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Trophic Status of Phewa, Begnas and Rupa Lakes in Pokhara Valley, Nepal: Past, Present and Future*

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Abstract: *Harnessing the natural resources is one of the basis of natural economy in developing countries. The wise use of such resources is very important to sustain the balance between immediate benefits and maintenance of the ecosystem. In Phewa, Begnas and Rupa lakes of Pokhara Valley, plankton feeding fish farming in net cage, enclosure and open water stocking is one of the effective example of natural resources utilisation which sustains a number of households in surrounding lakes for economic activities. These lakes are also used for drinking water, hydroelectricity, irrigation and recreation etc. However, the understanding of trophic status of the lakes is very important for long term sustainable use of the lakes in harmony with human activities. Here, we present the trophic status of three lakes of Pokhara Valley and discuss the impacts of human and natural activities on the trophic status of the lake. The study shows that heavy rain fall in the valley during monsoon is one of the strongest natural forces which flush out the accumulated nutrients from the lakes and migrate the eutrophication processes. Recommendations for sustainable use of lake water have also been discussed.*
Keywords: *trophic status, planktivorous fish, nutrients, eutrophication*

1. Introduction

Nepal is a Himalayan country located between the two countries China in the north and India in the south. It is located between 80°22' E and 88°12' E longitude and 26°20' N and 30°27'N latitude. It covers about 900 km from East to West and 240 km from North to South with a great variation in altitude from 60 m to 8 848 m above the sea level. The population is about 19 million and the main occupation is agriculture. The climate is varied from north to south depending upon the altitude. Dry and monsoon seasons diversify the climate in Nepal and the precipitation occurs during summer by the effect of monsoon.

Nepal is a favorable area for comparative studies on the influence of altitude and climate on biological, chemical and physical properties of waters (Hickel, 1973). The first study might be done on high altitude lakes (4 500-5 600 m above sea level) in Khumbu Himalayan Region (Loffler, 1969) and on Lake Rara (2 990 m) in the far west Nepal (Ferro, 1978/79; Okino and Satoh,

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1986). Some researchers also studied on low altitude lakes (600-750 m) in Pokhara Valley (Hickel, 1973; Ferro and Swar, 1978; Swar and Fernando, 1979, 1980; Kato and Hayashi, 1980; Ferro, 1981/82; Nakanishi, *et al.*, 1988). However, there is no detail and regular study on trophic status of the lakes, primary production and species diversity of phytoplankton and zooplankton in Nepalese Lakes. Nakanishi, *et al.* (1988) have reported that the lakes of Pokhara Valley are monomictic or incompletely monomictic and mostly anoxic in hypolimnion during thermal stratification period but due to lack of enough and analytical data, there is no information of diagnosis for trophic status of the lakes. So the objectives of these lakes study are to find out the trophic status of sub-tropical lakes Phewa (742 m), Begnas (650 m) and Rupa (600 m) in Pokhara Valley.

1.1 Study site

Pokhara Valley, about 200 km west from Kathmandu is one of the scenic and tourist place in the country. It is situated in the western development region about 84°00' E longitude and 28°13'N latitude. The temperature varied from 3.8 ℃in January to 35.1 ℃ in May. The average annual rainfall ranges 3 723 mm in 1994 to 4897 in 1995. There are eight lakes in Pokhara Valley of which Phewa (523 ha), Begnas (328 ha) and Rupa (135 ha) (Rai *et al.*, 1995) are the bigger lakes (Fig. 1). Traditionally the lakes in Pokhara Valley were used by a group of fishers who settled down around the lake sides.

The lakes not only contributing to the natural beauty of the valley but also attracting for tourists from all over the country and contributing about 16 % of Pokhara's total income (IUCN, 1995) from tourism. In addition to that lake waters are used for drinking water, irrigation, recreation, electricity generation, washing or cleaning as well as for the fish culture. However, the increasing tendency of the construction of hotels and houses around the lakes, particularly in Phewa lake side, and direct flow of sewage of hotels and residence into the lake, polluted discharge from Seti River as well as agricultural activities washed during monsoon and mixed into the lake have degraded the water quality of Phewa Lake. The mixing sewage and waste materials into the lake and the decomposition and decay of vegetation directly result the lake pollution by which the tourists are discouraging from boating and swimming due to water pollution. These activities cause higher nutrient concentrations which lead to eutrophication in the lakes. Natural soil erosion takes place easily due to fragile geo-structure and siltation are significant problems in Phewa watershed by which the natural life spawn of the lake decrease. Department of Soil Conservation and Watershed Management, HMG (1993) has reported that the soil erosion rate estimated 17.37 $m^3 \cdot ha^{-1}$ during 1993/94 and estimated about 175-225 thousands m^3 of silt per year accumulated in Phewa Lake by which the lake will be filled with silt completely within 100-175 years. Pollution and development problems are not yet significant in Begnas and Rupa lakes but Rupa Lake is becoming more shallow every year due to siltation and covering with macrophytes and if continue siltation at the present rate, Rupa Lake will disappear within 20 Years (IUCN, 1996). Begnas Lake has improved its scenic beauty after the increased in water depth and prolongs its life after damming. This study has been carried out with a view to know the trophic status of the lakes and seasonal variations of water temperature, dissolved oxygen, transparency, pH, light attenuation, Chlorophyll*a*, nutrients, primary production, phytoplankton and zooplankton composition.

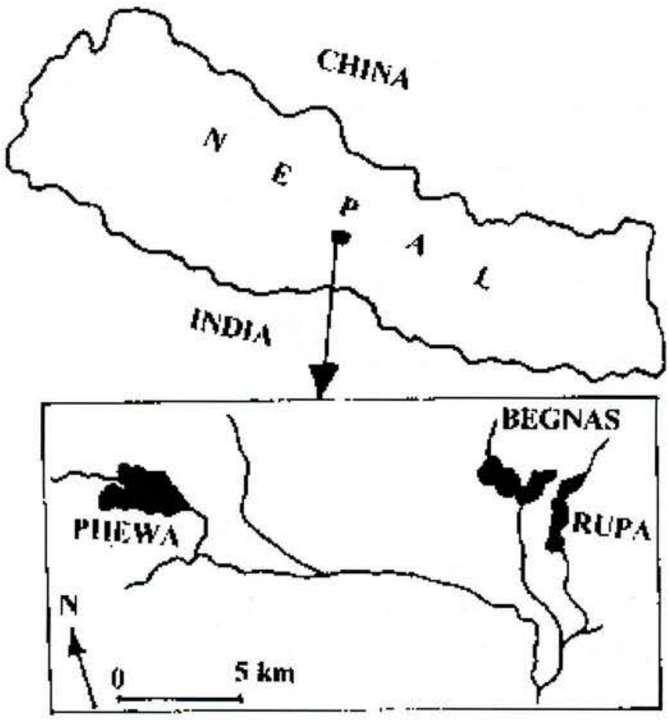

Fig. 1 Map of Nepal showing the study lakes in Pokhara Valley

1.1.1 Phewa Lake

Phewa (742 masl), is the biggest lake in Pokhara Valley (Fig. 2). The lake water is used as multipurpose mainly for irrigation, drinking water, recreation, tourism as well as fish culture. The surface area, water volume, maximum and average depths of the lake are 5.23 km^2, 39.32×10^6 tons, 24 m and 7.5 m respectively. Compared to the data of Ferro and Swar (1978), the maximum depth has increased by 5 m (23 % by volume) after the irrigation dam was constructed. Harpan khola flows from the west to the east is the main perennial stream which directly flows into the lake and also water flows sometimes from a canal of Seti river but not enough to fill up the lake. So the rainfall water is the main source which collect from 110 km^2 catchman area to fill up the lake especially during monsoon (June-August). The annual water temperature ranges from 15-29.5 ℃. Fourteen fish species are identified including carps which are cultured in cages, enclosures and open waters. Caged fish are mainly planktivorous species Silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) but in enclosure and open water stocking common carp and Indian major carps also in culture practice. Fishery is the main occupation of the low income fishers living around the lake sides. The culture of planktivorous fish species in cage, enclosure and open water fish stocking is popular due to more catch fish and more income.

The annual fish production in Phewa lake during 1984/85 to 1993/94 ranged from 30-59 kg · ha^{-1}(Rai and Yamazaki, 1995).

