbed condition with two species each of *Cyclops* and *Mesocyclops*.

The number of zooplankton ranged from 11 to 16/ml in the bog during the rainy season. Protozoans peaked during this season followed by rotifers. Copepods and ostracods were absent from both the sites and site conditions during the winter season. Cladoceran was dominated by *Daphnia* sp. that contributed 99% of bio-volume during the winter season (Fig. 7.6). *Gammurus* belonging to the "other species group" was found to be present only in the disturbed conditon of the bog.

7.3.3.3 Seasonal population density and biomass

The phytoplankton density was $0.75x10^4$ units/l at the bog and $4.84x10^4$ units/l in the lake, recorded during the winter season, and highest value of $5.57x10^4$ units/l at the bog and $19.45x10^4$ units/l in the lake during the rainy season (Fig. 7.7). In all the seasons, higher density values were recorded at the undisturbed condition of the lake, in contrary to the bog where highest values were in the disturbed condition (Fig. 7.7). Phytoplankton biomass ranged between 1.84 to 6.10 g/m^3 in the lake and 0.63 to 7.03 g/m^3 in the bog (Fig. 7.8). The biomass was greatest in the rainy season at both the sites and conditions. The contributions of *Spirogyra* sp., *Mougeotia* sp., *Oedogonium* sp. and *Uronema* sp. were highest in the rainy season. In all the seasons, higher biomass was recorded at the undisturbed conditions in case of the lake whereas it was highest at the disturbed site condition in the bog (Fig. 7.8).

The zooplankton density ranged from $0.70x10^4$ units/l in the undisturbed condition in the rainy season to $2.20x10^4$ units/l in the spring season at the disturbed condition of the lake. The density was recorded highest (1.6×10^4 units/l) in the bog during winter season (Fig. 7.7). In the bog, higher density was recorded at the undisturbed condition in rainy and disturbed condition in the winter season (Fig. 7.7). Biomass in terms of fresh weight did not reveal any relationship with density. Zooplankton biomass was relatively low compared to phytoplankton biomass in all the seasons. A sudden increase in biomass during winter (4.54 g/m^3 in the bog and 4.43 g/m^3 in the lake) was recorded and was contributed mainly by protozoan and cladoceran groups (Fig. 7.8). Rotifers, which were the largest contributor to total population during the spring and rainy seasons in terms of number, could not form a sizeable part as biomass resulting from their small size. Disturbed condition of the bog showed higher biomass of zooplankton compared to undisturbed condition in both the rainy and winter seasons (Fig. 7.8).

7.3.3.4 Diversity indices

Seasonal analysis of species richness, evenness, diversity and dominance at different site conditions in the lake and bog were made and presented in Table 7.6. The species richness of phytoplankton was recorded highest in the rainy season and lowest in the winter season with values higher in disturbed conditions of both the sites compared to undisturbed site conditions. The diversity index also followed the similar pattern being higher in disturbed site conditions than the undisturbed site conditions in the rainy season. Species like *Anabaena* sp., *Lyngbya* sp., *Fragilaria* sp., *Aphanizomenon* sp., *Asterionella* sp., *Rhoicosphenia curvata, Hantzschia amphioxys* and *Melosira* sp. were present at only certain time of the year.

The evenness was higher in spring (0.85) in undisturbed condition and rainy (0.88) in disturbed condition of the lake. The evenness was recorded highest in the spring season in the undisturbed site condition, reduced in rainy and again increased during the winter season. However in the case of disturbed condition, evenness was higher in the rainy season with greater number of species with less dominant species than the undisturbed condition. Evenness was always recorded higher in the rainy season along with species diversity and the richness index resulting from higher number of species. The dominance index showed the inverse relation with diversity being higher in winter season at both the sites and conditions.

The maximum species richness of zooplankton was recorded in the spring season (2.96) of the lake and rainy (3.79) of the bog. The richness of species in the spring season in both the site conditions of the lake was due to the presence of higher rotifer and protozoan groups. The diversity also showed the similar pattern but showed an inverse relationship with the dominance, which was least in the spring and rainy seasons in the lake and bog, respectively.

The dominance diversity curve has been repeatedly used to interpret the community organism in terms of resource share and niche space. The phytoplankton communities showed contiguous and non-overlapping distribution pattern with intense interspecific competition (Figs. 7.9 a & b). The overall density was recorded greater in the lake with dominating species like *Synedra* sp., *Chlorococcum* sp., *Ankistrodesmus* sp. and *Navicula* sp. In the bog, the dominating phytoplankton species was *Cosmarium* sp. represented as a typical chlorophyceaen member. Zooplankton showed intermediate sigmoid curve with partial rather than direct competition (Figs. 7.9 c & d). The overall diversity was low resulting from dominance by *Difflugia* sp., *Centroyxix* sp. and *Trichocerca* sp.

7.3.4 Plankton productivity and respiration

Gross primary productivity values showed higher trend in rainy season followed by spring and least in winter as the phytoplanktonic growth. The gross primary productivity varied between 16 to 250 mgC/m^2/d in 1997 and 15.5 to 243 mgC/m^2/d in 1998 (Table 7.7). The gross primary productivity showed highest value at site III during rainy season and lowest values in site I during winter season in both the years. Analysis of variance showed that the gross primary productivity significantly varied with sites and seasons (Fig. 7.10). The step-wise multiple regression analysis showed that natural logarithm of gross primary productivity was significantly related to temperature, free CO_2 and total nitrogen [*ln* gross primary productivity = 1.588 + 0.213 T – 0.127 CO_2 + 0.041 TN; R^2 = 0.956, F = 230, P<0.001].

Respiratory values of the lake water varied between 10.8 to 189 mg C/m^2/d in 1997 and 12.6 to 131.4 mgC/m^2/d in 1998 (Table 7.7). Respiratory loss significantly varied between seasons and sites (Fig. 7.10). The step-wise multiple regression analysis depicted significant relation of respiratory loss with total nitrogen, pH, temperature and carbon-dioxide [*ln*RES = 2.376 + 0.297 TN – 0.188 pH – 0.131 T – 0.066 CO_2; R^2 = 0.475, P= 7.004, P<0.001].

The net primary productivity showed negative values below zero during the winter seasons where as highest in rainy seasons. The net primary productivity values ranged from –43 to 178 in 1997 and –55 to 166 in 1998 (Table 7.7). Comparison of gross primary productivity and respiratory loss indicated that there was gain in productivity in rainy and spring seasons with positive net primary productivity, and loss in winter season with negative primary productivity (Table 7.7).

7.3.5 Faunal component

A detailed systematic list of faunal composition is given in Appendix 3.

7.3.5.1 Migratory birds

The lake and its surroundings form a very important habitats for many birds. The Trans-Himalayan migratory birds visit the site during winter months (November to March) as the lake and bog vegetation (marsh) provides the site for resting (see Photoplate 6). The most common ones were *Anas crecca*, *Mergus merganser orientalis* and *Athya ferina*. The number of migratory birds varied between 2-35, the highest species being observed during the months of December to February. A total of seven migratory bird have been identified during the study period (Table 7.8).

7.3.5.2 Fishes

A large number of fishes both indigenous and exotic were recorded in the lake. A total of seven species was identified. *Cyprinus carpio* was introduced by the State Forest Department during 1986 and seen to be dominating the lake. Some of these individuals decolourized to orange in recent years. *Schistura multifaciatus*, was recorded at the lake inlet of the lake and it is a new species report from the lacoustrine system of the Sikkim Himalaya. *Acrossochelius hexagonoiepsis* is an esteemed game fish as well as fish food in Sikkim. A trout *Schizothorax richardsonii* is the most dominant widely distributed species. It is an important game fish that has commercial value in the state. However, fishing is totally prohibited at the sacred Khecheopalri lake.

7.3.5.3 Amphibians and insects

Two species of amphibians were recorded. A large number of tadpoles were observed during the rainy season and disappeared by end of rainy season. These amphibians die in the peatland as a result of acidic condition and contribute to nutrient enrichment in the bog. A few invertebrates were also encountered from the lake and bog, among which *Gerris gracillocornis* a water strider was-very common. Various faunal components have their role to play in maintaining the ecological balance especially through actors in different trophic levels. A considerable detail work needed to understand the ecological balance which could not be taken up due to restrictions of animal collection and entry into the lake. The religious beliefs and sentiments of the local people were respected.

7.4 DISCUSSION

The Khecheopalri lake is "kettle hole" type with *Sphagnum* bog surrounding the open water surface. The broad-leaved forest surrounds the lake from all sides, hence it is protected from high wind action. The drainage of the lake is from the watershed through the perennial inlets and one major outlet. The water level in the lake decreased by 28 cm in the winter and 34 cm in spring compared to the highest level in the rainy season with 74% of excess outflow compared to the inlet water. This is expected due to the subsurface flow, internal seepage, overland flow and direct precipitation in the lake. Aquifers are also expected to be opening at the lake bottom. Hence the lake is considered polymictic type with continuous circulation.

The lake is gradually silting due to the sediment inflow from the surrounding watershed. Sediment buildup in the lake was rapid in recent years. On an average around 29 Mg of silt was deposited in the lake and bog every year through inlet sources only. Impacts of livestock grazing, trampling, deforestation and agricultural practices in the watershed area contributed to higher sediment concentration in the inlet water. High sediment deposition in the rainy season turned the lake turbid. The tremendously higher value of sediment deposition was recorded in 1998 with seven fold increase than that of 1997. It was due a landslide in August (30/8/1998) that resulted in the deposition of 32 cm silt at the northern part of the bog area. This affected the transparency of the lake tremendously and also deposition of silt.

It is a well-established fact that the metabolism of a lake depends on the continued inputs of nutrients. Nutrients entering the lake by the way of inlet streams or shallow seepage pass through the littoral zone. Acidity of the lake water was high with higher contents of free carbon dioxide. Hence, acidity of water was not controlled by free carbon dioxide rather it was due to the organic acids produced in the bog margins that percolated into the lake. Jewell and Brown (1929) showed that the acidity of certain northern Michigan bog lakes were not due to either the free carbon dioxide or the mineral acids but the organic acids present in the bog margins. Gessner (1929) and Waksman and Stevens (1929) postulated the origin of bog lake-water reaction depended on the chemical composition of the vegetations and the bottom materials of the lake. Free carbon dioxide showed positive correlation with temperature, acidity, dissolved oxygen and respiration. Water was sightly acidic at the outlet attributable to the outflow of vegetation and waste material from the lake. The lake water pH was not lowered although surrounded by the rich *Sphagnum* bog having low pH. *Sphagnum* does not invade alkaline waters directly but can only follow upon prior acidification by the more alka-tolerant organisms (Chouard and Prat 1929; Welch 1952). Potzer (1934) also reported that *Sphagnum* does not acidify the water. The temperature is basically important for its effects in the biological reactions of the organism. Surface water temperature was always higher compared to the ambient air temperature when recorded simultaneously. Water temperature showed a significant positive correlation with gross primary productivity, respiration, acidity, pH, dissolved oxygen and conductivity (Table 7.9).

Lake water was blackish in colour due to the addition of the eroded peat and the sediments from the surrounding bog. The marked seasonal variation of water transparency was controlled by the varying amounts of sediments, alga population, illumination and suspended organic matter. The significant difference in turbidity in two years was due to a landslide that took place during the second year of the study. The lower value of transparency was recorded in rainy season at Site I which was due to human interference and growth of a few hydrophytic plants. Negative correlation of transparency with gross primary productivity and respiration has seasonal effects rather than functional relationship. Sediment concentration in the lake water was higher lowering the transparency in the rainy season, while the gross primary productivity and respiration peaked in this season. Positive correlation of transparency with alkalinity can be explained by the decrease in alkalinity due to the formation of soluble $CaCO_3$ that precipitates decreasing the transparency level.

