CHAPTER 4

STUDY OF PLANKTON

INTRODUCTION

A microscopic community of plants (phytoplankton) and animals (zooplankton) found usually free floating, swimming with little or no resistance to water currents, suspended in water, non-motile depending for transport by currents are called plankton (Reynold, 2006). Planktons are of great importance as food and in the natural purification of polluted waters and clearance of sewage.

Plankton, particularly phytoplankton, have long been used as indicators of water quality. Because of their short life span and quick responses to environmental changes their standing crops and species composition indicate the quality of water in which they are found (Mercado, 2003). Clean water supports a great diversity of organisms, whereas, very few organisms survive in polluted water with one or two dominant forms (Saladia, 1997). Phytoplankton constitutes the basis of nutrient cycle of an ecosystem hence play an important role in maintaining equilibrium between living organisms and abiotic factors (Wetzel, 2001).

Zooplanktons, like phytoplankton, have also been used recently as indicators to observe and understand changes in ecosystem because they also seem to be strongly influenced by climatic features (Beaugarand and Reid, 2000; Li *et al*., 2000). The variability observed in the distribution of zooplankton is due to abiotic parameters (e.g. climatic or hydrobiological parameters like temperature, stratification and advection) or to a combination of both (Beyst *et al*., 2001). The use of zooplankton for environmental characterization of a water body is potentially advantageous. The individual generation time of zooplankton is short enough for them to quickly respond to acute stress but long enough for them to integrate the effects of chronic situations, making them favourable candidates/tools as community indicators of health of any ecosystem (Cairns *et al.,* 1974). Thus, the use of zooplankton for ecological biomonitoring of water bodies also helps in the analysis of water quality trends and judgement of adequacy of water quality for various uses. Hence, in present study of Lotus Lake both Phytoplankton and Zooplankton are considered.

MATERIAL AND METHODS

The study site was visited at an interval of fifteen days from December 2006 to November 2008. Surface water samples were collected from three stations of Lotus Lake (LL) namely LL-A, LL-B and LL-C as described in chapter 2 between 8 a.m. to 10 a.m. For each parameter studied the average of these stations are taken.

As given by (Edmonson, 1963) ten liters of water was filtered through the plankton net No. 25 of bolting silk with mesh size 64 micron. Net was washed with the water by inverting it to collect the plankton attached to the net and the final volume of sample was made to 100 ml. The samples were taken in separate vials and fixed with 1 ml of 4 % formalin and 1 ml of Lugol's Iodine at the collection sites. Only 10 ml of well mixed sample from each station was further concentrated by centrifuging at 2000 RPM for 10 min. For quantitative estimation of plankton, one ml well mixed sample was taken on 'Sedgewick Rafter Cell'. To calculate density of plankton the averages of 5 to 10 counts were made for each sample and the results are expressed as numbers of organisms per liter of sample. Qualitative study of phytoplankton and zooplankton were carried out up to the genus/species level using the standard keys given by Edmondson (1963), Philipose (1967), Sarode and Kamat (1984) and Battish (1992).

Statistical analysis

The data of the two year study (from December-2006 to November-2008) was pooled for three months and four seasons and analyzed for seasonal variations, with respect to winter (December, January, February), Summer (March, April, May), Monsoon (June, July, August) and Post monsoon (September, October, November). Further, the Mean, Standard Error of Mean (SEM) were calculated for each season and One-Way ANOVA with no post test for various parameters for four seasons was performed using Graph Pad Prism version 3.00 for Windows (Graph Pad Software, San Diego California USA). The correlation between the abiotic factors and the plankton density was calculated. The Pearson Correlation was calculated by keeping plankton as dependent variable and other abiotic and biotic factors as independent variables with the help of SPSS 7.5 for Windows.

CHAPTER 4A

PHYTOPLANKTON

INTRODUCTION

Biodiversity conservation seeks to maintain the human life by providing living resources essential for his survival. These vital resources from the ecosystems need to be carefully conserved for future generation. Plankton are especially important as they form one of the most sensitive component of an aquatic ecosystem that signal environmental disturbances. However, this important biodiversity in aquatic ecosystem has remained neglected (Gopal, 1997). At the base of aquatic ecosystem phytoplankton are the producers, hence, they are looked for as a major component of any freshwater system. They play a key role in solving several environmental problems, understanding aquatic ecosystem and also the production of useful substances (Kurano and Miyachi, 2004).

As species composition of phytoplankton communities changes in response to the environmental variations (Naselli-Flores, 2000) long term studies of phytoplankton component in relation to fluctuations of water quality parameters are useful in developing and evaluating significant general ecological ideas. The phytoplankton abundance is a result of spatial and temporal changes in physical (*e.g*. temperature, light and nutritive levels) and biological variables (*e.g*. grazing pressure and competition), but of the externally imposed or self generated spatial segregation (*e.g*. life cycles) (Roy and Chattopadhyay, 2007). The spatio-temporal variability in nutrient availability also plays an important role in determining the phytoplankton distribution and abundance (Naselli-Flores, 2000).