1.1.2 Begnas Lake

Begnas (650 masl), is the second biggest lake in Pokhara Valley (Fig. 2). Begnas lake water also is used as multipurpose as Phewa lake. The surface area, water volume, maximum and average depths of the lake are 3.2 km^2, 17.96X10^6 tones, 10 m and 6.6 m respectively. Ferro and Swar (1978) have reported the surface area was 2.24 km^2 which is increased by 1 km^2 after dam construction. The Shyankhudi khola which flows from the west to south is the main stream. The water flows into the lake is not enough and the rainfall water will collect from 19 km^2 catchment area to fill up the lake. The annual water temperature ranges from 15.2-32.0 ℃. The fish are cultured as in Phewa Lake. The annual fish production from 1984/85 to 1993/94 ranges 43-122 kg · ha^{-1} which is higher than in Phewa but less than in Rupa (223-445 kg · ha^{-1})(Rai and Yamazaki, 1995).

1.1.3 Rupa Lake

Rupa (600 masl), is the third biggest lake in Pokhara Valley (Fig. 2). The water of the lake is used for irrigation, drinking water, recreation as well as fish culture. The surface area, water volume, maximum and average depths of the lake are 1.35 km^2, 3.25 × 10^6 tones, 6 m and 3 m respectively. The inflow of water is from Talbeshi khola which flows from the north to south. The water flows into the lake is not enough and the rainfall water will collect from 30 km^2 catchman area. The annual water temperature ranges from 14-30 ℃. The fish are cultured as in Phewa and Begnas but the lake is becoming less productive, becoming shallow and covering with macrophytes. If the dam will not be constructed in near future at the outlet, the lake might be converted into swampy area in future. The annual fish production during 1984/85 to 1993/94 ranges 223-445 kg.ha^{-1} (Rai and Yamazaki, 1995) which is the highest production among the three lakes.

2. Materials and Methods

The limnological study was carried out in detail the first time since 1993 after the short term JICA expert Professor Dr. Masami Nakanishi was made available in Nepal. The parameters were measured monthly and regularly early in the morning for three years (1993-'95) making a fixed station in three lakes Phewa, Begnas and Rupa in Pokhara Valley. Each parameter was measured depthwise from 7 different depths (0 m, 0.5 m, 1.0 m, 2.5 m, 5.0 m, 7.5 m and bottom) in Phewa and Begnas Lakes and from 3 different depths (0 m, 0.5 m and 2.0 m) in Rupa lake which is shallow. Water samples were collected by 3 L capacity Van Dorm water sampler. Water temperature by thermister thermometer (Tohodentan, RB-2), Dissolved oxygen was measured by Winkler's method, transparency with Secchi disk of 20 cm diameter and pH with pH digital pen meter were measured. Light attenuation was measured with an underwater photometer (Tokyokoden ANA-200). Samples of Chlorophyll<u>a</u> and pheopigments were obtained by filtration through whatman GF/C glass fibre (Ca 1.2 µm pore size). Before extraction the Chlorophyll*a*, the samples were preserved in a sealed plastic container with silica gel and kept in refrigerator.

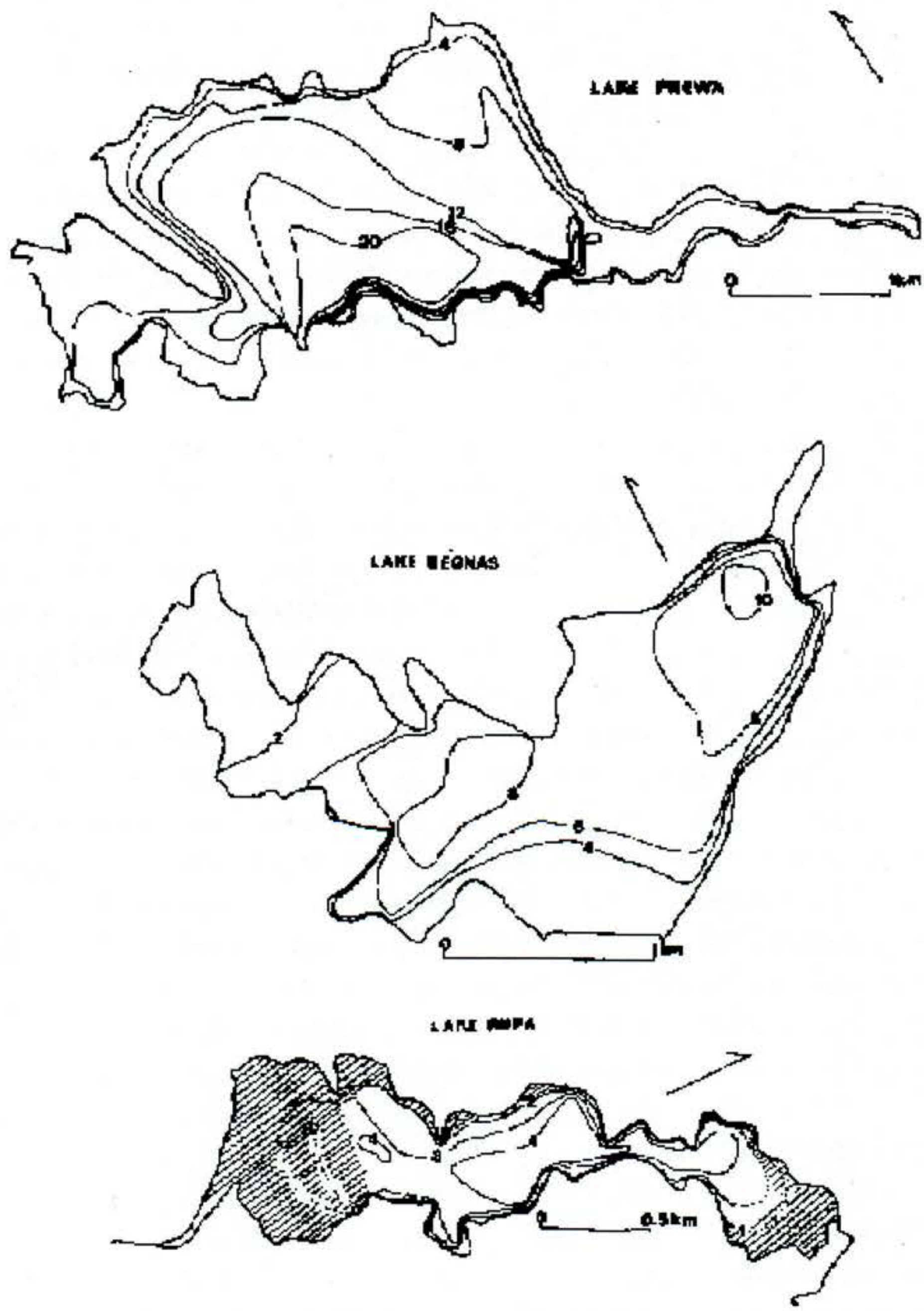

Fig. 2 Maps of study lakes Phewa, Begnas and Rupa drawn on the basis of bathymetric maps by Rai *et al.* (1995) showing shaded area as macrophyte zone.

The filtrate through a 1 µm pore size glass fibre was used for the determination of dissolved inorganic nitrogen NH_4-N (mg · l^{-1}), NO_2-N+NO_3-N (mg · l^{-1}) and dissolved inorganic phosphate PO_4-P (mg ·l^{-1}) (Nakanishi, *et al.*, 1986). The nitrate, nitrite and ammonium-N concentrations were analysed by the sodium salicylate method, the Bends Chneider-Robinson method and the indophenol-blue method modified after Bower and Holm-Hansen respectively. Dissolved inorganic phosphate was measured by molybdenum blue method and the total dissolved phosphorus was determined as for dissolved inorganic phosphate after persulfate digestion of the filtrate. The particulate organic carbon, nitrogen and phosphorus were collected on whatman GF/C glass fibre filter after pre-ignited at 450 ℃. The samples were taken in Kyoto University, Japan and analysed through Professor Dr. M. Nananishi. The particulate carbon and particulate nitrogen were analysed with a Hitachi 026 CHN analyser (YAMACO, MT-3) and particulate phosphorus was analysed by a modified method of MENZEL and CORWIN (1967). The amount of chlorophyll a and pheopigment were determined spectrophotometrically according to the standard method of Lorenzen (1967) and Unesco (1969).