Acidity was mostly higher at the Site I resulting from the various offerings made there. People burn the leaves of *Cryptomeria japonica, Juniperus recurva* and *Juniperus indica* as incense and the remains are acidic which find their way to the lake. Offerings like flowers, leaves and fruits in the water on decomposition also lead to increased acidity. Alkalinity refers to the amount of carbonates, bicarbonates and hydroxide-ions and are commonly found in the form of carbonates of sodium, calcium and magnesium (Zajic 1971). Alkalinity is the combined effect of the several substances and conditions generally associated with hardness and excessive dissolved solids. Conductivity of the water depends on the amount of solids present (A.P.H.A 1976). Generally the bog lakes have low conductivity (Welch 1952). The values recorded are higher in 1998 as compared with 1997, which may be due to the inflow of silt. The highest electrical conductivity was recorded at Site II in 1998 attributed to greater ionic concentration arising from the inlet flow as well as due to the land slide that occurred during rainy season. Our results confirm to the report that lake receiving direct runoff from inlets contained noticeable amounts of mineral precipitates that increased conductivity (Plass 1975). It showed positive correlation with temperature and respiration, and negative correlation with alkalinity (Table 7.9).

Dissolved oxygen plays an important role in the physical and biological processes of the aquatic system. The highest value in the spring season resulted from increased aquatic photosynthesis. It was low in winter due to less photosynthetic activity and presence of higher zooplanktons. Our results are consistent with the report on a central Himalayan lake (Khulbe 1992).

The higher mean values of ammonium nitrogen in spring season was due to the ammonification of organic matter, and also indicative by the growth of *Ceratophyllum* sp. that is known to require high inorganic nitrogen levels in the growing season. Moreover, increase in ammonium nitrogen level during the winter and spring seasons was due to the agriculture runoff and the leaching of nutrients from the dead plants. The pressure of zooplankton during spring season also influenced the nutrient enrichment in the water column. It is increasingly clear that the food web structure and particularly density of annual species have substantial effect on the dynamics of nutrients in lakes (Sterner 1995; Carpenter *et al.* 1992). The inlet source in winter showed high ammonium resulting from ammonification of organic matter from the bog and the agricultural runoff. Ammonium nitrogen in disturbed condition and total nitrogen in both disturbed and undisturbed conditions peaked during spring season due to ammonification of organic matter and leaching of nutrients to the lake where as higher values during the rainy season at disturbed condition of the bog was expected due to agriculture runoff. Ammonium nitrogen was recorded lower in the bog surface water compared to the lake water because of decomposition of organic nitrogen and nitrification of the products processed rapidly in this relatively aerated zone and accumulated in the anaerobic condition (Tunseen and Patrick 1972).

Nitrogen is the central element in the entire ecosystem because of its role in the production of amino acids, which are building blocks of proteins. Comparison between seasons showed that it was lower in the rainy season attributable to dilution effect and due to the phytoplankton blooms. The increasing trend of nitrogen in the winter season was attributed by the decomposition of certain cyanophycean algae such as *Nostoc* sp. thereby increasing the nitrogen level in the water.

High chloride values from the inlet sources in the present study during rainy season was related with animal wastes from cattle grazing in the bog and watershed and the sewage disposed off by the household residing in the watershed. High chloride values during the winter months in the lake and bog were attributed with animal waste from cattle grazing. Excess of chloride over 5.5 mg/l in water was associated with contamination from animal organic matter (Soltero 1969; Knee Wood 1970; Khulbe 1992, 1993; Jain *et al.* 1999). The phosphate phosphorus content was effected by many factors such as agricultural runoff and sediment inflow. Main source of phosphorous in the lake was runoff from the disturbed land use of the watershed.

Plankton is the indicator of the trophic status of water bodies. The planktonic production depends on various biotic and abiotic factors (Welch 1952; Hutchinson 1967; Wetzel 1975). However, generalization of the community structure of plankton from the different lakes of the same as well as those of the different geographical areas is difficult (Pant *et al.* 1985). Further, a comparison between the species composition of the different lakes may not yield the correct information due to the differences in the methodology, number of samples and morphological features of the lake. However, species spectrum, richness, dominance, diversity and evenness of species give good information of the dynamic balance of a community (Pant *et al.* 1985). The Khecheopalri lake is dominated by chlorophycean group, followed by chrysophycean and least by cyanophyceaen group and has been found very much common in bog lakes as reported by Prescott (1951) and Welch (1952). The lake watershed experienced most rainfall (85%) during rainy season and the runoff from the surrounding watershed containing silt and other allochthonous material (including nutrients and other dissolved materials) were deposited into the lake (Jain *et al.* 2000) which is evident from the higher values of conductivity during rainy seasons. Fish population also play an important role in nutrient cycling (Vanni and Findlay 1990). Higher nutrients eventually triggered the growth of algae that peaked in the rainy season. The higher plankton in spring could be attributed partly to increasing temperature and light after winter, and also partly due to rich nutrient availability. The seasonal phytoplankton biomass fluctuation for the entire lake and bog indicates that high biomass was observed during the rainy season contributed mostly by the filamentous forms. During the rainy season the diversity increased and evenness decreased in the undisturbed condition of the lake due to blooms of certain dominant species, whereas it again increased in the winter season showing the resilience capacity. However, this trend was not apparent in the disturbed condition due to higher species number and presence of many short lived seasonal species. The high diversity in case of rainy season was attributed to the inflow of nutrients since most of the nutrients such as ammonium nitrogen, total nitrogen, phosphate phosphorus along with the dissolved oxygen and carbon dioxide did not show difference between site conditions. The heavy influx of nutrients during rainy season also lead to suppression of certain species and dominance by a few species, thus bringing competitive exclusion principle. The high saturation values of dissolved oxygen during spring and rainy seasons coincided well with the peak in abundance of plankton during the respective periods. The phytoplankton density was however lower than the reports from the central Himalayan lakes (Pant and Joshi 1987; Khulbe 1992) which depict that the lake is still in oligo-meso trophic condition. Total nitrogen and pH being high may be playing a significant role in the growth of chlorophycean algae since its contribution was higher in spring in undisturbed condition in the lake and winter in disturbed condition of the bog. Chlorophycean algae was dominant in spring season with *Chlosteridium, Chlorella, Ankistrodesmus, Characium* and rainy season with all filamentous forms such as *Mougeotia, Uronema, Spirogyra* and others like *Cosmarium, Chlamydomonas*, *Eustraum* and *Cylindrocystis.* This was due to continuous addition of nutrients from the surroundings. Pandey (1980), Blum (1960) and Khulbe (1993) supported the blooming of chlorophyceae algae during the spring and rainy seasons, and indicated initiation of eutrophication. Phillipose (1967) reported that the low acidity with pH range of 7.7 to 8.5 and bright sunshine were responsible for the development of chlorococcales. The blue-greens were low in proportion and peaked in the rainy season at the disturbed site of the lake which was due to the inflow of nutrients and decomposed peat along with the overland flow to the lake. Rao (1955) observed higher concentration of oxidizable organic matter and longer period of sunshine appeared to be responsible for the growth of blue green algae. *Microsystis, Nostoc* and *Lyngbya* are the dominant ones among the cyanophycean group. The death and decay of blue greens (*Nostoc* sp.) at the disturbed condition of the lake may be enriching the site with nitrogen during winter seasons that may have favoured the growth of diatoms during this season. Nitrogen as NO_3-N is mostly utilized by diatoms (Patrick 1948; Rao 1955). Species such *as Navicula, Synedra, Tetracyclus* and *Gomphonema* were commonly present at both the sites and conditions. Presence of these species may be due to fecal pollution of animal origin from the surroundings as evidenced from the high values of chloride and the sliding down of eroded peat. The sewage from the human settlements, trampling and nutrient enrichment by the grazing animals and the tourist are the contributors of fecal pollution in the bog and watershed forest. Palmar (1969) and Rai and Kumar (1977) also supported this view. The presence of *Oscillatoria* species is a reliable indicator of eutrophication (Hynes 1971), and confirmed that side of the lake receiving sewage and polluted waters from its surroundings adds eutrophication. The presence of a single species *Colacium* of euglinoides in the disturbed site of the lake depicts the hypertrophic condition distinguished by high loading of phosphate phosphorus, chloride, and organic matter. Singh (1959) and Pavoni (1963) also supported the views that euglinoides grow in nutrient rich environment. *Nitella* sp. was found dominant in the bog. This species is reported to be confined to soft water with humic acid (Edmondson 1962).

Rotifers and copepods were the most important component of the zooplankton community. Gophen (1973) reported that these two communities were of common occurrence in South-East Asian lakes. Copepods were represented mostly during warmer months in the spring and rainy seasons. Gophen (1973) and Pant *et al.* (1985) also reported these species during warmer months. The peak abundance of rotifers during warm season can be attributed to low population of diatoms in this period. Cladocerans were consistently low in abundance for most of the year except winter season. Seasonal variation in zooplankton abundance both in terms of number and biomass indicates a greater abundance of protozoans and rotifers. Zooplankton, although showed higher density in spring season, their biomass showed inverse relationship being higher in the winter season. This was mainly attributable to small sized rotifers. The abundance of protozoans and cladocerans were observed higher during winter season that contributed to greater biomass in both the site conditions. *Daphnia* sp. among the cladocerans was found to be more abundant during winter season since high temperature adversely affected its presence (Pant *et al.* 1985). Bell and Ward (1970) found that *Daphnia* sp. moved to cooler region of the lake when the temperature rose above 20 °C.

The ratio of the phytoplankton to zooplankton (P/Z ratio) was 1.46, which was within the range given by Ruttner (1937). Our results are similar to that of the lake Lanao (1.4) studied by Lewis (1979). Temporal abundance patterns in terms of density and biomass of three major trophic levels of plankton is shown in Fig. 7.11. Community structure and the predator-prey relationships was studied in order to know the trophic status of the lake. The successional variation of the major trophic levels of the lake showed relationship between density and biomass except during the winter season when the herbivore biomass exceeded the total phytoplankton biomass (Fig. 7.11). The increase of biomass of herbivores in the winter season was due to the presence of *Daphnia* sp. that attained higher biomass by grazing on producers (Romanovsky and Feniova 1985).

Productivity of plankton studied in the same lake revealed that energy stored during spring and rainy seasons were utilized in winter months (Jain *et al.* 1999).

The herbivores comprised of all the zooplanktonic groups except *Asplanchana* sp. of rotifers group, and *Cyclops* and *Mesocyclops* of copepods were the primary carnivores. The dominance of *Keratella* sp. of rotifers and *Daphnia* sp. among cladocerans in particular showed dominance during winter season where *Keratella* sp. showed affinity for filamentous or elongated cells. It appears quite possible that producers being fed upon by *Keratella* and *Daphnia* species which in turn fed upon by *Asplanchana* species. Fig. 7.11 showed that there is a large gap in biomass between herbivores and primary carnivore levels as compared to phytoplankton and herbivores. In general, first and second trophic levels have a direct relationship whereas second and third trophic levels indicate inverse relationships. This indicates that energy transfer between the first and second trophic levels is relatively more efficient than between second and third trophic levels. Perhaps fishes in the lake are playing a major role in controlling the population of the primary carnivore. Besides, the density of the herbivores was found slightly low during rainy season because of grazing by omnivorous fishes that breed during the rainy season stressing the herbivores. *Schiziothorax* species have more affinity towards the zooplankton during their fingerling stage causing reduction in less herbivore number.