The study of aquatic communities and the factors affecting their stability are the central challenges of ecology since water bodies have always been of great importance for man-kind as source of water and also for food from fisheries (Kamenir *et al*., 2004). Of the various factors, temporal variability is of fundamental importance in the structure and function of a phytoplankton community and its metabolism (Calijuri *et al*., 2002). Since phytoplankton are the primary producers forming the first trophic level of food chain in aquatic system, investigations of the phytoplankton community are of great importance for monitoring them.

Algae being sensitive to the pollution or other changes in water, serve as bio-indicator of water quality and pollution status (Saladia, 1997) and hence are commonly used for monitoring environmental contamination (Wu, 1999). The pollution in water causes changes not only in physical and chemical variables but also in algal species composition (Mercado, 2003), especially in tropical inland waters leading to deterioration of potable potential of water (Sedamkar and Angadi, 2003). Hence, study of phytoplankton is also significant to assess the quality of freshwater.

Hurlbert (1971) has correlated plankton species richness positively with various measures of ecological diversity. In Indian reservoirs, three distinct plankton pulses are reported which coincide with post-south west monsoon (September- November), winter (December-February) and summer (March-May) (Sugunan, 2000). According to this author the southwest monsoon (June-August) disturbs and often dislodges the standing crop of plankton by causing turbulence in water. As post monsoon merges into winter, the turbulence decreases and water becomes clean, creating a favourable climate for phytoplankton community to progress through a series of serial successions to culminate in a peak. The summer maxima of plankton coincide with the drastic drawdown of water level that brings the deep, nutrient rich areas into the fold of tropholytic zone. Higher temperature, bright light and rapid tropholytic activities also accelerate the multiplication of phytoplankton during summer.

Hence, while studying hydrobiology of the Lotus Lake it is important to evaluate status of primary producers- the phytoplankton. The present chapter deals with density and diversity of phytoplankton at Lotus Lake, Toranmal Plateau, North Maharashtra, India.

RESULTS

1. Total Phytoplankton

During the two years (December 2006 to November 2008) study, total 41 species of phytoplankton (Annexture I, Plate 6 and 7) were identified from Lotus Lake water belonging to four taxonomic assemblages: Cyanophyceae, Chlorophyceae, Bascillariophyceae and Euglenophyta. The percentage density of these four groups of phytoplankton recorded as two years % average (Table 4a.1, Fig.4a.2), in decreasing order, was Bacillariophyceae (44.33 %), Chlorophyceae (30.16 %), Cyanophyceae

(21.78 %) and Euglenophyta (3.71 %). This Density of total phytoplankton registered significant seasonal variations (P < 0.0001) ($F_{3\ 44}$ 40.74) with maximum density in summer (3786 ± 143.9 /l) and minimum in post monsoon (1805 ± 72.39 /l) while it was 2135 ± 187.3 /l and 3221 ± 151.7 /l in monsoon and winter respectively (Table 4a.1, Fig. 4a.1).

The two years percentage of species richness of total phytoplankton of Lotus Lake (Table 4a.2, Fig. 4a.4) also occurred in the similar decreasing order as density with Bacillariophyceae (45.96 %), Chlorophyceae (25.67 %), Cyanophyceae (20.57 %) and Euglenophyta (7.78 %). Species richness of total phytoplankton also showed highly significant seasonal variations (P < 0.0001) ($F_{3\ 44}$ 67.16). Maximum species of total phytoplankton were recorded in summer (27.75 ± 0.52) and minimum in winter (16.67 ± 0.65) with 22.67 ± 0.48 and 19.58 ± 0.63 in monsoon and post-monsoon respectively (Table 4a.2, Fig. 4a.3). Various groups of phytoplankton showed following trends:

Cyanophyceae (Blue Green Algae)

Blue green algae were third dominant quantitative component of total phytoplankton with two years percentage abundance of 21.78 % (Table 4a.1, Fig. 4a.2).
Density of the Cyanophyceae was maximum in winter (857.4 ± 42 /l) and minimum in monsoon (420.5 ± 38 /l) with 652.7 ± 37.09 /l in summer and 453.7 ± 28.23 /l in post monsoon. (Table 4a.1 Fig. 4a.1) (P < .0001 $F_{3\ 44}$ 30.05). Total seven genera with seven species of Cyanophyceae (Annexture-II) were identified during the study. Mean two years average percentage of species richness of blue greens was 20.57. Maximum Species richness for Cyanophyceae was also recorded in winter (5 ± 0.26). In monsoon and post monsoon the species richness were (4 ± 0.17) and 4 ± 0.25 respectively while in summer it was 4.9 ± 0.22. (Table 4a.2, Fig.4a.4) (P < 0.01 $F_{3\ 44}$ 7.487).