The depthwise primary production rate of phytoplankton was determined by the situ light and dark bottle oxygen method setting in 6 different depths (0 m, 0.5 m, 1.0 m, 2.5 m, 5.0 m and 7.5 m) in Phewa and Begnas and in 3 different depths (0 m, 0.5 m and 2.0 m) in Rupa. The bottles were set 24 hours for incubation from morning around 6-7.30 am and collect next morning the same time. The primary production rate obtained in terms of O_2 and converted to carbon unit using a PQ value of 1.13 and daily net production of phytoplankton respiration rate was obtained by calculating hourly respiration rate calculated by 24 hours (Harris and Piccin, 1977).

Phytoplankton samples were collected from 5 different depths (0 m, 1.0 m, 2.5 m, 5.0 m and 7.5 m) in Phewa and Begnas and from 3 different depths (0 m, 0.5 m and 2.0 m) in Rupa. The zooplankton samples were collected using Wisconsin plankton net (45 μm) from bottom to surface and depthwise from 4 different depths 0-2.5 m, 2.5-5.0 m, 5.0-7.5 m and 7.5-bottom) in Phewa and Begnas and from 0-1.5 m in Rupa. Phytoplankton samples were fixed with acid lugol's solution (Saraceni and Ruggiu, 1969) and identified using a haematocytometer under microscope after over night concentration to 0.2-0.4 ml (Nakanishi *et al.*, 1992). The zooplankton samples were preserved in 5 % formaline before identification. Both phytoplankton and zooplankton were identified quantitatively (No · l^{-1}) and qualitatively (up to genus/species).

3. Results and Discussions

3.1 Water Temperature

The annual water temperature ranged 15-29 ℃, 15-31 ℃ and 13-28 ℃ in Phewa, Begnas and Rupa where Ferro (1981/82) observed 15.2-28.2 ℃, 15.1-30.3 ℃ and 15.2-30.2 ℃ in Phewa, Begnas and Rupa respectively showing slightly difference after Ferro (1981/82). Water temperature showed higher during June (29 ℃) in 1993 and in 1994 and during May, June, July and September (27 ℃) in 1995 in Phewa, during June (30 ℃) in 1993, during July (31 ℃) in 1994 and during August and September (29 ℃) in 1995 in Begnas and during June, July in 1994 and during September (28 ℃) in 1995 in Rupa. There was not much difference in depthwise water temperature even up to the bottom with less than 20 ℃ during January and February.

3.2 Dissolved Oxygen

The dissolved oxygen was higher 12 $mg \cdot l^{-1}$ and remained up to 11 $mg \cdot l^{-1}$ even at 5 m depth during April in 1993 with less than 4 $mg \cdot l^{-1}$ during November in 1994 in Phewa and Begnas. The dissolved oxygen did not show much difference depthwise up to 2.5 m depth except during August (2.1 $mg \cdot l^{-1}$) in 1994 and September (1.9 $mg \cdot l^{-1}$) in Phewa. *Ceratium hirudinella* population was high and might cause oxygen depletion by which many caged fish died at night. The great variations of oxygen was below 2.5 m depth during July and August in 1993, during July in 1994, during June, August, September and October in 1995 in Phewa, during August in 1993, during April, May, June, August & September in 1994 and during March through July in 1995 in Begnas. The depthwise dissolved oxygen showed great variation in summer with less variation in winter during November through February. The dissolved oxygen was not found from below 7.5 m depths in Begnas except during winter. The depthwise dissolved oxygen was not fluctuate much though it differed seasonally ranging from 0.6-9.1 $mg \cdot l^{-1}$ in Rupa. Oxygen concentration was higher in Begnas followed by Phewa and Rupa respectively. The macrophytes which utilise most of the nutrients and develop less phytoplankton for which oxygen production is low compare to Phewa and Begnas.

3.3 Secchi disk visibility

The transparency fluctuated differently in Phewa and increased from January to March and decreased till August and increased again in 1994 (Fig. 3). Transparency showed higher during February and fluctuate up and down in 1993. It decreased from March till August and increased slightly again in 1995. Transparency decreased during rainfall which collect the waste materials including silt and soil and affect transparency directly. It ranged from 0.8 m during October in 1995 to 4.80 m during February in 1995 in Phewa. Transparency showed similar pattern in Begnas except during July with highest transparency 4.27 m during September in 1993 and lowest transparency 0.93 m during November in 1994. The transparency in Rupa also showed similar pattern except during October through December. Phewa being deepest lake compared to Begnas and Rupa showed higher fluctuation and Rupa being shallow has shown less fluctuation ranging from 0.7 m during June in 1994 and 1995 to 2.55 m during August in 1994.

3.4 pH

The pH value ranged from 6.3-9.7 during March in Phewa with not much difference depthwise. In case of Begnas, the pH ranged from 6.5 during October to 9.8 during February. The depthwise pH from surface to bottom did not fluctuate much though differed by season. The pH ranged from 5.4 during April, 1993 to 8.7 during February, 1994 in Rupa. The pH value remained within the range for aquaculture 6.5-9 (Boyd, 1984) except in Rupa during April (5.4).

3.5 Light Intensity

Light attenuation was observed 0.46-1.39, 0.41-1.71 and 0.35-2.33 in Phewa, Begnas and Rupa (Table 1) where Nakanishi (1982) observed the light attenuation 0.7-1.02, 1.06-1.30 and 1.15 in the respective lakes. The depthwise relative light attenuation showed higher during January through May in Phewa in 1995 and light attenuation reached up to 5 m depth through out the season with low below 2.5 m depth but no light attenuation below 7.5 m depth. The relative light attenuation in Begnas observed up to 5 m depth showing high intensity during June, August, September, March, May through October and no light or very low below 7.5 m depth. The light attenuation in Rupa did not show any regular pattern with high intensity observed during January, February, June, July, August, September, November in1994 and January in 1995.

Tab.1 Monthly Light intensity in the lakes Phewa, Begnas & Rupa in Pokhara Valley 1993-1995

1993	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Phewa			0.54	0.82	0.51	0.69	0.51	0.89	0.97	1.2	1.39	1.11
Z /%			8.5	5.6	9.0	6.7	9	5.2	4.7	3.8	3.3	4.1
Begnas			0.49	0.75	0.78	0.43	0.59	0.56	0.41	0.69	1.71	1.2
Z /%			9.4	6.1	5.9	10.7	7.8	8.2	11.2	6.7	2.7	3.8
Rupa			2.33	1.77	1.66	2.41	0.84	0.89	0.44	1.24	1.43	0.69
Z /%			2.0	2.6	2.88	1.9	5.5	5.2	10.5	3.7	3.2	6.7
1994												
Phewa	0.69	0.66	0.51	0.6	0.54	0.77	0.71	1.07	0.65	0.76	0,91	1.2
Z /%	6.66	6.96	9.02	7.67	8.52	5.97	6.48	4.3	7.1	6.05	5.05	3.83
Begnas	0.91	0.84	0.94	0.86	0.69	0.61	0.61	0.81	0.48	0.91	1.04	1.23
Z /%	5.05	5.48	4.89	5.35	6.67	7.54	7.54	5.68	5.58	5.05	4.42	3.74
Rupa	0.91	0.86	2.04	1.6	0.35	1.02	1.14	0.71	0.91	1.83	1.2	1.06
Z /%	5.05	5.35	2.25	2.87	13.14	4.51	4.03	6.48	5.05	2.51	3.83	4.34
1995												
Phewa	0.56	0.48	0.54	0.56	0.46	0.8	1.08	0.51	1.24	1.2	0.84	0.77
Z /%	8.0	9.6	8.5	8.2	10.0	5.8	4.2	9.0	3.7	3.8	5.5	6.0
Begnas	1.02	1.14	0.73	0.97	0.65	0.69	0.58	0.58	0.43	0.69	1.24	1.08
Z /%	4.5	4	6.3	4.7	7.0	6.7	8.0	8.0	10.7	6.7	3.7	4.3
Rupa	0.75	1.39	1.39	2.3	1.35	1.24	0.61	0.78	1.02	1.24	1.31	0.82
Z /%	6.1	3.3	3.3	2.0	3.4	3.7	7.5	6.0	4.5	3.7	3.5	5.6

3.6 Chlorophyll *a*

The distribution pattern of chlorophyll *a* amounts in the lakes Phewa, Begnas and Rupa might be influenced mainly by the water movement and the trophic status. The chlorophyll *a* amounts showed higher during September and October in 1995 and followed by October and November in 1995 and during February, March, June, July, August, September, October and November in 1994.