It is apparent that the Khecheopalri lake supports luxuriant growth of both phytoplankton and zooplankton depicting its high aquatic biodiversity. The lake is presently dominated by chlorophyceae and chrysophyceae groups, however the eutrophic indicator species such as *Cryptomonas* sp., *Spirogyra* sp., *Anabaena* sp., *Oscillatoria* sp. and *Nostoc* sp. have invaded. This shows that the lake has been adversely affected by the inflow of silt and nutrients from the grazing livestock and the visitors that has initiated the eutrophication process in the lake. The interaction of algae, herbivores and the predators with favored climatic conditions has kept the lake within the resilience capacity however its longevity depends solely on the management of the surrounding watershed ■

Table 7.1 Physico-chemical parameters of lake water of Khecheopalri lake for the year 1997

Parameters		Site I	Site II	Site III	Site IV	Inlet	Outlet
pH	W	6.89± 0.005	6.89 ± 0.004	6.88 ± 0.02	6.75 ± 0.06	6.64 ± 0.03	6.83 ± 0.09
	S	7.01± 0.004	7.12 ± 0.01	7.12 ± 0.01	7.12 ± 0.03	6.70 ± 0.04	7.00 ± 0.09
	R	7.8±0.002	6.66±0.002	6.98±0.075	6.89±0.002	8.5±0.12	6.58±0.1
Temperature	W	8.7 ± 0.002	8.7 ± 0.002	9.2 ± 0.047	9.2 ± 0.02	12.1 ± 0.02	9.19 ± 0.002
(^{0}C)	S	13.6 ± 0.07	13.5 ± 0.05	13.4 ± 0.07	13.4 ± 0.05	12.5 ± 0.05	13.9 ± 0.15
	R	19.4 ± 0.05	20 ± 0.07	20 ± 0.02	19.8 ± 0.19	17.8 ± 0.47	18.3 ± 0.05
Transparency	W	138 ± 0.13	128 ± 0.23	133 ± 0.4	129 ± 0.13	-	-
(cm)	S	112 ± 0.13	110 ± 0.13	112 ± 0.00	104 ± 0.13	-	-
	R	75 ± 0.04	80 ± 0.36	95 ± 0.27	75 ± 0.36	-	-
Acidity	W	6.7 ± 0.86	3.0 ± 0.81	5.8 ± 0.68	3.3 ± 0.72	3 ± 0.81	5.8 ± 0.68
(mg/ml)	S	14.2 ± 0.68	9.2 ± 0.68	11.6 ± 0.68	15.8 ± 0.68	19.2 ± 0.68	14.2 ± 0.68
	R	11.6 ± 0.68	8.3 ± 0.68	11.7 ± 0.68	5.0 ± 0.68	13.4 ± 0.68	14.2 ± 0.68
Alkalinity	W	28.2 ± 0.27	20 ± 0.24	20 ± 0.2.35	23.3 ± 0.28	20 ± 2.35	23.3 ± 0.1.2
(mg/ml)	S	36.6 ± 1.36	35 ± 2.35	31.6 ± 2.72	26 ± 2.72	26 ± 2.72	33.3 ± 1.36
	R	17.8 ±0.47	18.3 ± 1.36	16.7 ± 1.36	13.3 ± 1.4	14.4 ± 0.16	16.7 ± 1.36
Conductivity	W	28 ± 0.94	18 ± 0.94	19 ± 0.42	35 ± 1.86	18 ± 0.38	18 ± 0.47
(µS)	S	14.5 ± 0.95	13 ± 0.25	13 ± 0.47	16 ± 0.12	18.5 ± 0.17	19 ± 0.17
	R	60 ± 0.27	55 ± 2.35	65 ± 0.87	28 ± 0.94	37 ± 0.14	70 ± 2.3
CO_2	W	6.4 ± 0.12	6.4 ± 0.08	6.95 ± 0.05	6.2 ± 0.07	4.0 ± 0.06	6.99 ± 0.05
mg/ml)	S	4.22 ± 0.12	4.1 ± 0.07	5.1 ± 0.07	4.67 ± 0.03	5 ± 0.003	4.3 ± 0.16
	R	4.4 ± 0.09	5.1 ± 0.04	4.34 ± 0.05	5.0 ± 0.05	5.4 ± 0.09	4.1 ± 0.09
DO	W	2.36 ± 0.09	2.56 ± 0.09	2.07 ± 0.05	1.96 ± 0.8	4.1 ± 0.02	2.5 ± 0.02
(mg/l)	S	6.99 ± 0.26	7.0 ± 0.03	6.7 ± 0.06	7.0 ± 0.005	8.5 ± 0.02	6.9 ± 0.03
	R	7.9 ± 0.11	6.24 ± 0.04	6.55 ± 0.04	6.02 ± 0.02	10.09 ± 0.18	6.17 ± 0.01
NH_4-N	W	1.1 ± 0.12	0.8 ± 01	1.0 ± 0.05	1.1 ± 0.12	2.1 ± 0.02	1.2 ± 0.05
(mg/l)	S	0.61 ± 0.05	2.6 ± 0.05	0.87 ± 0.09	0.62 ± 0.04	0.62 ± 0.02	0.50 ± 0.05
	R	1.37 ± 0.16	0.58 ± 0.02	0.66 ± 0.13	1.12 ±0 .04	0.70±0.007	0.79 ± 0.01
Total nitrogen	W	5.95 ± 0.47	4.9 ± 0.32	4.9 ± 0.33	4.86 ± 0.1	4.99 ± 0.05	8. ± 0.05
	S	4.82 ± 0.2.8	6.1 ± 0.05	6.9 ± 0.02	4.68 ± 0.21	4.1 ± 0.09	6.9 ± 0.09
(mg/l)	R	4.18 ± 0.09	3.55 ± 0.33	2.56 ± 0.1.5	3.49 ± 0.33	2.56 ± 0.21	4.9 ± 0.33
Chloride	W	8.9 ± 0.02	7.99 ± 0.002	5.99 ± 0.49	7.1 ± 0.047	7.01 ± 0.01	5.1 ± 0.05
(mg/l)	S	3.15 ± 0.14	2.65 ± 0.136	3.24 ± 0.25	2.82 ± 0.14	2.65 ± 0.14	2.65 ± 0.27
	R	5.72 ± 0.36	6.59 ± 1.006	7.67 ± 0.13	9.47 ± 0.13	10.03 ± 0.19	8.98 ± 1.96
PO_4-P	W	0.13 ± 0.002	0.13 ± 0.002	0.12 ± 0.005	0.12 ± 0.01	0.12 ± 0.005	0.13 ± 0.01
(mg/ml)	S	0.12 ± 0.01	0.11 ± 0.002	0.1 ± 0.001	0.13 ± 0.02	0.1 ± 0.005	0.18 ± 0.18
	R	0.15± 0.002	0.16 ± 0.09	0.14 ± 0.002	0.15 ± 0.001	0.14 ± 0.002	0.12 ± 0.01

W=winter, S=spring, R=rainy

Table 7.2 Physico-chemical parameters of lake water of Khecheopalri lake for the year 1998

Parameters		Site I	Site II	Site III	Site IV	Inlet	Outlet
pH	W	6.99 ± 0.04	6.81 ± 0.007	6.89 ± 0.004	6.61 ± 0.035	6.55 ± 0.03	6.7 ± 0.01
	S	7.75 ± 0.11	7.62 ± 0.007	7.80 ± 0.25	8.16 ± 0.01	6.83 ± 0.04	6.89 ± 0.02
	R	8.5 ± 0.04	8.55 ± 0.04	7.35 ± 0.07	7.10 ± 0.06	8.62 ± 0.05	6.67 ± 0.01
Temperature	W	8.9 ± 0.002	8.9 ± 0.002	9.1 ± 0.02	9.1 ± 0.02	11.9 ± 0.03	9.53 ± 0.05
(^{0}C)	S	14.4 ± 0.04	14.5 ± 0.03	14.4 ± 0.05	14.4 ± 0.00	13.2 ± 0.02	14.1 ± 0.15
	R	19.2 ± 0.04	19.2 ± 0.02	19.1 ± 0.07	19 ± 0.07	19.2 ± 0.05	19.1 ± 0.05
Transparency	W	130 ± 0.23	112 ± 0.13	129 ± 0.14	123 ± 0.13	-	-
(cm)	S	114 ± 0.40	108 ± 0.4	108 ± 0.13	102 ± 0.27	-	-
	R	65 ± 0.36	67 ± 0.27	89 ± 0.13	69 ± 0.13	-	-
Acidity	W	5.83 ± 0.68	5 ± 0.00	5.82 ± 0.68	5.83 ± 0.68	5.8 ± 0.68	8.3 ± 0.68
(mg/ml)	S	12.5 ± 0.12	10 ± 0.00	12.5 ± 0.17	10 ± 0.00	5 ± 0.00	9.16 ± 0.68
	R	9.16 ± 0.68	11.7 ± 0.68	9.2 ± 0.68	11 ± 0.68	13.3 ± 0.68	14.1 ± 0.53
Alkalinity	W	32.6 ± 1.73	20.2 ± 2.35	22.4 ± 0.28	23.3 ± 0.28	22.3± 0.28	22.5 ± 1.17
(mg/ml)	S	25 ± 2.35	25 ± 2.35	20 ± 0.00	30 ± 0.00	31.6 ± 2.72	20 ± 0.24
	R	16.7 ± 1.4	20.2 ± 0.4	20.2 ± 2.4	21.66±1.4	23.33 ± 1.4	20±0.001
Conductivity	W	32 ± 0.94	22 ± 0.94	21 ± 0.54	45 ± 0.94	22 ± 0.94	22 ± 0.94
(μS)	S	15.5 ± 0.59	15 ± 0.47	17 ± 0.43	16 ± 0.47	19.5 ± 0.59	21 ± 0.27
	R	88 ± 0.94	133 ± 0.47	81 ± 0.70	32 ± 0.94	59 ± 0.19	76 ± 0.72
CO_2	W	6.56±0.06	6.6 ± 0.07	6.4 ± 0.05	6.44 ± 0.11	4.2 ± 0.07	7.21 ± 0.17
mg/ml)	S	4.58 ± 0.17	4.5 ± 0.02	5.3 ± 0.05	5.13 ± 0.007	5.4 ± 0.1	5.48 ± 0.11
	R	4.46 ± 0.09	5.18 ± 0.07	4.58 ± 0.12	5.26 ± 0.07	6.32 ± 0.14	4.7 ± 0.047
DO	W	0.98 ± 0.50	1.27 ± 0.22	1.96 ± 0.27	2.15 ± 0.2	3.5 ± 0.26	2.41 ± 0.44
(mg/l)	S	7.94 ± 0.10	7.34 ± 0.05	6.87 ± 0.42	7.54 ± 0.11	9.76 ± 0.05	7.32 ± 0.049
	R	4.83 ± 0.32	4.93 ± 0.13	4.83 ± 0.32	3.45 ± 0.13	4.23 ± 0.17	3.4 ± 0.138
NH_4-N	W	1.48 ± 0.02	1.14 ± 0.12	1.24 ± 0.04	1.46 ± 0.05	2.04 ± 0.02	1.46 ± 0.24
(mg/l)	S	3.25 ± 0.22	2.75 ± 0.03	1.5±0.09	1.75 ± 0.16	1.37 ± 0.12	1.87±0.23
	R	2.16 ± 0.11	2.08 ± 0.44	2.08 ± 0.44	2.08 ± 0.06	2.25 ± 0.00	1.83 ± 0.06
Total nitrogen	W	6.15 ± 0.35	5.6 ± 0.07	5.36 ± 0.12	5.16 ± 0.02	5.51 ± 0.02	10.6 ± 0.16
	S	4.93 ± 0.009	6.5 ± 0.05	7.1 ± 0.22	5.12 ± 0.02	4.3 ± 0.14	7.16 ± 0.07
(mg/l)	R	4.9 ± 0.22	6.3 ± 0.33	4.9 ± 0.32	4.9 ± 0.32	4.9 ± 0.32	7 ± 0.65
Chloride	W	10.94 ± 0.04	9.18 ± 0.11	7.18 ± 0.05	7.38 ± 0.04	8.19 ± 0.03	5.46 ± 0.05
(mg/l)	S	7.19 ± 0.31	7.19 ± 0.31	7.19 ± 0.31	7.44 ± 0.54	6.69 ± 0.053	7.94 ± 0.03
	R	5.62 ± 0.35	5.45 ± 0.40	4.79 ± 0.13	4.79 ± 0.26	4.79 ± 0.26	5.78 ± 0.13
PO_4-P	W	0.14 ± 0.005	0.14 ± 0.005	0.13 ± 0.003	0.13 ± 0.002	0.13 ±0.002	0.14 ± 0.005
(mg/ml)	S	0.05 ± 0.03	0.05 ± 0.28	0.16 ± 0.03	0.21 ± 0.01	0.18 ± 0.18	0.20 ± 0.007
	R	0.14 ± 0.14	0.16 ± 0.007	0.13 ± 0.00	0.14 ± 0.002	0.14 ± 0.001	0.14 ± 0.002

W=winter, S=spring, R=rainy

Table 7.3. Seasonal variation in physico-chemical characteristics of bog water in disturbed and undisturbed conditions in Khecheopalri peatland during 1998.