2. Chlorophyceae (Green Algae)

Green algae were second dominant quantitative component of algal composition of Lotus Lake with two years percentage abundance of 30.16 %. (Table 4a.1,Fig. 4a.1). The density of this group was maximum in winter (1203 ± 50.65 /l) and minimum (553.1 ± 42.13 /l) in monsoon, while it was 564.8 ± 29.77 /l and 981.1 ± 75.1 /l in post monsoon and summer respectively. (Table 4a.1, Fig. 4a.2) (P < 0.0001, $F_{3\ 44}$

37.94). Total nine species of green algae (Annexture-II) were identified during the present study. This comprised 25.67 % of two years average (Table 4a.1, Fig. 4a.2). Maximum species were observed in summer (5.9 ± 0.22) and minimum in monsoon (5 ± 0.24) with 5.5 ± 0.28 species noted in post monsoon and 5.83 ± 0.27 in winter. Green algae varied non-significantly across the season (Table 4a.2, Fig. 4a. 4) ($F_{3\ 44}$ 2.56).

3. Bacillariophyceae (Diatoms)

Diatoms appeared to be the most dominant quantitative as well as qualitative components among assemblage of algae at the Lotus Lake with two years average percentage density of 44.33 % (Table 4a.1, Fig. 4a.2) and significant seasonal variations ($F_{3\ 44}$ 67.92). Maximum density of diatoms (Table 4a.1, Fig. 4a.2) were recorded in summer (2099 ± 69.25 /l) and minimum in post monsoon (585.8 ± 21.91 /l), while it was 1115 ± 72.81 /l and 1054 ± 115.1 /l in winter and monsoon respectively. Total twenty one species of diatoms (Annexture-II) were recorded in the Lotus Lake which showed significant seasonal variations ($P < 0.0001$, $F_{3\ 44}$ 135.9) with 45.96 % of average (Table 4a.2, Fig. 4a.3). Maximum species of diatoms were also recorded in summer (15.83 ± 0.42) but minimum in winter (5.5 ± 0.45), while it was 11.33 ± 0.25 and 7.16 ± 0.42 in monsoon and post monsoon respectively (Table 4a.2, Fig. 4a.3).

4. Euglenophyta

The Euglenophyta appeared to be minor group quantitatively as well as qualitatively that comprised only 3.71 % of two years average percentage density. However, this also showed significant seasonal variations ($P< 0.0001$ $F_{3\ 44}$ 77.69) (Table 4a.1, Fig. 4a.2). Maximum density of Euglenophyta was recorded in post monsoon (200 ± 9.19 /l) and minimum in winter (45.08 ± 5 /l), while it was 53.5 ± 4.05 /l and 107.3 ± 11.67 /l in summer and monsoon respectively.

Total four species of Euglenophyta (Annexture-II) were recorded in the Lotus Lake comprising two years average species richness 7.78 %. Maximum species (Table 4a.2, Fig. 4a.4) were recorded in post monsoon (2.91 ± 0.23) and minimum in winter (0.42 ± 0.15), while it was 1.08 ± 0.19 and 2.33 ± 0.14 in summer and monsoon respectively ($P < 0.0001$, $F_{3\ 44}$ 39.49).

As given in Table 4a.3, total Phytoplankton density was positively correlated with TDS, Trans., chloride, TH at level of .01 and WT and pH at .05 while negatively with WC, NO_2^-, NO_3^- at .01 level and PO_4^{-3} at .05 level (Two tailed). However, Bacillariophyceae was positively correlated with AT, WT, TS, TDS, CO_2, Cl^-, TH, pH at .01 level and Trans. at .05 whereas negatively with WC, TSS, DO, NO_2 and NO_3 at .01 (two tailed). Somewhat different correlations compared to Bacillariophyceae are shown by Chlorophyceae and Cyanophyceae are negatively correlated at the level of .01 with AT, WC, TS, TSS, NO_2, NO_3 and PO_4 while with TS at .05 and Cyanophyceae at .01. Both these families showed positive correlations with Trans. and TH at .01. When Euglenophyta is considered, it showed somewhat opposite trend with positive correlations with WC, TSS, NO_2^- at .01 and NO_3 at .05, and negative correlations with TDS, Trans., TH at .01.