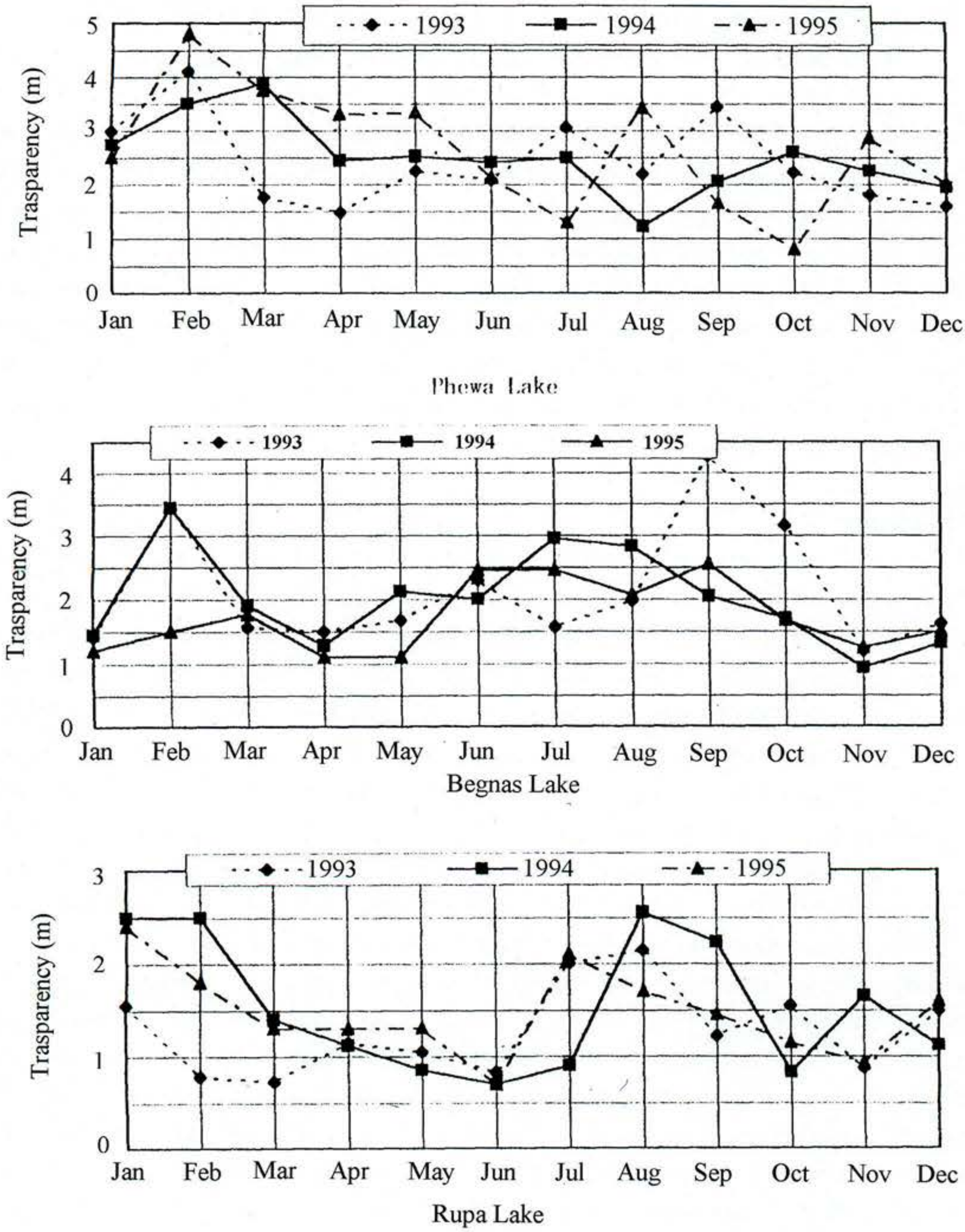

Fig.3 Monthly Secchi disc Visibility (m) of Lakes Phewa, Begnas and Rupa

The highest amounts of chlorophyll*a* (55.9 $mg \cdot l^{-1}$) observed during September and 0 during

July in 1995 in Phewa but it was higher during winter in Begnas and Rupa which might be due to mix of water from bottom to surface during heavy rainfall. The highest amounts (71.4 $mg \cdot l^{-1}$) obtained during November at 5 m depth with lowest amount (0.3 $mg \cdot l^{-1}$) during August in 1993. It showed highest amount (78 $mg \cdot l^{-1}$) during July in 1994 at 1 m depth and lowest amount -14 $mg \cdot l^{-1}$ during February in 1995 in Rupa and is higher than in Phewa and Begnas. The Chlorophylla amount depend upon the phytoplankton available but directly affected with the rainfall and water flush out. In Phewa and Begnas Lakes water flush out depending upon the rainfall and farmer's used for irrigation. In case of Rupa it flush out immediately during rainfall because of no dam and shallow. The vertical distribution of chlorophylla amount was heterogenous and the fluctuation might brought due to water displacement and chlorophylla concentration. The relationship between chlorophyll*a* + pheopigments has shown positive correlation with particulate carbon ($y=48.915x+383.523$, $r^2=10.886$), particulate phosphorus ($y=0.363x+9.444$, $r^2=0.319$) and particulate nitrogen ($y=6.743x+77.021$, $r^2=0.506$) (Fig. 4).

3.7 Nutrients

NH_4-N ranged from 0->2 $mg \cdot l^{-1}$ with highest amount (>2 $mg \cdot l^{-1}$) during March in 1995 and NO_2-N+NO_3-N ranged from 0-0.455 $mg \cdot l^{-1}$ with highest amount (0.455 $mg \cdot l^{-1}$) during January at bottom in 1994 in Phewa. NH_4-N ranged from 0->2 mg/l with highest amount (>2 $mg \cdot l^{-1}$) during February through May, July, August and November in 1994 and $N0_2$-N+$N0_3$-N ranged from 0-0.306 $mg \cdot l^{-1}$ with highest amount (0.306 $mg \cdot l^{-1}$) during October at bottom in 1995 in Begnas. NH_4-N ranged from 0->0.2 $mg \cdot l^{-1}$ showing highest during February at 1 m depth in 1995 and NO_2-N+NO_3-N ranged from 0-0.4 $mg \cdot l^{-1}$ with highest (0.4 $mg \cdot l^{-1}$) during August at 2 m depth in 1994 in Rupa. PO_4-P concentration ranged from 0-0.012 $mg \cdot l^{-1}$, 0-0.080 $mg \cdot l^{-1}$ and 0-0.155 $mg \cdot l^{-1}$ and total phosphorus ranged from 0-0.077 $mg \cdot l^{-1}$, 0-0.052 $mg \cdot l^{-1}$ and 0-0.057 $mg \cdot l^{-1}$ in Phewa, Begnas and Rupa respectively. PO_4-P was higher in Begnas followed by Rupa and Phewa whereas total phosphorus was higher in Phewa followed by Rupa and Begnas respectively. The nutrients among nitrogen, carbon and phosphorus have shown the positive correlation in Phewa, Begnas and Rupa lakes (Fig. 5). Although CP:CN:NP ratios do not always reflect the phytoplankton chemical ratio especially in the waters where phytoplankton biomass contributes relatively small portion of total particulate matter (Goldman, 1980; Gachter and Bloesch, 1985; Tezuka, 1985), but their ratios seemed to be a useful tool for rough diagnosis of nutritional state of phytoplankton. Nakanishi *et al.* (1986) reported the low nitrogen and low N:P ratios in Pokhara Valley Lakes and N:P values ranged from 11-18 in post-monsoon period which is reported similar by Lohman *et al.* (1988). In this study the mean N:P ratios ranged from 16.2-27, 14.1-34.8 and 6.7-19.1, C:P ratios ranged from138.6-279.9, 151-363.4 and 56.1-174.8 and C:N ratios ranged from 8.3-11.6, 8.2-11.7 and 6.4-8.7 in Phewa, Begnas and Rupa Lakes respectively. The nutrient ratios may very seasonally and C:N and N:P ratios are somewhat close to the Redfield ratio except C:P ratios is far above the Redfield ratio that means P is limited, however high C:P and N:P ratio cannot conclude phytoplankton growth in the lakes limited by P (Nakanishi, *et al.*, 1988).