Site		Seasons	pH	Alkalinity (mg/l)	Conductivity (μS)	DO (mg/l)	CO_2 (mg/l)	NH_4-N (mg/l)	Total-N (mg/l)	Chloride (mg/l)	PO_4-P (mg/l)
Bog	Undisturbed	Spring	-	-	-	-	-	-	-	-	-
		Rainy	3.80	15.50	26.00	3.85	4.11	0.46	7.30	7.26	0.28
		Winter	4.22	26.66	15.50	0.99	4.93	0.16	4.20	9.45	0.24
	Disturbed	Spring	-	-	-	-	-	-	-	-	-
		Rainy	4.40	16.66	28.00	4.11	3.99	0.73	4.20	5.78	0.281
		Winter	4.00	18.00	18.00	0.98	4.40	0.16	7.60	5.46	0.243
ANOVA											
	Site Conditions		0.05	0.05	0.05	NS	0.05	NS	NS	0.001	NS
	Seasons		NS	0.05	0.001	0.05	0.05	0.05	0.001	0.001	0.001
	Site conditions × Seasons		0.05	0.05	NS	NS	NS	NS	NS	0.05	NS
	LSD (0.05)		0.25	3.22	2.5	1.75	0.35	0.32	0.412	0.51	0.025

Dash = No water on bog surface in spring

Table 7.4 Seasonal distribution of plankton species at different sites in the Khecheopalri lake and bog.

Planktons	Lake						[a]Bog			
	UD			D			UD		D	
	S	R	W	S	R	W	R	W	R	W
PHYTOPLANKTON										
Chlorophyceae										
Ankistrodesmus sp.	●	●	×	●	×				◊	
Characium sp.	●	●			◊					
Bulbochaete sp.	●			◊	×				●	
Chlamydomonas sp.	×	●	◊						●	
Chlorella sp.	●	×			×		×			
Closteridium sp.	●				×				×	◊
Chlorococcum sp.		×	◊	◊		◊			●	◊
Cosmarium sp.		●	●		●	×			●	●
Cylindrocystis sp.		●	×						◊	●
Euastrum sp.	×	●		●	●	×				●
Kirchneriella sp.	◊	●			×				●	
Penium sp.				◊	×	●				
Mougeotia sp.	×	●	●				●	●	●	◊
Oedogonium sp.	◊	×	×	◊	●	◊	●		●	◊
Phymatodocis sp.	◊	×			●		◊		◊	
Pithophora sp.	●	×		×			◊			
Spirogyra sp.		●	◊	◊	◊	◊	●		●	
Uronema sp.	●	●	◊		◊		◊		●	
Cyanophyceae										
Aphanothece sp.									◊	
Anabaena sp.					◊					
Aphanizomenon sp.					◊					
Gloeocapsa sp.	◊	×		◊	×	◊	×		◊	
Lyngbya sp.					●					
Microcystis aeruginosa (Kutz).		×		◊	●	◊	◊			
Nostoc commune	◊	●	◊	×	●				◊	

(vauch).										
Oscillatoria sp.		◊	◊	◊	◊	◊				
Phormidium sp.		◊	◊	×	◊		◊	◊	◊	
Spirulina sp.		◊								
Synechococcus aeurogenosus (Nag).		◊	◊		•				◊	
Crysophyceae										
Coscinodiscus sp.							◊	◊		
Cocconeis sp.				•	◊	◊			◊	
Fragilaria sp.					◊					
Gomphonema berggreni (Cleve).			◊	◊	◊	◊				◊
Pinnularia sp.	×	×	×						◊	
Navicula sp.	×	•	×		◊		◊			
Hydrosera sp.				◊	×	×			•	
Melosira sp.					◊				•	
Tetracyclus sp.				×	×	•	•	◊	◊	◊
Cymbella palustri's (Hust).			◊	◊						
Terpsinoe sp.		◊	◊							
Asterionella sp.		◊								
Synedra sp.	◊	◊	•							
Rhoicosphenia curvata (Kutz).									•	
Hantzschia amphioxys (Ehr) Grun.									◊	
Cryptophyceae										
Nitella sp.		×					•	•	•	◊
Euglinophyceae										
Colacium sp.				×	•					
Dinophyceae										
Peridinium sp.		◊			◊		◊	◊	•	◊
Pyrrophyceae										
Cryptomonas sp.				◊	•					

ZOOPLANKTON										
Protozoa										
Arcella sp.			◊	•			◊	×		◊
Centropyxix constricta (Ehrenberg)	×	×	×	◊	×		◊			×
Didinium sp.	×					×		×		
Difflugia sp.	•	◊	•	×	×	•	◊		◊	
Zonomyxa sp.	◊						◊			•
Rotifera										
Asplanchna sp.	×		×	•	×	◊				
Adineta sp.				×						
Keratella sp.	×		×	◊		×	◊			×
Notholoca sp.	×			◊			◊			
Philodina sp.				×		×	×		◊	
Elosa sp.		◊					◊	×	×	◊
Trichocerca sp.	◊	◊		×				×	×	◊
Cyclopoda										
Cyclops sp.					×		◊		×	
Mesocyclops sp.		◊		◊	×		◊		×	
Cladocera										
Cypridopsis sp.	◊				×		◊			
Sida sp.			×						×	
Daphnia sp.		◊	×			×		◊		◊
Isopoda										
Gammurus sp.									×	◊

◊ Species just present; × Species commonly present; • Dominant species; UD = undisturbed, D = disturbed; S = spring; R = rainy; W = winter, [a] = During spring time there was no water on the bog surface.

Table 7.5 Similarity index of phytoplankton and zooplankton among sites and conditions (undisturbed and disturbed) during different seasons

Plankton	Site & conditions	Spring	Rainy	Winter
Phytoplankton				
	Lake (UD × D)	0.368	0.590	0.375
	Bog (UD × D)	-	0.476	0.471
Zooplankton				
	Lake (UD × D)	0.700	0.833	0.615
	Bog (UD × D)	-	0.526	0.364
Phytoplankton				
	Lake × Bog (UD)	-	0.558	0.160
	Lake× Bog (D)	-	0.576	0.417
	Lake× Bog (UD & D)	-	0.189	0.000
Zooplankton				
	Lake × Bog (UD)	-	0.471	0.167
	Lake× Bog (D)	-	0.430	0.286
	Lake× Bog (UD & D)	-	0.190	0.100

UD= undisturbed site; D= disturbed site

Table 7.6 Seasonal plankton species indices at undisturbed and disturbed site conditions in the lake and bog of Khecheopalri.

		Undisturbed			Disturbed		
Plankton		S	R	W	S	R	W
Phytoplankton							
Total species	Lake	20	29	19	20	32	13
	Bog	-	15	6	-	27	11
Species richness	Lake	3.71	4.69	3.69	3.61	5.49	2.63
	Bog	-	3.44	1.85	-	5.48	2.51
Species diversity	Lake	2.53	2.74	2.45	2.33	3.05	1.93
	Bog	-	2.54	1.38	-	2.91	1.67
Evenness index	Lake	0.85	0.82	0.83	0.78	0.88	0.75
	Bog	-	0.94	0.77	-	0.88	0.69
Dominance index	Lake	0.09	0.07	0.13	0.12	0.05	0.22
	Bog	-	0.09	0.30	-	0.07	0.31
Zooplankton							
Total species	Lake	10	6	7	10	6	6
	Bog	-	11	5	-	8	8
Species richness	Lake	2.96	2.56	2.27	2.91	2.17	2.01
	Bog	-	3.79	1.67	-	2.92	2.52
Species diversity	Lake	2.18	1.75	1.81	2.14	1.20	1.71
	Bog	-	2.34	1.55	-	1.97	1.96
Evenness index	Lake	0.95	0.98	0.93	0.93	0.67	0.95
	Bog	-	0.98	0.96	-	0.73	0.94
Dominance index	Lake	0.13	0.18	0.18	0.14	0.18	0.19
	Bog	-	0.10	0.22	-	0.16	0.156

S = spring; R = rainy; W = winter; - = no water on bog surface in spring.

Table 7.7 Plankton productivity of the Khecheopalri lake.

Parameters	Season	Year	Site I	Site II	Site III	Site IV
Gross primary productivity ($mgC/m^2/day$)	Winter	1997	16.01 ± 0.94	16.53 ± 1.41	26.60±0.42	18.34±0.91
		1998	15.49 ± 0.47	16.00 ± 2.14	25.72 ± 0.95	17.85 ± 1.40
	Spring	1997	64.13 ± 1.18	67.16 ± 0.512	87.80±4.76	91.46 ±2.82
		1998	60.75 ± 2.59	64.46 ± 2.05	81.10 ± 2.73	71.20 ± 0.40
	Rainy	1997	199.00 ± 0.27	170.00 ± 0.47	249.80 ±1.53	203.20 ±1.43
		1998	131.6 ± 0.58	168.40 ± 0.89	243.00 ± 0.14	205.90 ± 0.49
Respiration ($mgC/m^2/day$)	Winter	1997	59.40 ± 3.63	36.90 ± 2.59	10.80 ± 0.94	54.90 ±0.19
		1998	70.20 ± 2.35	38.70 ± 0.34	12.60 ± 1.01	56.70 ± 0.27
	Spring	1997	63.90 ± 1.28	54.90±1.19	80.10 ± 2.16	27.00 ±2.00
		1998	53.10 ±1.64	58.50 ± 1.90	78.30 ± 0.67	14.40 ±1.37
	Rainy	1997	189.00 ± 0.72	89.10 ± 1.86	72.00 ± 0.74	89.00 ±1.98
		1998	131.40 ± 0.40	94.50 ± 1.76	77.40 ± 3.09	96.30 ±2.47
Net primary productivity ($mgC/m^2/day$)	Winter	1997	-43.39	-20.37	15.84	36.56
		1998	-54.71	-22.7	13.12	-38.85
	Spring	1997	0.225	12.26	7.56	64.46
		1998	7.65	5.96	2.7	56.81
	Rainy	1997	10.125	81.34	177.75	114.1
		1998	0.2	73.9	165.6	112.27

Table 7.8 Faunal composition of the Khecheopalri lake.