Table 4a.1 Seasonal Variations in density of different groups of phytoplankton (/l) with two years mean percentage density at Lotus Lake during December 2006 to November 2008

Parameters	F value ($F_{3\ 44}$)	Winter	Summer	Monsoon	Postmonsoon	Two years %
Tot. Phy.	40.74	3221 ± 151.7	3786 ± 143.9	2135 ± 187.3	1805 ± 72.39	-
Cyano.	30.05	857.4 ± 42.34	652.7 ± 37.09	420.5 ± 38.42	453.7 ± 28.23	21.78
Chloro.	37.94	1203 ± 50.65	981.2 ± 75.10	553.1 ± 42.13	564.8 ± 29.77	30.16
Bacill.	67.92	1115 ± 72.81	2099 ± 69.25	1054 ± 115.1	585.8 ± 21.91	44.33
Eugle.	77.69	45.08 ± 5.01	53.50 ± 4.052	107.3 ± 11.67	200.3 ± 9.197	3.71

Table 4a.2 Seasonal Variations in Species richness of different groups of phytoplankton (no. of species) with two years mean percentage density at Lotus Lake during December 2006 to November 2008

Parameters	F value ($F_{3\ 44}$)	Winter	Summer	Monsoon	Postmonsoon	Two years %
Tot. Phy.	67.16	16.67 ± 0.65	27.75 ± 0.52	22.67 ± 0.48	19.58 ± 0.63	-
Cyano.	7.487	5.00 ± 0.26	4.91 ± 0.30	4 ± 0.17	4 ± 0.25	20.57
Chloro.	2.568	5.83 ± 0.27	5.91 ± 0.22	5 ± 0.24	5.5 ± 0.28	25.67
Bacill.	35.9	5.5 ± 0.45	15.83 ± 0.42	11.33 ± 0.25	7.17 ± 0.42	45.96
Eugle.	39.49	0.42 ± 0.15	1.08 ± 0.19	2.33 ± 0.14	2.91 ± 0.23	7.78

(Tot. phy.-Total phytoplankton, Cyano.-Cyanophyceae, Chloro.-Chlorophyceae, Bacill.-Bacillariophyceae, and Eugle.-Euglenophyta).

Table 4a.3 Pearson correlation of total Phytoplankton density along with individual group with Abiotic parameters of Lotus Lake during December 2006 to November 2008

Sr. No.	Parameter	Total Phyto.	Cyano.	Chloro.	Bacillario.	Eugleno.
1	Atmospheric Temperature	.072	-.458**	-.372**	.464**	.083
2	Water Temperature (WT)	.338*	-.238	-.139	.705**	-.241
3	Water Cover (WC)	-810**	-.429**	-.515**	-889**	.640**
4	Total Solids (TS)	.039	-.374**	-.319*	.381**	-.161
5	Total Suspended Solids (TSS)	-.761	-.837**	-848**	-476**	.507**
6	Total Dissolved Solids(TDS)	.610**	.163	.239	.816**	-.572**
7	Transparency	.653**	.867**	.845**	.300*	-.508**
8	Carbon Dioxide (CO_2)	.162	-.398**	-.308*	.556**	-.013
9	Dissolved Oxygen (DO)	-.133	.243	.210	-.384**	-.170
10	Chloride	.566**	.123	.195	.788**	-.590**
11	Total Hardness (TH)	.794**	.493**	.570**	.798**	-.520**
12	pH	.346*	-.211	-.145	.708**	-.202
13	NO_2^-	-.714**	-.823**	-.827**	-.431**	.604**
14	NO_3^-	-.666**	-.498**	-.567**	-.583**	.355*
15	PO_4^{-3}	-.362*	-.742**	-.630**	.022	.203

** The pearson correlation is significant at the 0.01 level (two tailed)
*The pearson correlation is significant at the 0.05 level (two tailed)

Fig. 4a.1 Seasonal Variations in density of different groups of phytoplankton (/l) at Lotus Lake during December 2006 to November 2008

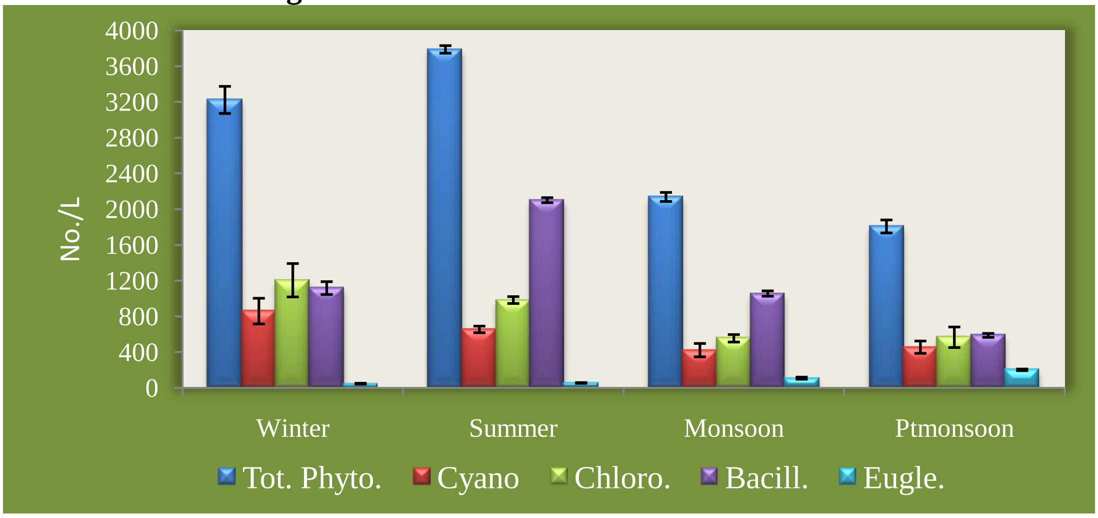


Fig. 4a.2 Two years Percentage density of different groups of Phytoplankton at Lotus Lake during December 2006 to November 2008