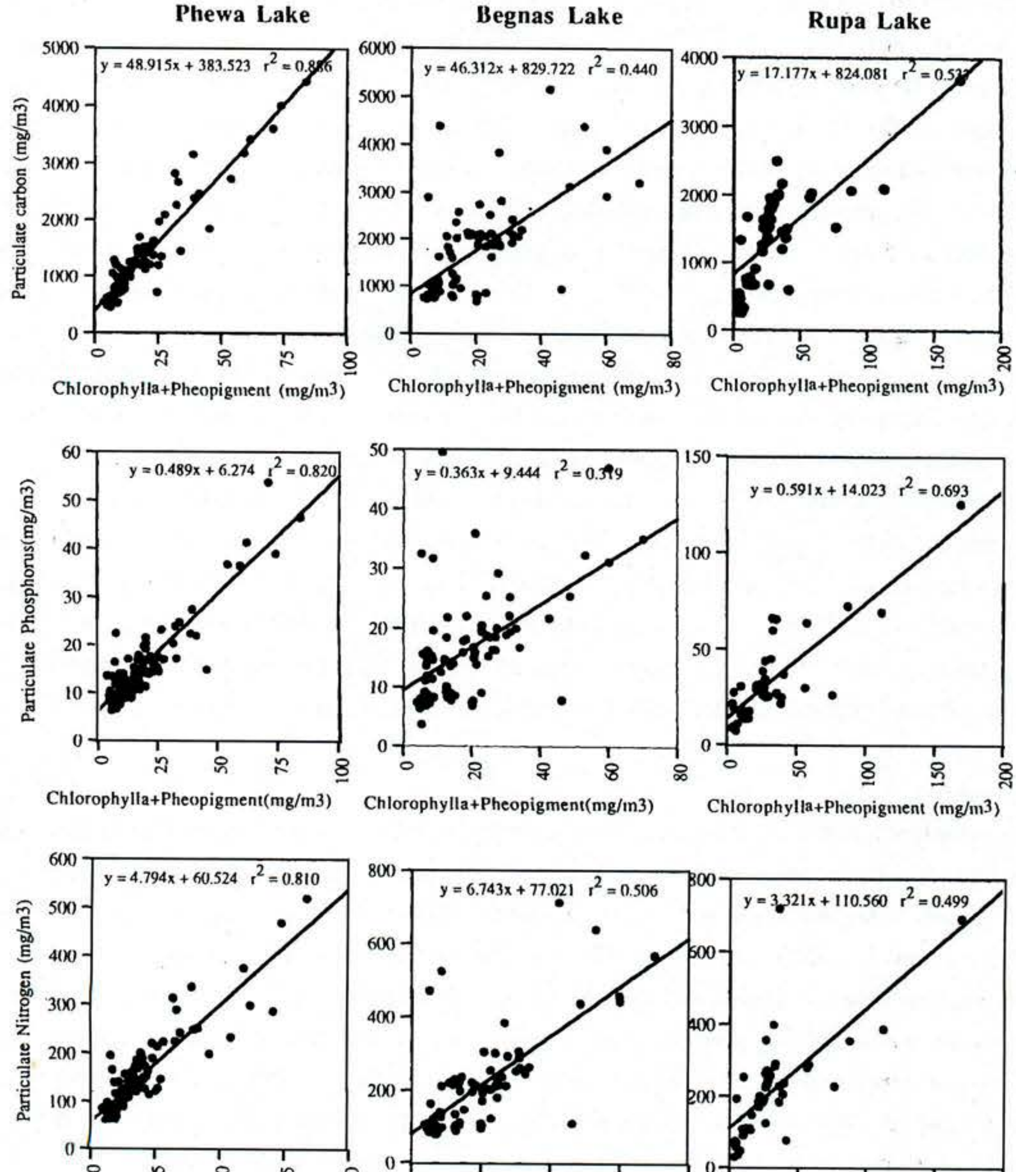

Fig.4 Relationship between Chlorophylla+Pheopigment (mg·m^{-3}) and particulates carbon, phosphorus & nitrogen of Phewa, Begnas and Rupa Lakes 1994.

3.8 Primary Production

Annual gross primary production, net primary production and community respiration showed higher in Phewa followed by Begnas and Rupa Lakes but the annual net primary production was higher in Rupa compared to Phewa and Begnas Lakes (Tab.2). The daily gross primary production ranged from 0.069 in December 1994 to 4.75 g · m^{-2} · d^{-1} in October 1993 in Phewa, 0.52 in

September 1993 to 2.0 g · m^{-2} · d^{-1} in January 1994 in Begnas and 0.095 during January in 1995 to 2.08 g · m^{-2} · d^{-1} during June 1993 in Rupa. Daily primary production showed great fluctuation in Phewa than in Begnas and Rupa and it was observed 1.490 and 1.380 in Begnas and Rupa (Nakanishi *et al.*, 1982). The fluctuations may suggest that water temperature, nature of algae, abiotic environment influence on photosynthetic behaviour of natural phytoplankton (Watt, 1971; Magaire, 1971). The primary production did not fluctuate much for three years except in October where it fluctuated very high and obtained gross primary production up to 5 g · m^{-2} · d^{-1} (Fig. 6) and net primary production was negative (Fig.7). The primary production remained within 0-2 g · m^{-2} · d^{-1} in Begnas and it fluctuated morethan in Phewa might be due to the water used by the farmers frequently for irrigation and fluctuate the productivity of water in the lake. Rupa is very shallow and increasing macrophytes which used the nutrients as a result primary production is very low compared to Phewa and Begnas lakes. The primary production showed higher during June in 1993 and during July in 1994, however it showed the decreasing pattern from 1993 to 1995 means the productivity is decreasing in Rupa. The daily net primary production ranged from -0.628-1.45 g ·m^{-2} ·d^{-1}, -1.82-0.793 g ·m^{-2} ·d^{-1} and -0.27-1.21 g ·m^{-2} ·d^{-1} in Phewa, Begnas and Rupa and Nakanishi *et al.* (1982) reported that daily net production was -0.004 and 0.64 g · m^{-2} · d^{-1} in Begnas and Rupa respectively. The negative net production tells the community respiration exceeded for phytoplankton photosynthesis in deeper layers (Nakanishi *et al.*, 1982).

Phytoplankton

The phytoplankton density fluctuated very high in Phewa with high density during June and July and decreased sharply during August in 1993 and during April in 1994. The density has shown the decreasing tendency in Lake Phewa from 1993-1995 but was higher density than in Lake Begnas and less than Lake Rupa (Fig. 8). The dominant species were found *Microsystis aeruginosa, Ceratium hirudinella* and *Peridinium* spp, *Melosira granulata, Crucigenia tetrapedia, Sphaerocystis schroeteri, Merismopedia tennuissima, Anabaena* spp., and *Cosmerium botrytsi.* with *Ceratium hirudinella* and *Peridinium spp.* were most abundant during September/October in Phewa Lake in 1994 and killed caged fish due to oxygen depletion. The density was high in Begnas during January in 1995 with dominant species of *Microsystis aeruginosa, Melosira granulata, Sphaerocystis schroeteri, Merismopedia tennuissima, Cyclotella* spp., *Quadrigulla pfitzeri, Crucigenia tetrapedia* with most abundant of *Microsystis aeruginosa mostly at 7.5 m depth*. The phytoplankton fluctuation in Rupa was higher than in Begnas and the dominant species were *Tabellaria fenestra, Cyclotella spp., Sphaerocystis schroeteri, Microsystis aeruginosa, Crucigenia tetrapedia, Euglena* spp., *Volvox aureus*. Phytoplankton composition was dominated by diatoms in Phewa and by blue-greens in Begnas (Lohman, *et al.*, 1988). The depthwise phytoplankton density in Phewa obtained high up to 7.5 m depth during June, July and October in 1993 and during April in 1994. The plankton population fluctuation in Lakes Phewa and Begnas also-might affected by the quantity of rainfall and the use of water by farmers for irrigation, however the phytoplankton density did not show much fluctuate in Begnas (Fig.8). The depthwise phytoplankton density in Begnas obtained high up to 7.5 m depth during October, November and De cember in 1993, during January and December in 1994 and during January and February in 1995 respectively. In Rupa the phytoplankton density fluctuated greatly showing higher density during June in 1993, during June, July and November in 1994 and during November in 1995. Seasonal change of pattern of phytoplankton composition varies greatly depending upon the season and