Scientific name	Common name/local name
Invertebrates	
Phyllium sp.	Leaf insects
Carausius sp.	Stick insects
Gerris gracillcornis	Water strider
Cybister sp.	Aquatic beetle
Hydatiscus sp.	Small water bettle
Fishes	
Cyprinus carpio	Common carp
Garra gotyla stenorhynchus	Nakatuwa buduna
Danio aequipinnatus	Bhitti
Schistura multifaciatus	-
Labeo pangusia	Theyr
Schizothorax richardsonii	Dothay asala
Acrossochellus hexagonoiepsis	Katley
Amphibians	
Bufo himalayana	Common toad
Hyla sp.	Bhyguta
Migratory birds	
Anas crecca	Common teal
Aythya baeri	Baer's pochard
Mergus merganser orieantalis	Eastern goosander
Anser indicus	Barheaded goose
Phalacrocoxas fuscicollis	Indian Shag
Todorna ferriginea	Brahmini duck
Aythya ferina	Common pochard

Table 7.9 Pearson's correlation coffiecient for physio-chemical characteristics, plankton productivity and respiration of the Khecheopalri lake (*n*=12, d.f. = 10 for transparency, gross primary productivity and respiration, and for all other parameters *n*= 18, d.f. = 16)

Parameters	Transparency	Temperature	pH	Conductivity	Acidity	Alkalinity	DO	Free CO_2	Total Nitrogen	NH_4-N	PO_4-P	Chloride	GPP	Respiration
Transparency	-	-0.949	-0.631	-0.630	-0.445	0.690	-0.538	0.654	0.508	-0.327	-0.390	0.426	-0.869	-0.708
Temperature	0.01	-	0.518	0.634	0.624	-0.511	0.549	-0.639	-0.458	0.381	0.197	-0.257	0.944	0.681
pH	0.05	0.05	-	0.328	0.490	-0.134	0.494	-0.172	-0.340	0.409	0.120	-0.230	0.396	0.620
Conductivity	0.05	0.01	NS	-	0.198	-0.602	-0.008	-0.165	-0.272	0.082	0.347	0.144	0.488	0.598
Acidity	NS	0.01	0.05	NS	-	0.158	0.833	-0.516	-0.146	0.254	0	-0.558	0.412	0.272
Alkalinity	0.05	0.05	NS	0.01	NS	-	0.274	0.001	0.292	0.120	-0.424	-0.286	-0.630	-0.327
DO	NS	0.05	0.05	NS	0.01	NS	-	-0.665	-0.270	0.308	-0.086	-0.728	0.445	0.391
Free CO_2	0.05	0.01	NS	NS	0.05	NS	0.01	-	0.331	-0.454	0.214	0.403	-0.620	-0.566
Total nitrogen	NS	NS	NS	NS	NS	NS	NS	NS	-	-0.074	-0.135	-0.170	-0.622	-0.113
NH_4-N	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-0.602	-0.279	0.226	0.563
PO_4-P	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.01	-	0.138	0.351	-0.002
Chloride	NS	NS	NS	NS	0.05	NS	0.01	NS	NS	NS	NS	-	-0.339	-0.245
GPP	0.01	0.01	NS	NS	NS	0.05	NS	0.05	0.05	NS	NS	NS	-	0.560
Respiration	0.01	0.05	0.05	0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	-

NS= Not significant; Lower matrix = Probability values; Upper matrix = Correlation coefficients

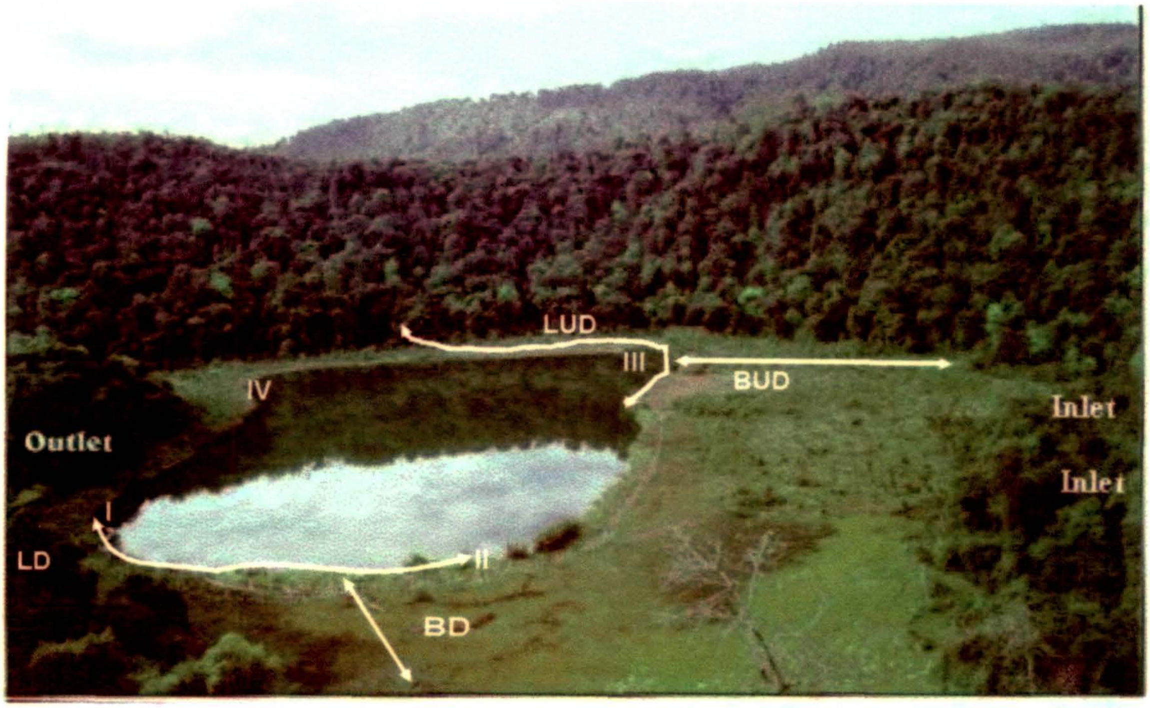

Fig. 7.1 Khecheopalri Lake showing perennial inlets and outlet, and sample collection sites

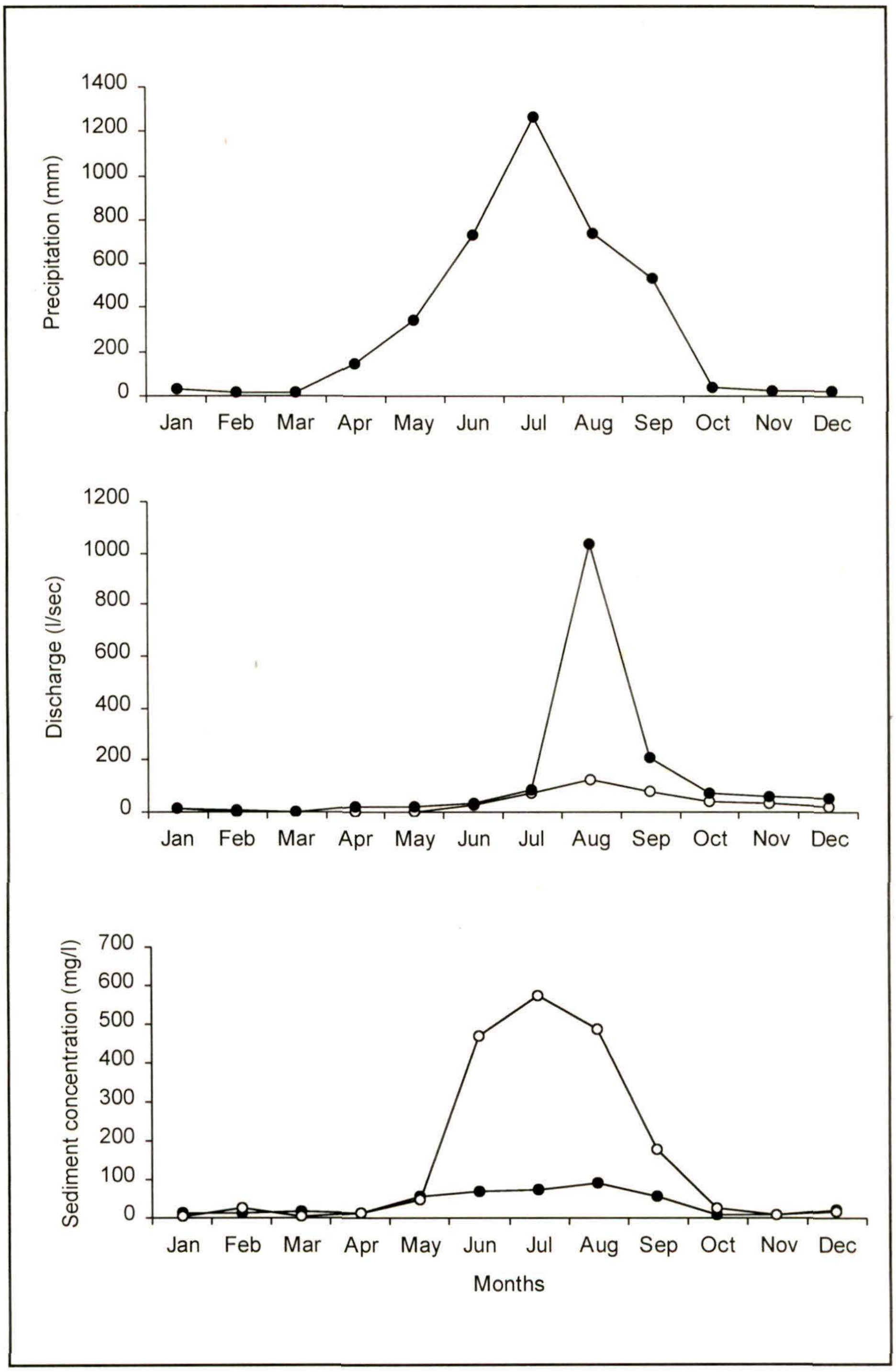

Fig. 7.2 Monthly precipitation, discharge and sediment concentration in the inlets (○—○) and outlet (●—●) in 1997

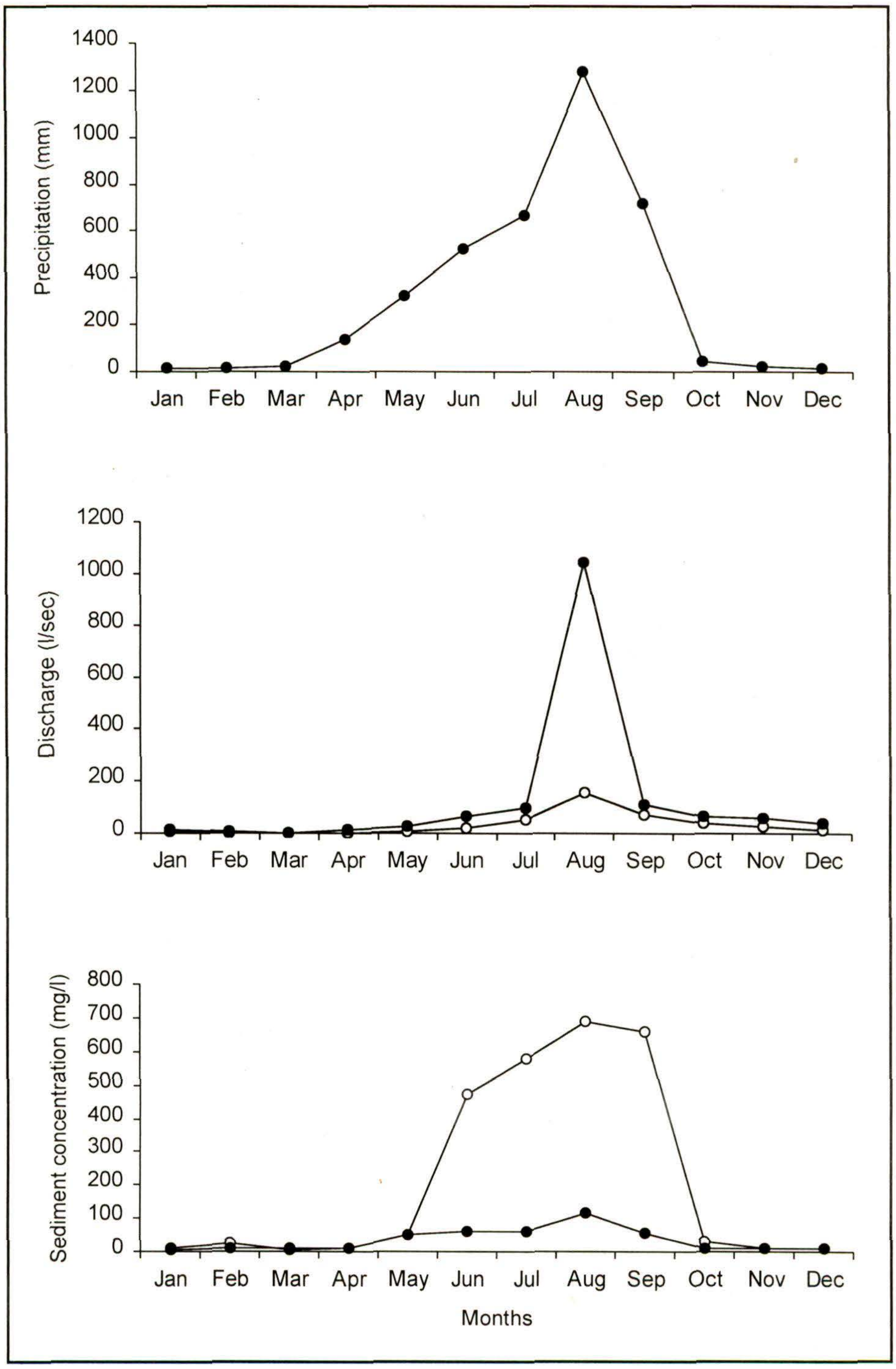

Fig. 7.3 Monthly precipitation, discharge and sediment concentration in the inlets (○—○) and outlet (●—●) in 1998