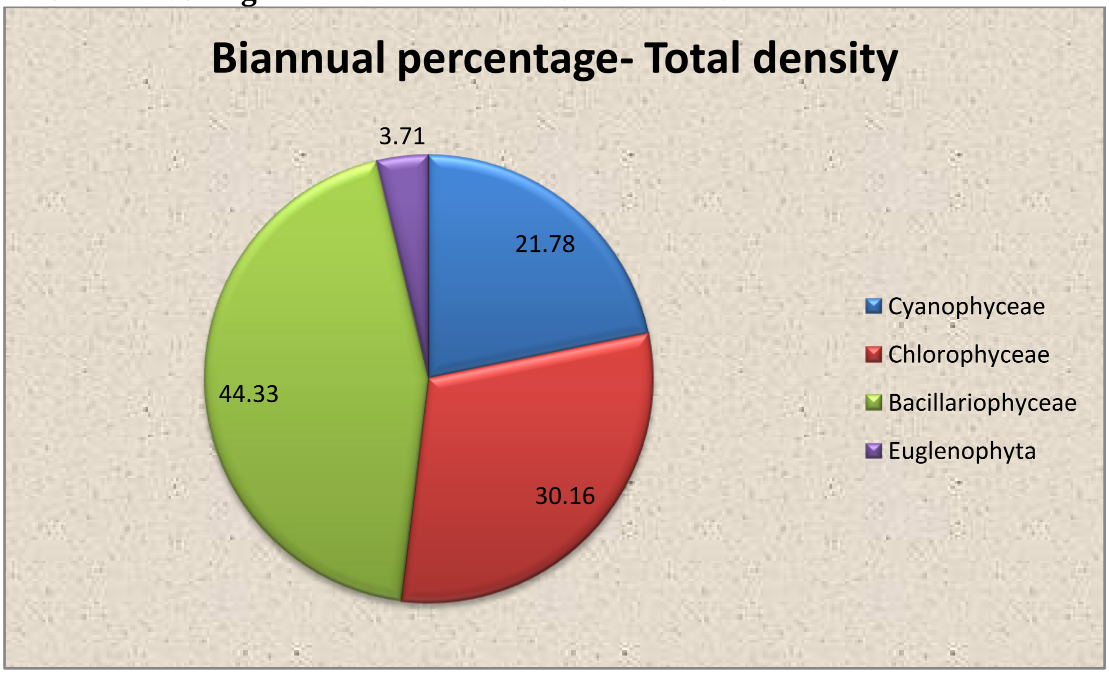


Fig. 4a.3 Seasonal Variations in species richness (no. of species) of different groups of phytoplankton at Lotus Lake during December 2006 to November 2008