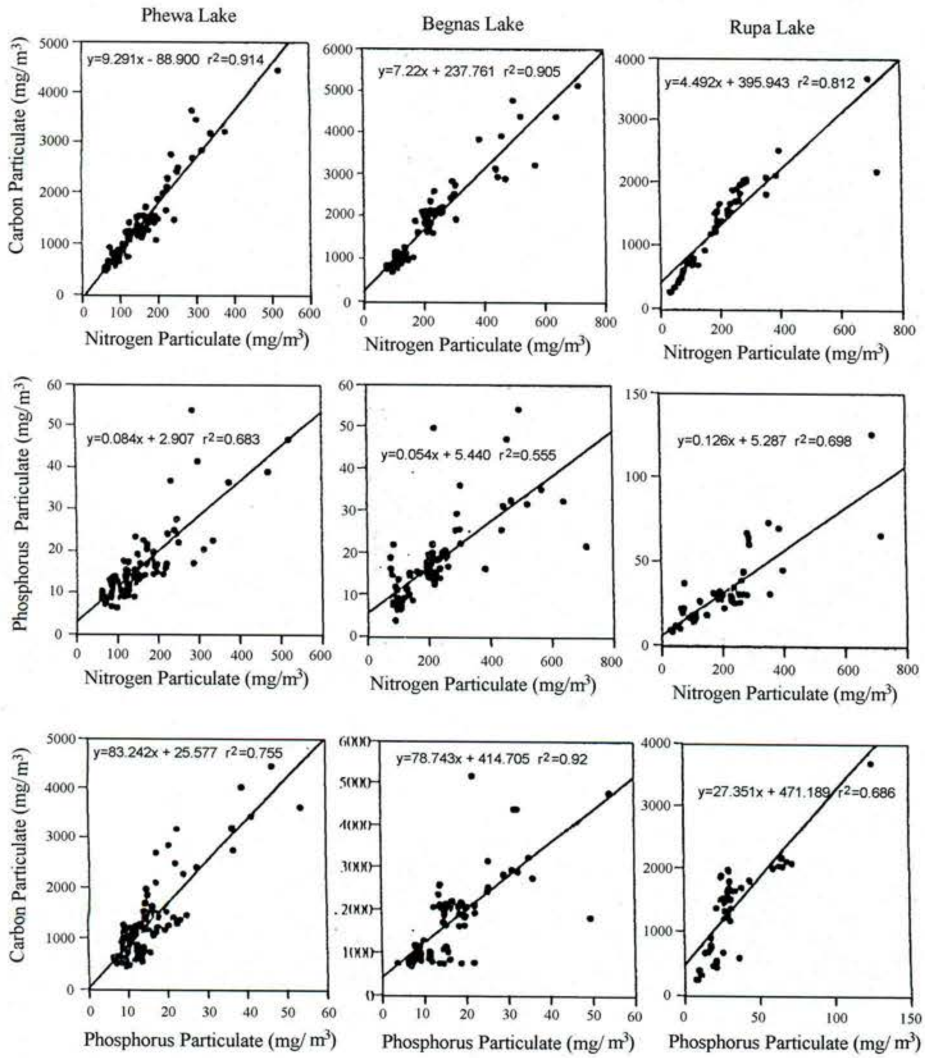

Fig. 5 Relationship between particulates of nitrogen & carbon, nitrogen & phosphorus and carbon & phosphorus of Phewa, Begnas and Rupa Lakes 1994.

that might suggest that physical, chemical and biological factors in the water influence the growth of planktonic algae. Phytoplankton biomass are strongly related to nutrient availability and in eutrophic systems. Nutrients are likely to be the primary determinate of phytoplankton biomass and water clarity (Lafontaine & McQueen 1991)

Tab. 2 Annual Primary Production in the lakes Phewa, Begnas & Rupa 1993-'95.

	Annual Primary Production ($Ct \cdot a^{-1}$)			Annual Primary Production ($Cg \cdot m^{-2} \cdot a^{-1}$)		
Phewa	1993	1994	1995	1993	1994	1995
Gross Primary Production	2700	2800	3000	520	530	530
Net Primary Production	750	250	180	140	50	30
Community Respiration	1950	2550	2820	380	480	550
Begnas						
Gross Primary Production	1500	1200	1000	460	360	310
Net Primary Production	300	40	200	100	10	70
Community Respiration	1200	1160	800	360	350	240
Rupa						
Gross Primary Production	500	400	200	380	290	170
Net Primary Production	200	200	20	150	150	10
Community Respiration	300	200	180	230	140	160

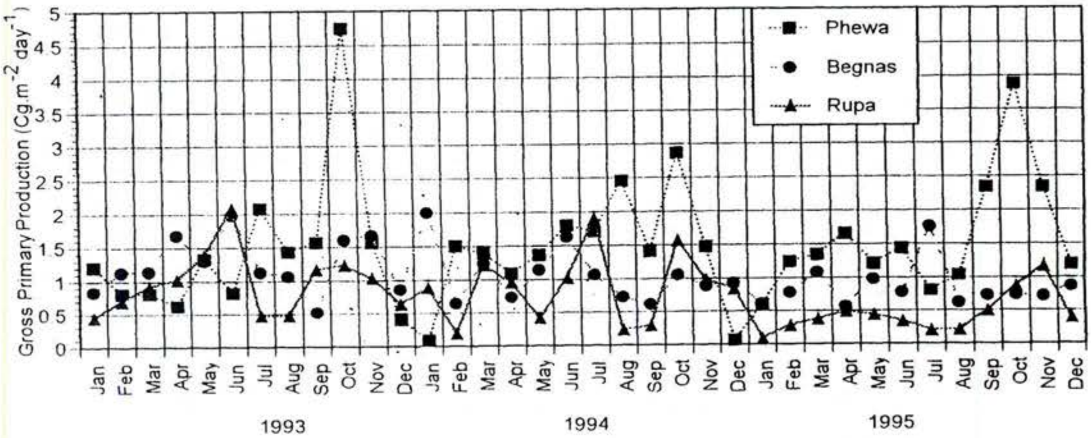

Fig. 6 Daily gross primary production ($g \cdot m^{-2} \cdot d^{-1}$) **in Lakes Phewa, Begnas & Rupa**

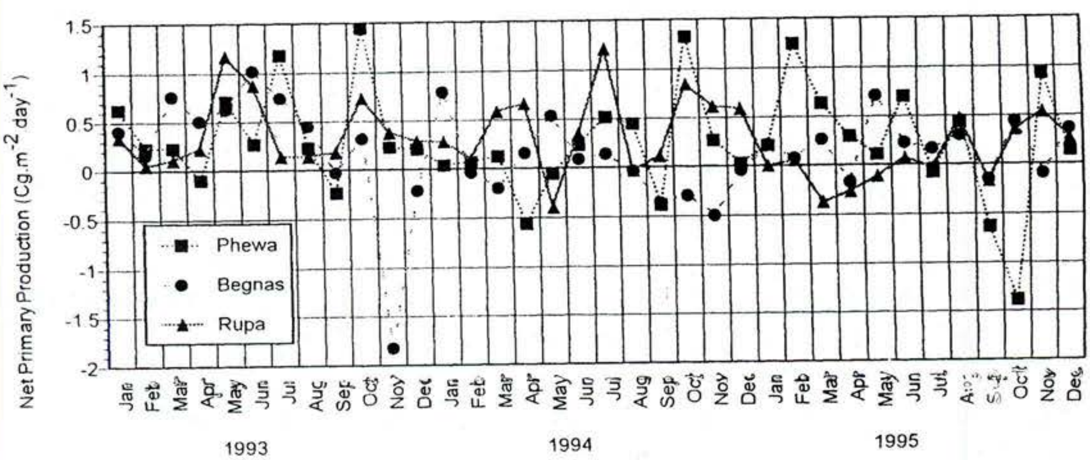

Fig. 7 Daily net primary production ($g \cdot m^{-2} \cdot d^{-1}$) **in Lakes Phewa, Begnas & Rupa 1993-1995**