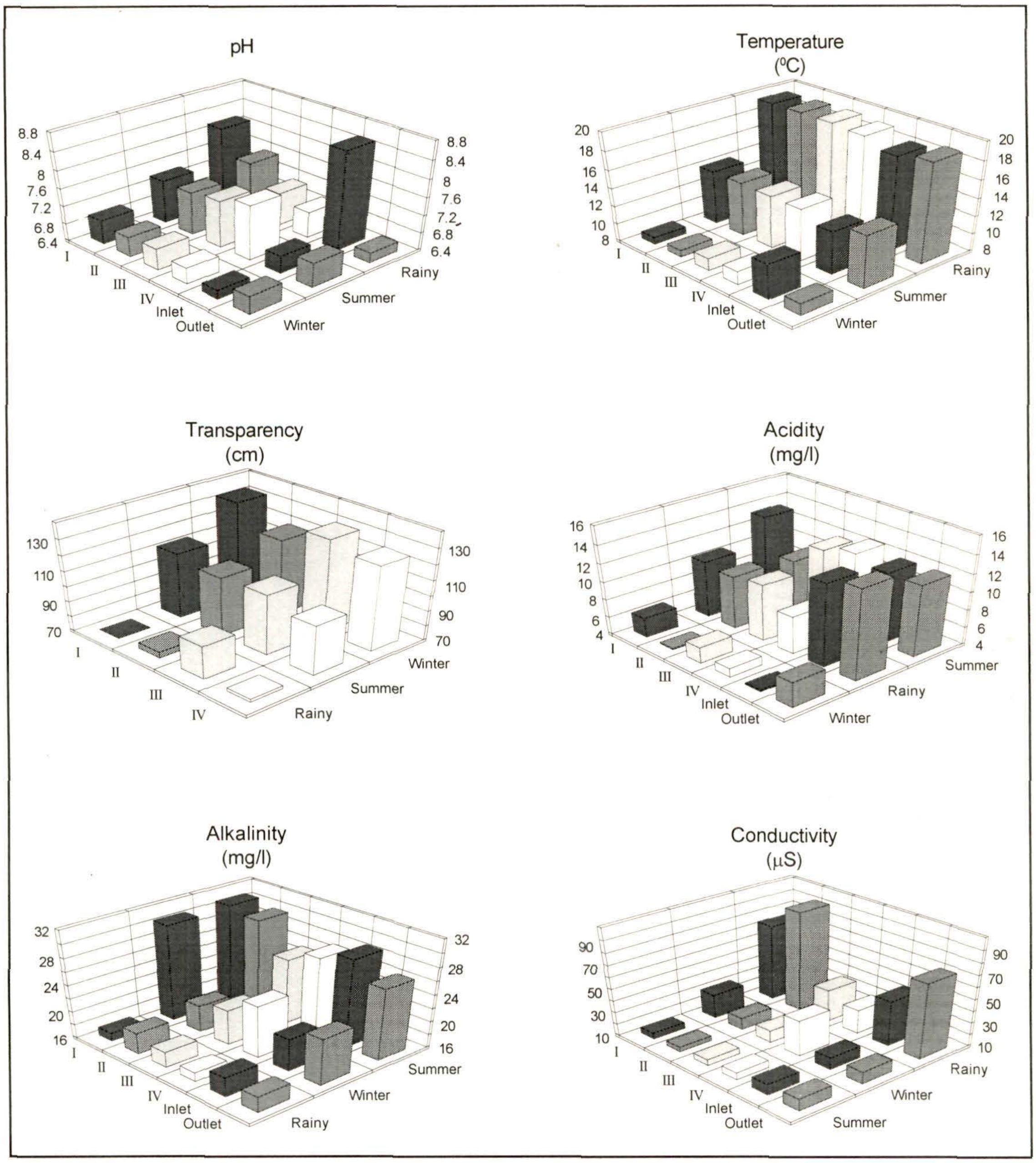

Fig. 7.4 Seasonal variation in pH, temperature, transparency, acidity, alkalinity and conductivity of water at six sites in the Khecheopalri lake. *ANOVA*: pH- Site $F_{5,36}=28$, $P<0.001$; Season $F_{2,36}=142$, $P<0.001$: Site x Season $F_{10,36}=45$, $P<0.001$, LSD (0.05)=0.082; Temperature- Site $F_{5,36}=8$, $P<0.001$; Season $F_{2,36}=38872$, $P<0.001$; Site x Season $F_{10,36}=277$, $P<0.001$, LSD(0.05)=0.071; Transparency- Site $F_{3,24}=278$, $P<0.001$; Season $F_{2,24}=9653$, $P<0.001$; Site x Season $F_{6,24}=156$ $P<0.001$, LSD(0.05)=0.759; Acidity- Site $F_{5,36}=37$, $P<0.001$; Season $F_{2,36}=670$, $P<0.001$; Site x Season $F_{10,36}=15$, $P<0.001$, LSD(0.05)=0.395; Alkalinity- Site $F_{5,36}=29$, $P<0.001$; Season $F_{2,36}=812$, $P<0.001$; Site x Season $F_{10,36}=36$, $P<0.001$, LSD(0.05)=0.498; Conductivity- Site $F_{5,36}=177$, $P<0.001$; Season $F_{2,36}=7665$, $P<0.001$; Site x Season $F_{10,36}=455$, $P<0.001$, LSD(0.05)=0.855.

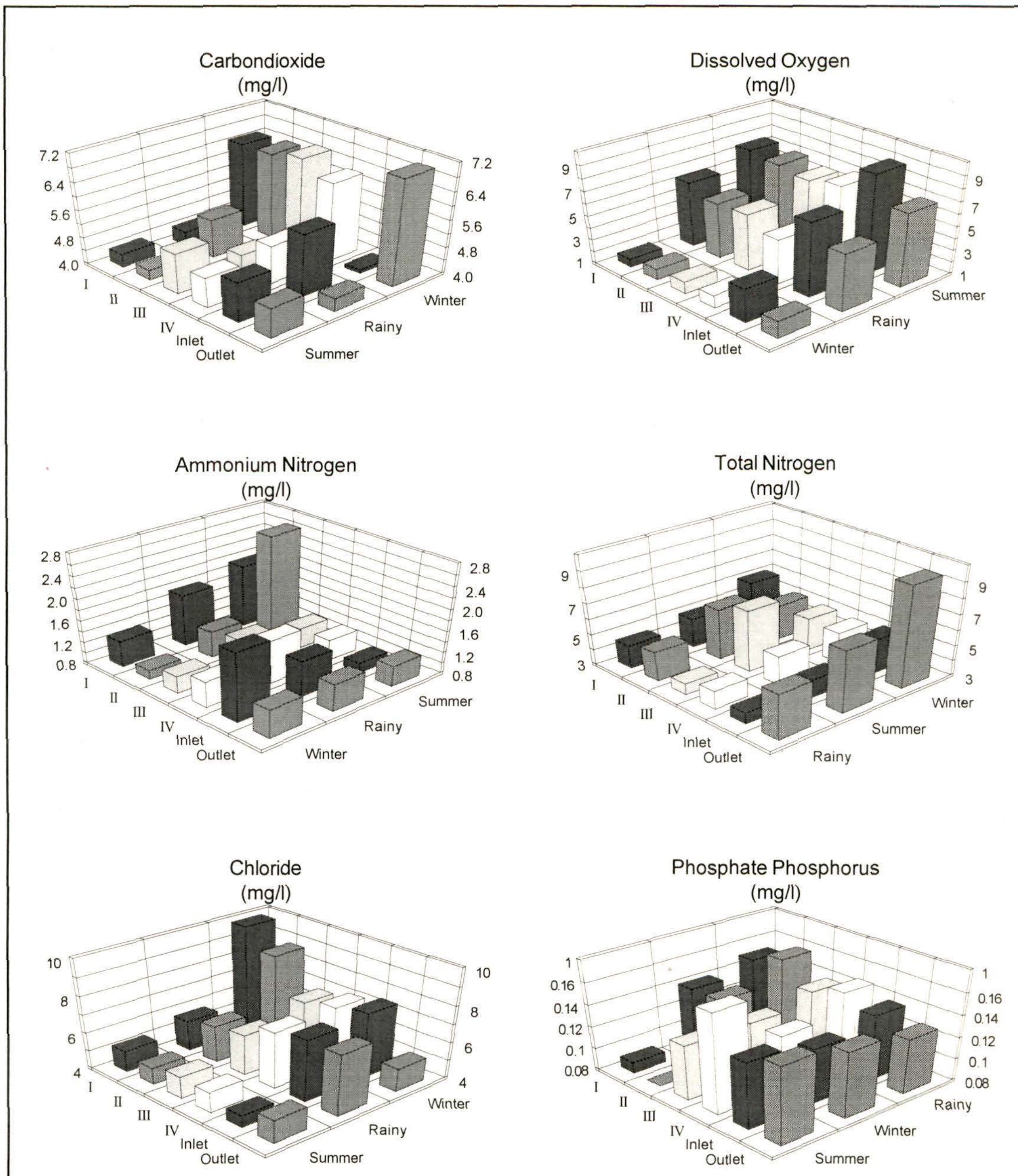

Fig. 7.5 Seasonal variation in free CO_2, DO, NH_4-N, total nitrogen, chloride and PO_4-P of water at six sites in the Khecheopalri lake. *ANOVA*: Free CO_2- Site $F_{5,36}$=7, P<0.001; Season $F_{2,36}$=181, P<0.001; Site x Season $F_{10,36}$=36, P<0.001, LSD(0.05)=0.164; DO- Site $F_{5,36}$=37, P<0.001; Season $F_{2,36}$=703, P<0.001; Site x Season $F_{10,36}$=4, P<0.002, LSD(0.05)=0.28; NH_4-N - Site $F_{5,36}$=15, P<0.001; Season $F_{2,36}$=10, P<0.001; Site x Season $F_{10,36}$=49, P<0.001, LSD(0.05)=0.082; Total nitrogen- Site $F_{5,36}$=181, P<0.001; Season $F_{2,36}$=228, P<0.001; Site x Season $F_{10,36}$=47, P<0.001, LSD(0.05)=0.157; Chloride- Site $F_{5,36}$=38, P<0.001; Season $F_{2,36}$=987, P<0.001; Site x Season $F_{10,36}$=113, P<0.001, LSD(0.05)=0.115; PO_4-P - Site $F_{5,36}$=6, P<0.001; Season $F_{2,36}$=2, not significant, Site x Season $F_{10,36}$=2.5, P<0.02, LSD(0.05)=0.013.