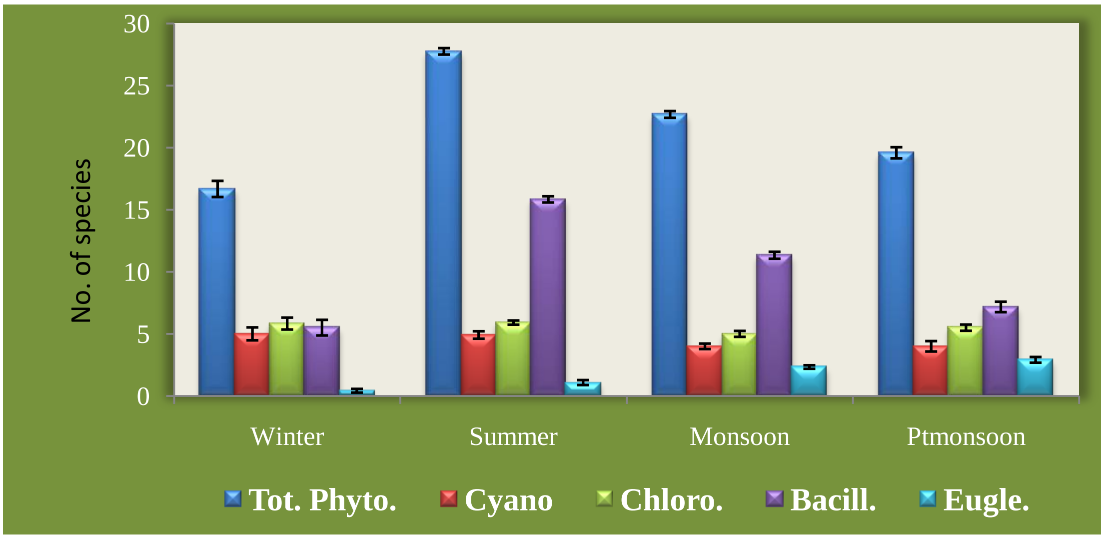
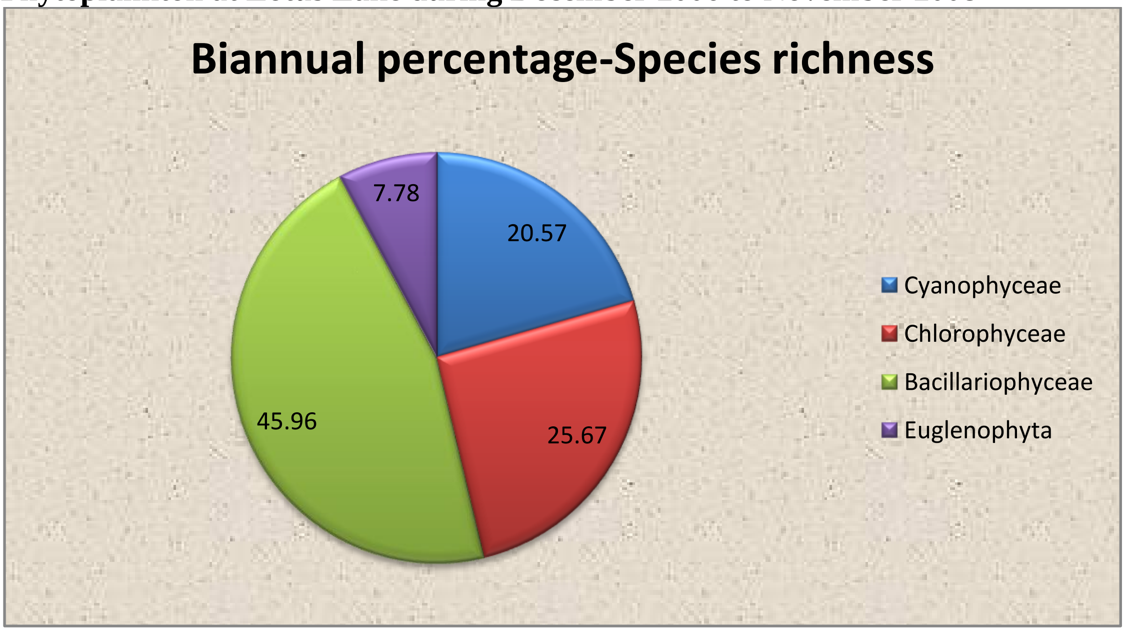


Fig. 4a.4 Two years Percentage Species richness of different groups of Phytoplankton at Lotus Lake during December 2006 to November 2008



DISCUSSION

Diversity of algae is an indication of purity. The use of community structure to assess pollution is conditioned by four assumptions: 1) the natural community evolves towards greater species complexity, 2) this eventually stabilizes and increases the functional complexity of the system 3) complex communities are more stable than simple communities, and 4) pollution stress simplifies a complex community by eliminating the more sensitive species (Cairns, 1974). At the Lotus Lake 41 different species belonging to 4 algal groups *i.e.* Cyanophyceae, Chlorophyceae, Bacillariophyceae and Euglenophyta could be identified. Practically, environmental instability with temporal and spatial changes determines the community present in a lake (Levandowsky, 1972). In addition, not only the physical environment (*i.e*. Light intensity and temperature) influences the distribution of algal populations (Bormans and Condie, 1998) but nutrients along with chemical compounds like CO_2 and composition and abundance of biotic component like Zooplankton also influence the phytoplankton assemblages in an aquatic ecosystem (Mortensen *et al*., 1992; Carpenter and Kitchell, 1993; Shapiro, 1997). This all is reflected at Lotus Lake with maximum density of total phytoplankton recorded in summer.

Total Phytoplankton

Different groups of phytoplankton contributed to total plankton density during different seasons *i.e*. Chlorophyceae with Bacillariophyceae in winter, mainly Bacillariophyceae in summer and monsoon while almost all the groups together during postmonsoon. This indicates that various climatic factors influence phytoplankton groups in various ways over the seasons. This is reflected with difference in correlation of physicochemical parameters with different groups of phytoplankton.