3.9 Zooplankton

The distribution pattern of zooplankton showed high fluctuation with higher density in Phewa than in Begnas but less than in Rupa (Fig. 9). Zooplankton obtained high density with dominant species of copepod: *Cyclopoid* spp. and *Calanoid* spp. during May in 1993 and during October in 1995 with dominant species of rotifera: *Keratella* spp. and *Brachionus* spp. in Lake Phewa. The zooplankton density was higher during January, July, November and December in 1993 with dominant species *Ceriodaphnia spp.*, *Cyclopoid* spp. and *Bosmina longistris.* in Lake Begnas. The population decreased from February till April and remained about similar density in the following months with slightly increased in 1993 but the density showed decreasing trend from 1993 to 1995 (Fig. 9). The depthwise zooplankton density both in Phewa Lake and Begnas Lake was higher during September and November in 1994 and during January and October in 1995. In case of Rupa the density was higher during May, November and December 1995 with very low density during June through September in 1994 and during June through August in 1995. The dominant species were nauplii during May, *Synchaeta stylata, Keratella* spp. and *Conochilodes* spp. during December and *Colurella* spp. during November 1995.

3.10 Trophic status

According to Hutchinson (1937), based on the phytoplankton available Phewa classified as oligotrophic and Begnas and Rupa classified as eutrophic. Hickel(1973) also considered Phewa Lake as oligotrophic but Brook (1965) mentioned that a high number of species found in eutrophic waters. Rawson (1956) has mentioned that *Melosira granulata* indicates the eutrophic lake. The dominant phytoplankton species available *Microsystis aeruginosa, Melosira granulata, Merismopedia tennuissima, Anabaena* spp., *Ceratium hirudinella* and *Peridinium* spp,. in Phewa Lake which can be classified as meso-eutrophic based on Hutchinson (1937) classification). In Begnas Lake *Microsystis aeruginosa*, *Melosira granulata, Crucigenia tetrapedia* and *Sphaerocystis schroeteri* were dominant and *Tabellaria fenestra, Volvox aureus* and *Cyclotella* spp. were dominant species in Rupa which also can be classified under meso-eutrophic. Judging from the total phosphorus concentration, Nakanishi *et al.* (1982) reported that Phewa seems to be oligo-mesotrophic and Begnas and Rupa seem to be eutrophic. Aruga (1965) summarised that the chlorophyll<u>a</u> contents within euphotic layer were 1-30 $mg{\cdot}m^{-2}$, 11-123 $mg{\cdot}m^{-2}$ and 100-290 $mg{\cdot}m^{-2}$ in Japanese oligotrophic, mesotrophic and eutrophic lakes. Chlorophyll<u>a</u> were available 0.8-66 $mg{\cdot}l^{-1}$, 1-51 $mg{\cdot}l^{-1}$ and 0.6-63 $mg{\cdot}l^{-1}$ in Phewa, Begnas and Rupa and under Aruga's (1965) classification Phewa, Begnas and Rupa are under oligo-eutrophic. Ichimura (1960) estimated the gross primary production in the lakes 0.03-0.10 $g{\cdot}m^{-2}{\cdot}d^{-1}$, 0.05-0.27 $g{\cdot}m^{-2}{\cdot}d^{-1}$ and 0.18-1.72 $g \cdot m^{-2} \cdot d^{-1}$ in oligotrophic, mesotrophic and eutrophic lakes. In this study daily gross primary production were within the range 0.069-4.75 $g{\cdot}m^{-2}{\cdot}d^{-1}$ in Phewa, 0.52-2.0 $g{\cdot}m^{-2}{\cdot}d^{-1}$ in Begnas and 0.095-2.08 $g{\cdot}m^{-2}{\cdot}d^{-1}$ in Rupa respectively. Under his classification Phewa and Rupa are meso-eutrophic and Begnas is eutrophic. Yoshimura (1937) classified trophic state of lakes on the basis

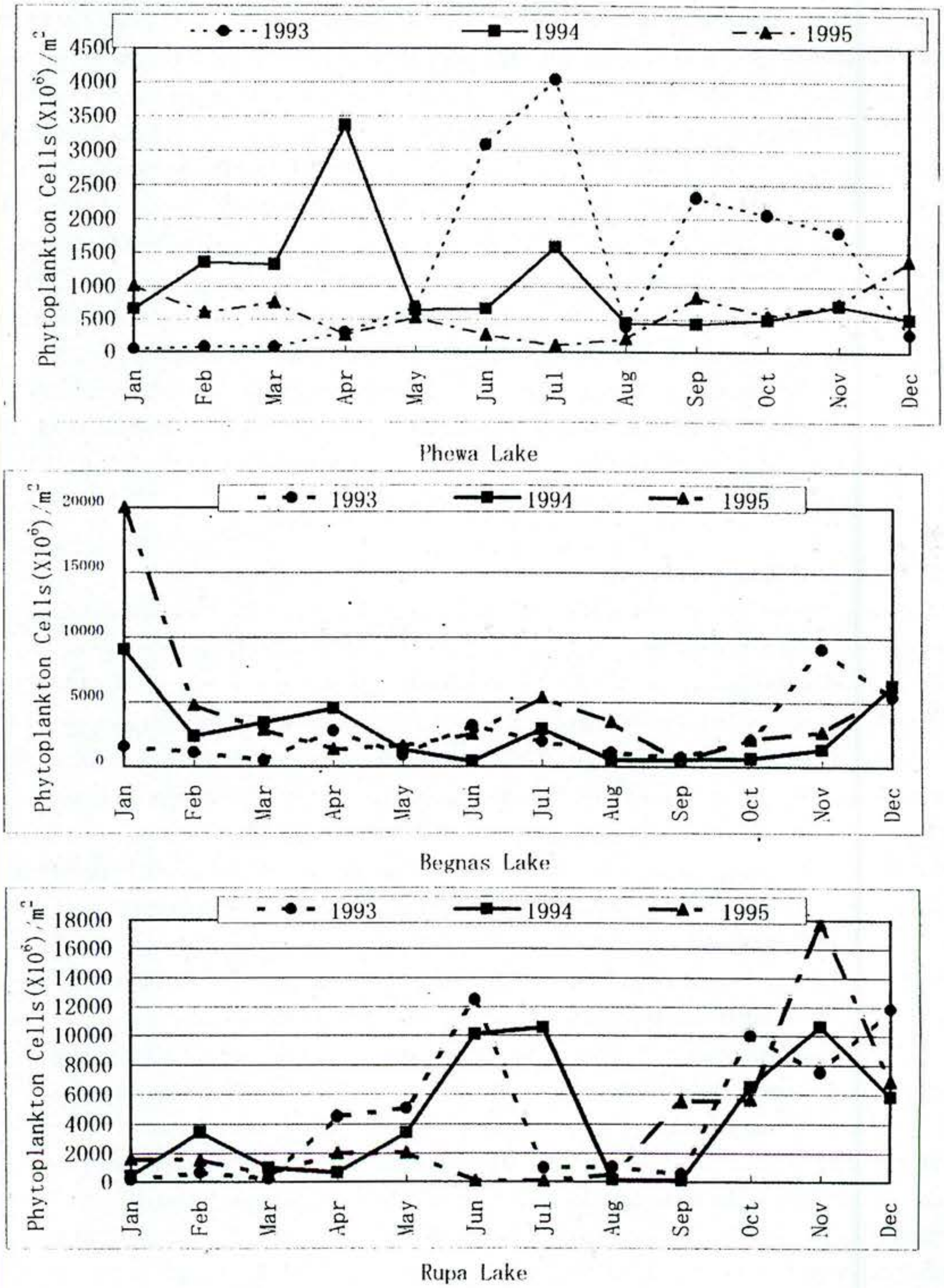

Fig.8 Monthly phytoplankton cells ($\times 10^6$ m^{-2}) in the Lakes Phewa, Begnas & Rupa 1993-1995