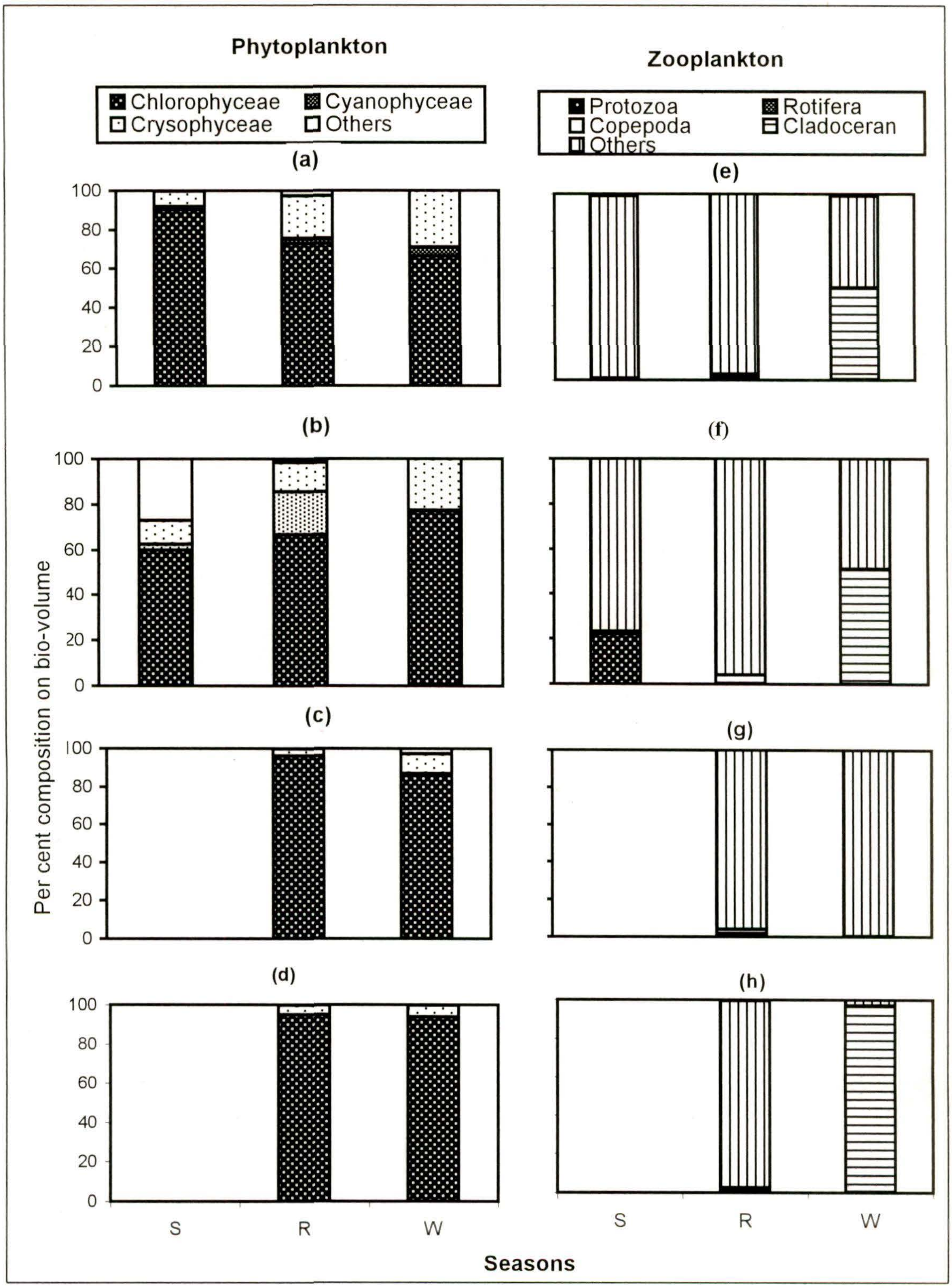

Fig. 7.6 Seasonal composition (%) of the phytoplankton and Zooplankton at various site conditions (Phytoplankton: a=lake undisturbed, b=lake disturbed, c=bog undisturbed, d=bog disturbed; Zooplnkton: e=lake undisturbed, f=lake disturbed, g=bog undisturbed, h=bog disturbed)

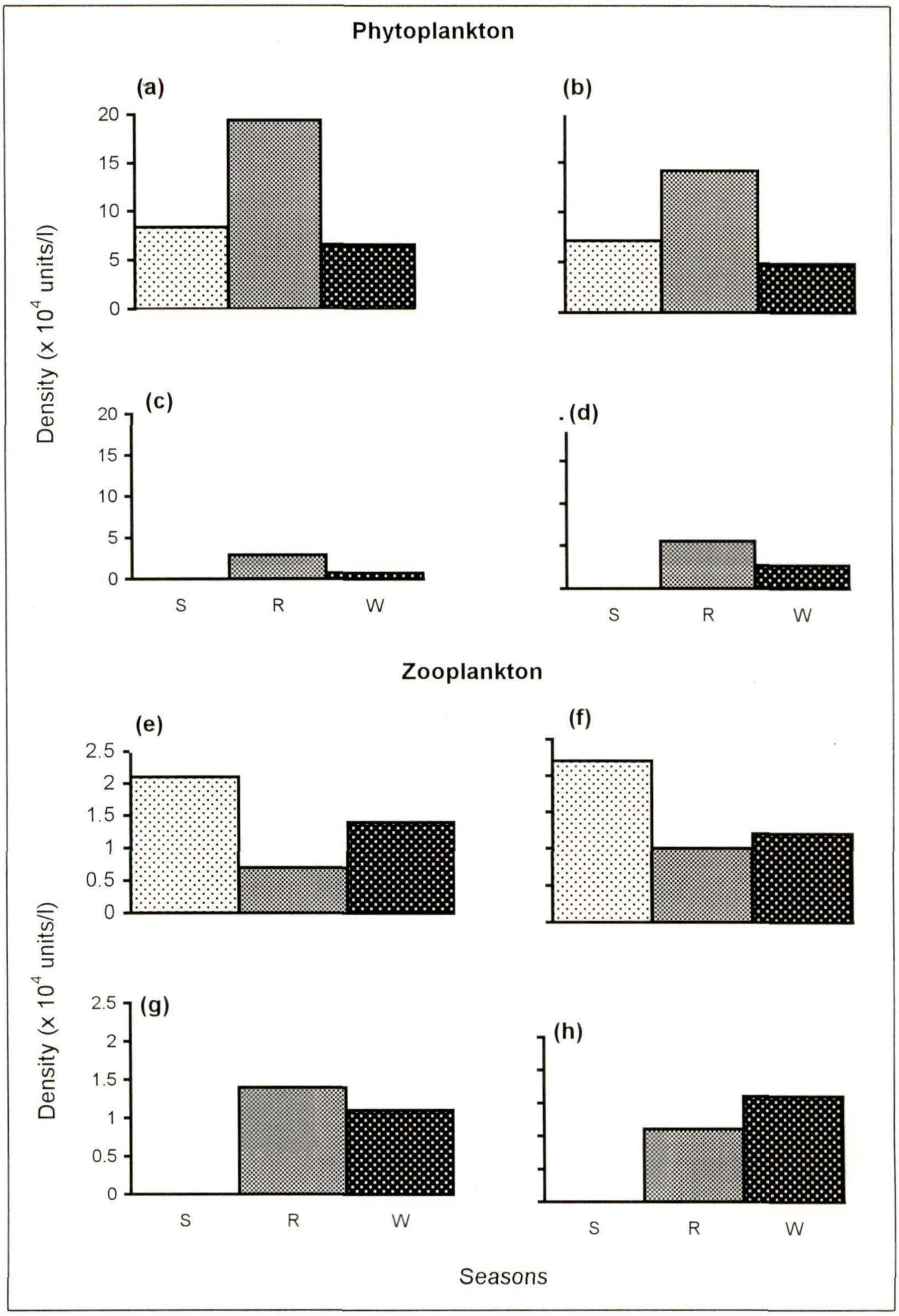

Fig. 7.7 Seasonal variation in phytoplankton and zooplankton density at various site conditions (Phytoplankton: a=lake undisturbed, b=lake disturbed, c=bog undisturbed, d=bog disturbed; Zooplankton: e=lake undisturbed, f=lake disturbed, g=bog undisturbed, h=bog disturbed)

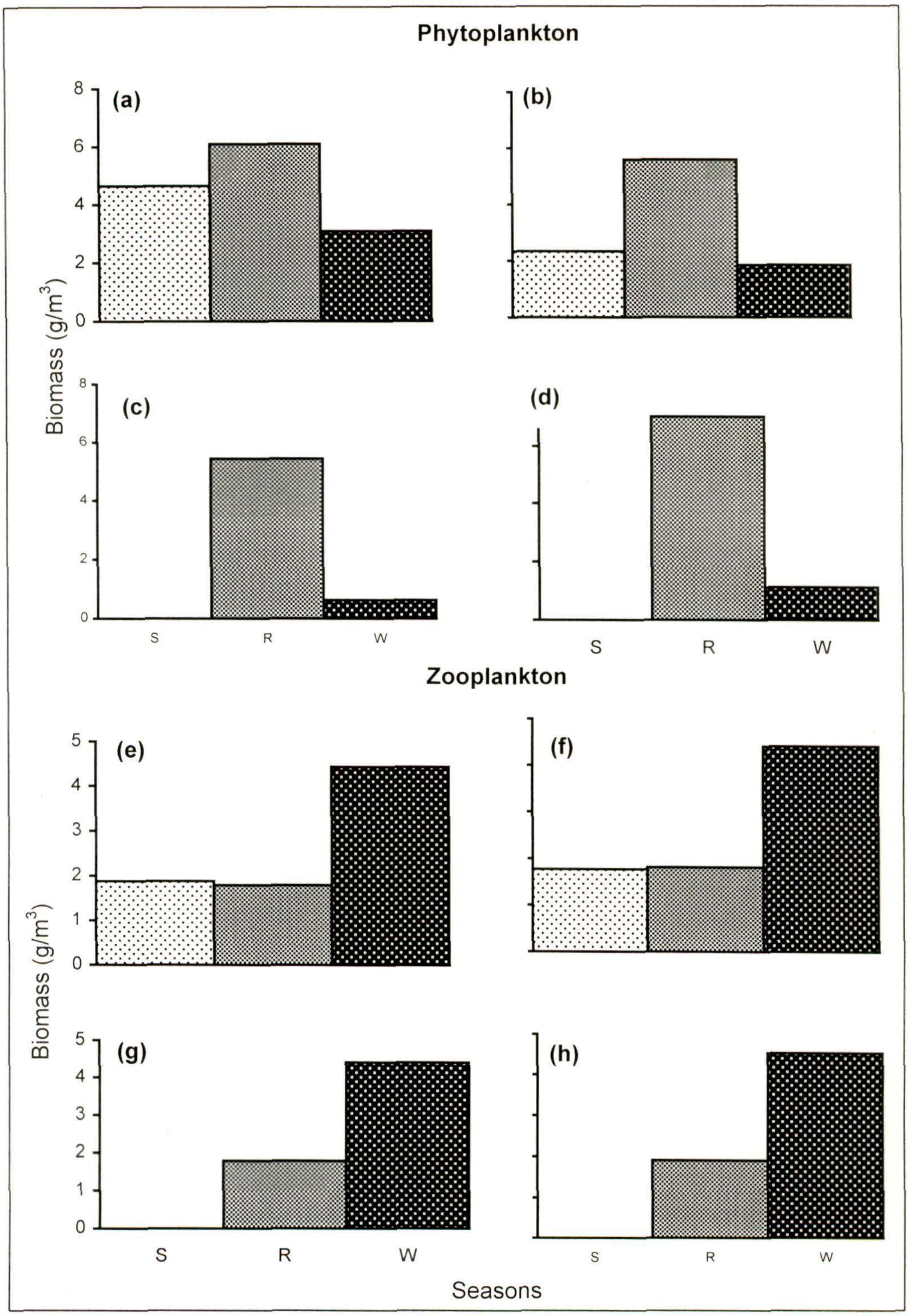

Fig. 7.8 Seasonal variation in phytoplankton and zooplankton biomass at various site conditions (Phytoplankton: a=lake undisturbed, b=lake disturbed, c=bog undisturbed, d=bog disturbed; Zooplankton: e=lake undisturbed, f=lake disturbed, g=bog undisturbed, h=bog disturbed)