Higher overall phytoplankton density occurred at Lotus Lake in summer as is also reported by Murugavel and Pandian (2000); Deshkar (2008); Hulyal and Kaliwal (2009); Ekhande (2010) in summer associated with higher temperature. Available literature indicates that temperature is one of the important determining factors for phytoplankton density and shows positive correlation (Unni and Pawar, 2000). However, various classes as well as individual species of algae have minimum, optimum and maximum temperatures for growth (Palmer, 1980). This is reflected at Lotus Lake where positive correlation for AT and WT at the level of .01 is established only with Bacillariophyceae whereas other two groups show negative correlation with AT and non significant correlation with WT. Further, the density of Bacillariophyceae influences the total phytoplankton density which is correlated positively at level of .05 only with WT. This family augments the density with 44.33 % of total density as 20 (nearly 50 %) species noted in this study belong to this family. According to Palmer (1980) the optimum temperature for diatoms is 18-30˚C, for Green algae 30-35˚C and for Blue green algae 35-40˚C. Since the surface water temperature fluctuations in Lotus Lake varied in narrow range between 18.38 ± 0.15˚C and 22.02 ± 0.37˚C, temperature regime in the Lake is moderately supportive for Cyanophycean and Chlorophycean algae and most favourable for diatoms (Bacillariophyceae) which were dominating the lake influencing the total plankton density positively. This temperature is probably unfavourable for Euglenophyta.

Further, Palmer (1980) has also reported that majority of algae grow best in water at or near neutral pH but some Blue greens grow best at high pH. Slightly alkaline pH observed in Lotus Lake water is therefore suitable for community structure dominated by Diatoms and Chlorophyceae as is revealed in the present study. Besides the temperature, higher pH during summer can be another factor for summer maxima of total phytoplankton density (Hujare, 2005). The Lotus Lake fall in semiarid zone of Maharashtra that receives maximum photoperiod during summer favoring growth of the aquatic autotrophs. However, the minimum density of total phytoplankton recorded in the post monsoon (wet summer) indicates dilution due to the maximum water level and water cover when phytoplankton get more distributed and hence reduction in density. Water cover was significantly negatively correlated with the density of total phytoplankton (Table 4a.3). No significant correlation was established between total phytoplankton and CO_2 and DO. However, group wise correlation studies showed different trends.

Calcium is an important part of plant tissue that increases the availability of other ions and reduces the toxic effect of NO_2-N (Manna and Das, 2004). Thus, total hardness (due to calcium and magnesium ions in the water) probably plays a vital role in the growth of phytoplankton. Further, the negative correlation established between total phytoplankton and nutrients (NO_2^-, NO_3^- and PO_4^{-3}) indicates depletion of these nutrients due to utilization for growth that in turn increases density of phytoplankton. Phytoplankton and higher plants that utilize different forms of Nitrogen, differentially influence phytoplankton growth, size, structure and community composition (Rabalais, 2002).

Species richness of Total Phytoplankton

Regions with seasonal climatic oscillations show an ecosystem diversity governed by cyclic modifications (Margalef, 1994), whereas periods of high diversity are followed by high dominance of few species (Reynolds, 2006). In tropical lakes, oscillations in the total radiation and water temperature are narrow compared to those observed in temperate regions. Nevertheless, seasonal patterns in tropical phytoplankton communities are not negligible (Talling, 1987; Giani, 1994). Like temperate lakes, tropical lakes also suffer climatic seasonal changes (especially in relation to precipitation) that induce modifications in the physical and chemical characteristics of the water (Costa and Silva, 1995) that can influence biotic characteristics. At Lotus Lake, a high altitude lake in tropics, 41 species of phytoplankton that include 9 chlorophyceae, 20 Bacillariophyceae, 7 cyanophyceae and 4 Euglenophyta did showed oscillations. Among these, Bacillariophyceae appeared to be the dominant group. The nutrient increase in a lake due to human activities in the catchments, leads to change of lake flora from Diatom assemblage to those of greens and blue greens (Hutchinson, 1967). The nutrient enrichment at Lotus Lake is reflected as increase and decrease in these three groups quantitatively as well as qualititatively over major part of the year in accordance to nutritional changes.

Species richness of total phytoplankton in the Lotus Lake also showed significant oscillations ($P < 0.0001$, $F_{3\ 44}$ 67.16) with decreasing trend from summer to monsoon to post monsoon to minimum in winter. Diversity can be considered as an attribute of the successional progress (Reynold, 1988) in response to modifications encountered in various parameters along the years. Diversity values are generally higher when disturbances show intermediate frequencies (Connell, 1978). Many factors are regulated by phytoplankton themselves or some external controls, that can minimize competition, allowing the coexistence of several species in stable environment (Nico, 2003) as noted for density. Maximum species richness in summer may also be attributed to increasing thermal stability of Lake water coinciding with the maximum photoperiod reflected by maximum growth of plankton resulting in nutrient depletion (nutrients are significantly negatively correlated with total phytoplankton). With the growth of plankton during the period of higher nutrient concentration, the interaction and competition among species also increases, but without the selection of exclusive winners. After the high peak of species richness in summer the monsoon precipitation and mixing disrupts the equilibrium dynamics. At Lotus Lake, various species of diatoms recorded in summer dominated the lake (45.96%) and ultimately increased the species richness of total phytoplankton, while their lowest species richness recorded in winter also reflected in the lowest species richness of total phytoplankton.