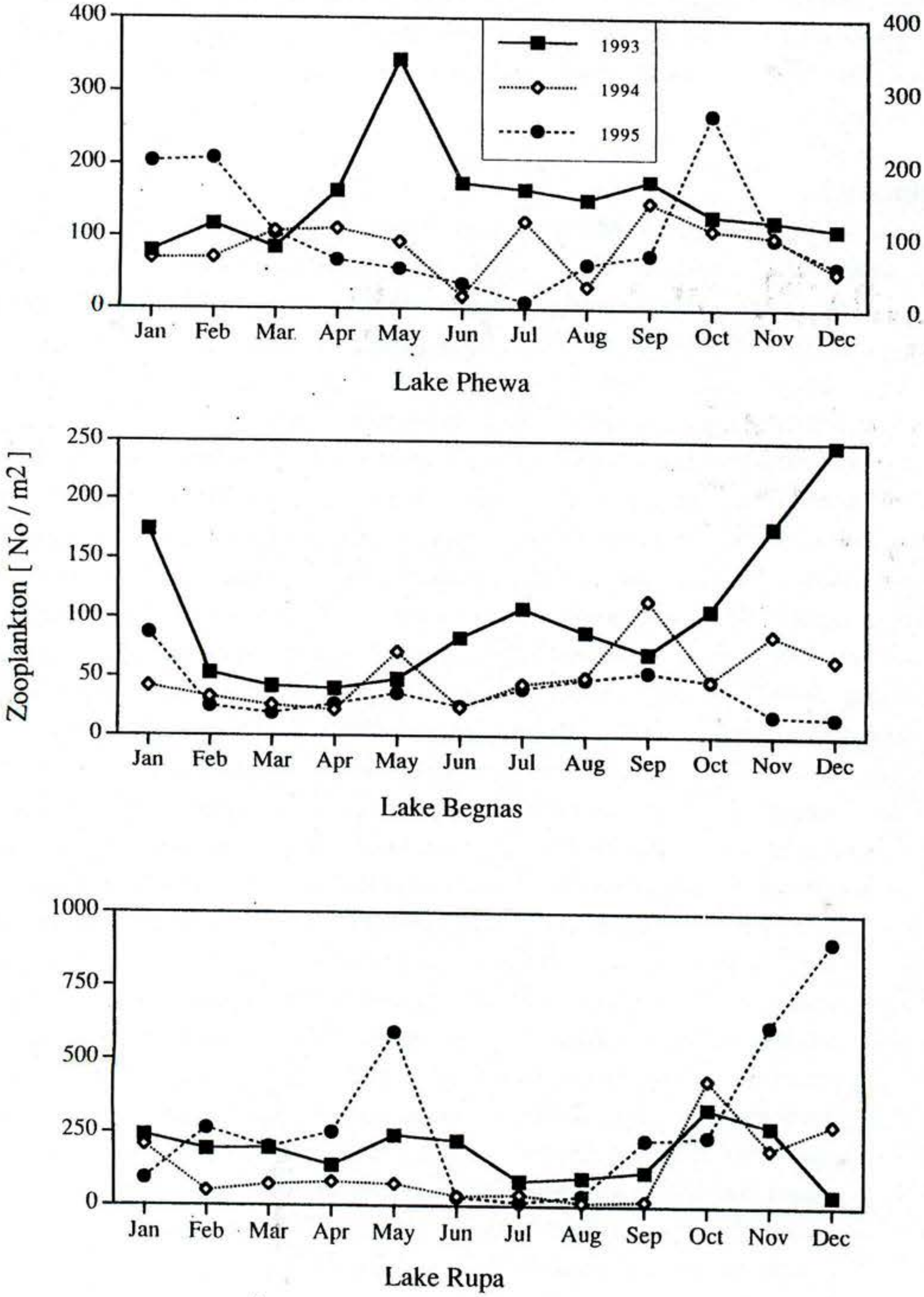

Fig. 9 Monthly zooplankton (No.· m^{-2}) in Lakes Phewa, Begnas and Rupa

of nitrogenous compounds-N and phosphorus-P as the indicators having over 0.15 N $mg \cdot l^{-1}$ and 0.02 P $mg \cdot l^{-1}$ as eutrophic and below as oligotrophic. The nitrogen content ranged from 0-0.226 N

$mg \cdot l^{-1}$, 0->2 N $mg \cdot l^{-1}$ and 0->2 N $mg \cdot l^{-1}$ and dissolved phosphorus content ranged from 0-0.010 P $mg \cdot l^{-1}$, 0-0.019P $mg \cdot l^{-1}$ and 0-0.133 P $mg \cdot l^{-1}$ in Phewa, Begnas and Rupa respectively. So under Yoshimura (1937) classification of nitrogen and phosphorus content all these lakes are under oligo-eutrophic.

4. Summary

The trophic status of the lakes Phewa, Begnas and Rupa were investigated on the basis of nitrogenous compounds-N, phosphorus compounds-P, gross primary production, chlorophyll^{a} and phytoplankton productivity. Nitrogen concentrations were varied from 0-0.240 N $mg \cdot l^{-1}$ during February and July in 1995 in Phewa, 0->0.20 N $mg \cdot l^{-1}$ during November 1995 in Begnas and 0-0.125 N $mg \cdot l^{-1}$ during February 1995 in Rupa. Phosphorus varied from 0-0.017 $mg \cdot l^{-1}$ during March in Phewa, 0-0.052 $mg \cdot l^{-1}$ during December 1994 in Begnas and 0-0.155 $mg \cdot l^{-1}$ during May 1994 in Rupa and these lakes are classified under different parameter of different researchers and classified differently from oligotrophic to eutrophic. According to classification of Hutchinson (1937) and Rawson (1956) the presence of *Microsystis aeruginosa*, *Melosira granulata, Merismopedia tennuissima, Anabaena* spp., *Ceratium hirudinella* and *Peridinium* spp. in Phewa Lake, *Microsystis aeruginosa, Melosira granulata, Crucigen tetrapedia* and *Sphaerocystis schroeteri* in Begnas and *Tabellaria fenestra, Volvox aureus* and *Cyclotella* spp. in Rupa, these lakes are under oligo-eutrophic. On the basis of chlorophyll*a* contents classification (Aruga, 1965), Phewa, Begnas and Rupa are under oligo-eutrophic. Under Ichimura's (1960) classification Phewa and Rupa are under meso-eutrophic and Begnas is under eutrophic. Under on Yoshimura's (1937) classification all these lakes Phewa, Begnas and Rupa are under oligo-eutrophic. The wide difference is due to the exchange of water in the lakes due to seasonal heavy rainfall and used of water by the farmers for irrigation and fluctuate very much seasonally. Nakanishi *et al.* (1982) also reported based on the total phosphorus concentration Phewa seems to be oligo-mesotrophic and Begnas and Rupa seem to be eutrophic. *Ceratium hirudinella* and *Peridinium* spp. showed dominant species during September and October in Phewa Lake and that is different from Begnas and Rupa Lakes whereas *Tabellaria fenestra and Volvox aureus* were dominant seasonally in Rupa. The relative low concentration of dissolved phosphorus suggests that phosphorus become limiting nutrients for algal growth and high chlorophylla and ammonia concentrations suggest that an active heterotrophic community was present. The fluctuation in photosynthetic activity may suggest that not only water temperature but also physiological conditions inherent nature of algae or many kinds of abiotic environment (Watt, 1971; Magaire and Neil, 1971). The lakes accumulate lots of nutrients loads from the villages and people living around the lakes but flush out the accumulated nutrients during heavy monsoon and control from eutrophication.

Since the activity of the people directly affect the environment, public awareness should be generated regarding the status and the value of the flora and ecosystem of the lakes. Polluted discharge from Seti river and accumulation of nutrients from villages including unplanned construction of hotels and houses around the lakes degraded the water quality of the lakes. To prevent

such problems Government should implement effective program to educate people for conservation and utilisation of natural resources. Soil conservation and watershed management by plantation should be done with public participation as private forestry around watershed area for conservation and sustainable of natural resources and also lake area should be demarcated to protect the lakes from encroachment. Water need to control properly from irrigation channel and release only required amount without making wastage and limnological/biological study of the lakes should be continued for monitoring and evaluation of the lake status. Rupa Lake is becoming more shallow every year due to siltation and covering with macrophytes. If continue siltation at the present rate, Rupa Lake will disappear within 20 Years (IUCN, 1996), so Government should give special attention by damming downstream areas with a series of check dams towards upstream areas.

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