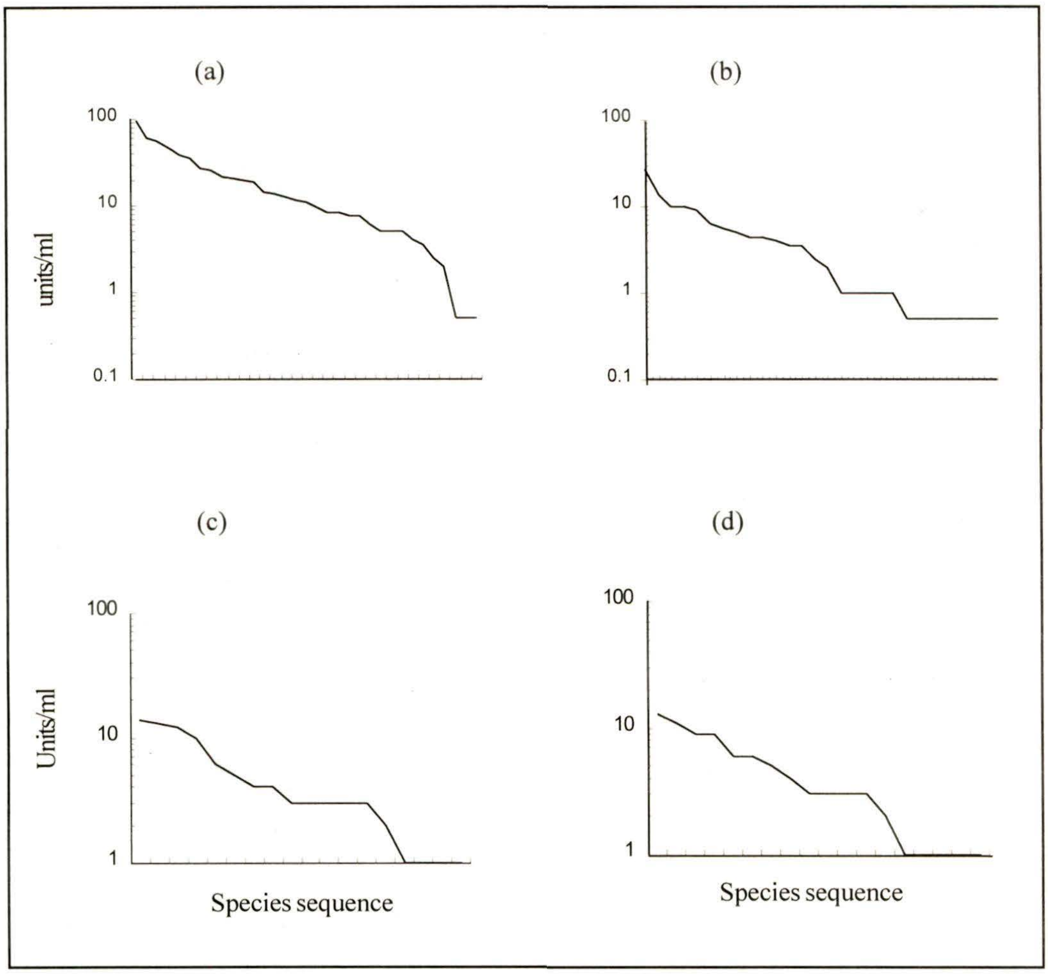

Fig. 7.9 Dominance diversity curve of lake phytoplankton, (a) bog phytoplankton, (b) lake zooplankton (c) and bog zooplankton

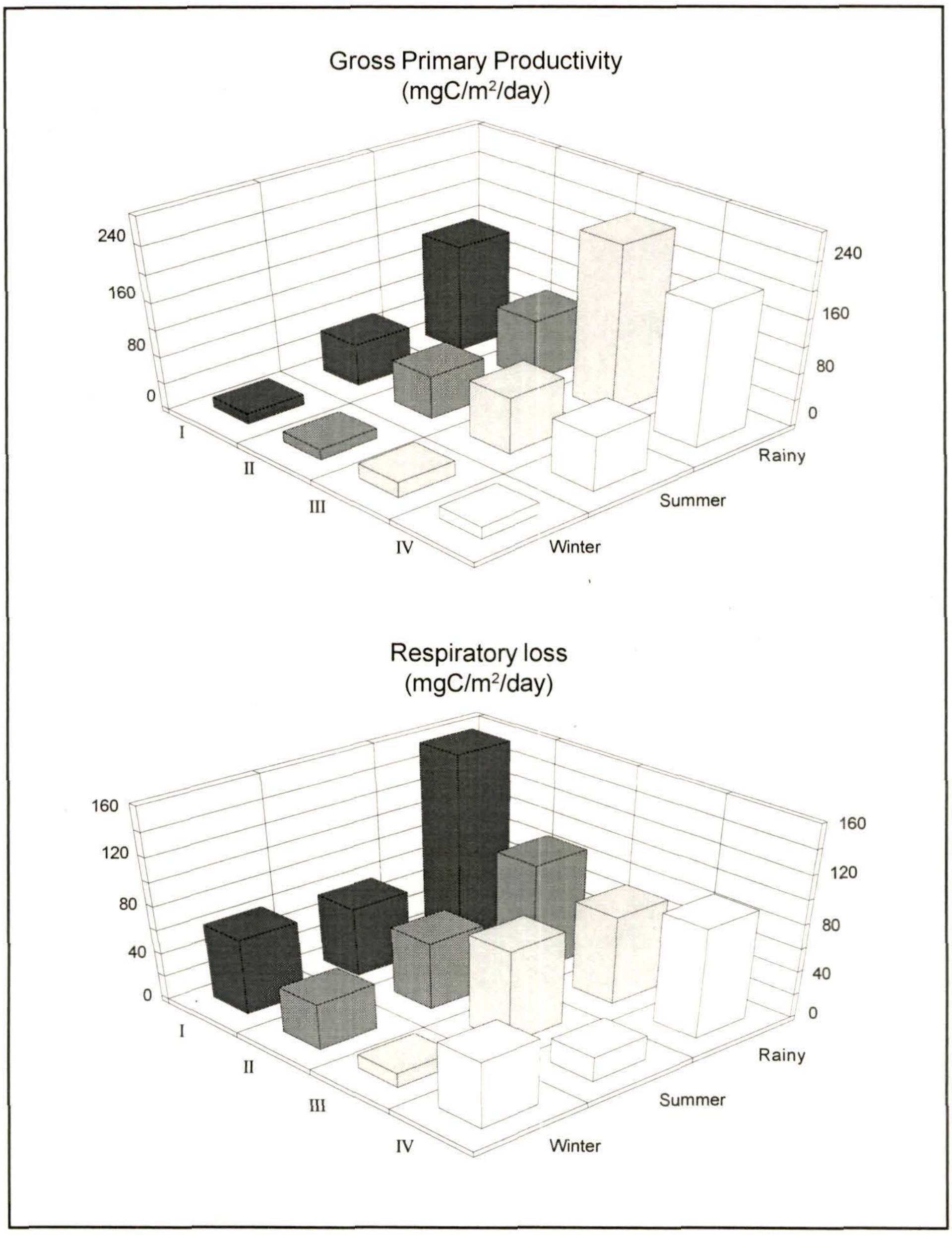

Fig. 7.10 Seasonal variation in GPP and respiration by plankton in the water at four sites of the Khecheopalri lake. *ANOVA*: GPP – Site $F_{3,24}$=5.5, P<0.005; Season $F_{2,24}$=206, P<0.001; Site x Season interaction not significant; Respiration – Site $F_{3,24}$=24, P<0.001; Season $F_{2,24}$=101, P<0.001; Site x Season $F_{6,24}$=20, P<0.001, LSD(0.05)=9.45.

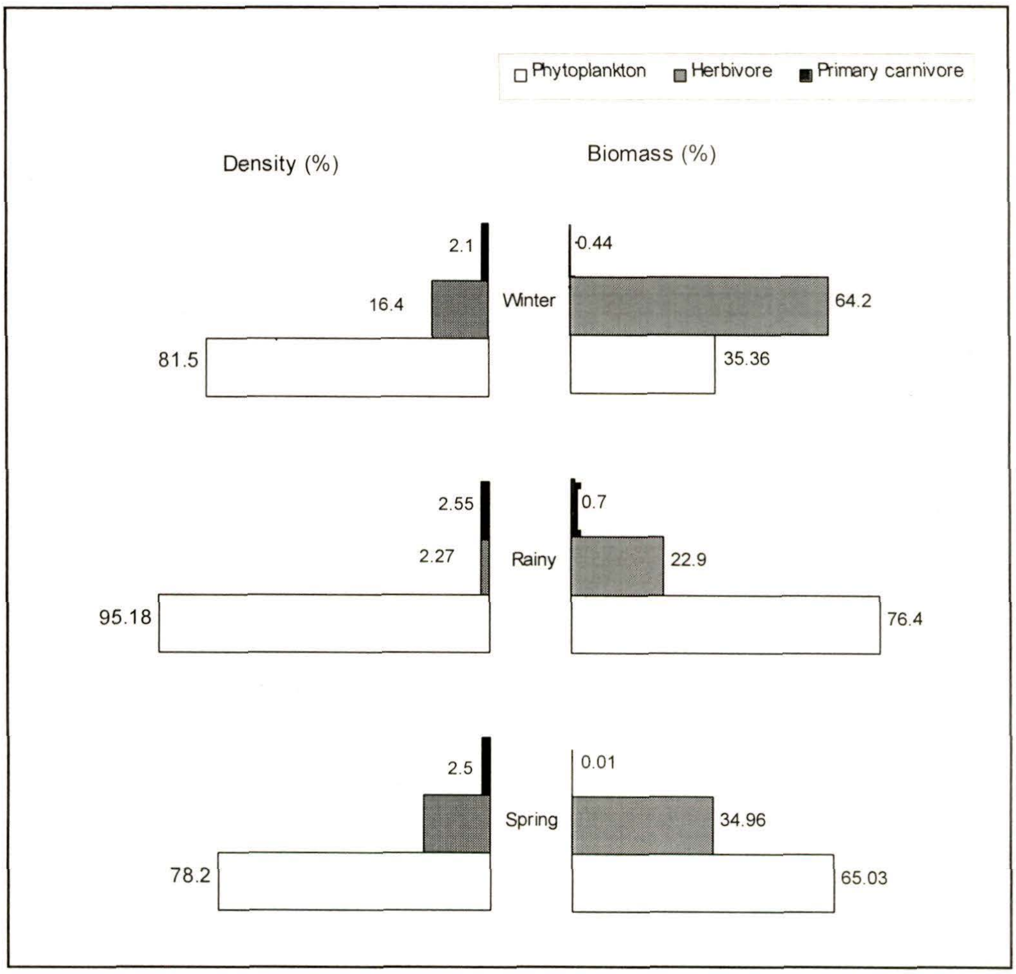

Fig. 7.11 Trophic relationship (in terms of density and biomass) between phytoplankton, herbivores and the primary carnivores in the Khecheopalri lake