Cyanophyceae (Blue green Algae)

Water temperature plays an important role in the periodicity of blue green algae (Hutchinson, 1967) as moderately high temperatures support their growth (Tucker and Loyd, 1984; Naik *et al.*, 2005). The density of cyanophyceae (Table-3) at LL was maximum in winter and early summer. However, a negative correlation with AT at 0.01 level and non-significant with WT has been established at Lotus Lake as is also observed by Bhatt *et al*. (1999). Further, Cyanophyceae has been reported to dominate phytoplankton communities under reduced light environment (An and Jones, 2000) which can be produced when transparency is low. Contrary to this in present study transparency showed positive correlations with cyanophyceae at Lotus Lake. As said earlier majority of algae grow best in water at or near neutral pH, but some Blue green algae grow best at high pH (Palmer, 1980). When the Lotus Lake water was showing pH around 7.48, the seasonal density of Cyanophyceae was high. This group ranked third among the 4 taxa studied. Among other parameters (chapter 3) significant positive correlations were observed between total hardness and density of Cyanophyceae as is also observed by many authors (Iqbal and Katariya, 1995; Bhade *et al*., 2001; Krishnan, 2008) and significant negative correlations with CO_2 (Johnston and Jacoby, 2003) are of the opinion that low dissolved CO_2 favours growth of Cyanophyceae.

The nutrients NO_2^-, NO_3^-, and PO_4^{-3} were significantly negatively correlated with density of Cyanophyceae. As discussed earlier, the utilization of the nutrients for the growth results into higher density. Since significant correlation between Cyanophyceae density and PO_4 are observed at Lotus Lake, the belief that PO_4 highly stimulates Cyanophycean growth (Izaguirre *et al*., 2004) appears relative to other factors as well. In Lotus Lake, Cyanophyceaen group was represented by only seven species representing 20.57 % (Table 2.1) of total species richness. All throughout the year the Cyanophyceae species richness varied between 3 to 6.

According to Brunberg and Blomqvist (2002) *Microcystis* is a widely distributed organisms which dominates the phytoplankton community in nutrient rich lakes. *Microcystis aeruginosa* is one of the main pollution producers of Lakes (Lindholm *et al*., 2003). Its presence poses a threat to the aquatic ecosystem. The degree to which a lake may be affected by this algae must therefore well monitored. Interestingly, instead of *Microcystis aeruginosa M. virdis* was recorded from Lotus Lake. Further, other two pollution indicator genera *Anabaena* and *Oscillatoria* that produces neurotoxins characterized as contact irritants were also recorded at Lotus Lake but in low density. The presence of *Anabaena* and *Oscillatoria* indicates beginning of biological pollution. Members of Oscillatoriaceae family are known to tolerate the combination of intermittent nutrient deficiency and low light conditions. Such conditions are produced by the frequent but irregular mixing of water in summer and they built up very dense population that increases turbidity (Mischke and Nixdorf, 2003). However, in summer the nutrient deficiency and high light conditions due to increase in transparency prevail. At higher temperature with high CO_2 and low oxygen levels in summer *Oscillatoria sp., Microcystis sp., Nostoc sp.* and *Anabaena species* flourish (Tiwari and Chauhan, 2006). Blooms of Cyanophyceae in freshwater ecosystems are attributed to nutrients, particularly to phosphorus enrichment. Increased detection of 'cyano-toxins' in water bodies has generated a complex change for water resource managers all over the world (Johnston and Jacoby, 2003). Other factors that regulate Cyanophyceae are high water temperature, stable water column, low light availability, high pH, low dissolved CO_2 and low total N to P ratio TN: P ratio (Welch, 1992; Paerl, 1988). Though density wise insignificant, the presence of the species such as *Microcystis* in Lotus Lake is a definite pollution signal. Dominance of *Microcystis* adversely affect the growth of other taxonomic groups of phytoplankton especially Chlorophyceae group in lakes (Kearns and Hunter, 2001). However, in the present study the Cyanophyceae and Chlorophyceae are positively significantly correlated (Table 4a.3) indicating that the members of Cyanophyceae are not dominating the system. Natural systems are characterized by a variety of biotic and abiotic factors coupled with multiple species interactions. Although nutrient concentrations are considered fundamental for the development of cyanobacterial blooms, many other variables are involved in their ecological success (Dokulil and Teubner, 2002). Population density of Cyanobacteria is expected to be moderate in natural and unpolluted water bodies. However, in nutrient rich water bodies, they grow abundantly and their density increases to millions of cells per liter leading to a Cyanobacterial blooms (Sangolkar *et al*., 1999). No such condition is noted at Lotus Lake over the two year study period.

Chlorophyceae:

Presence of Chlorophyceae, the second dominant group both with respect to density and diversity, suggests beginning of organic pollution. In cold climatic conditions, an increase in organic load commonly leads to a shift in the ecosystem from Diatom-dominated flora to green and blue green in the form of nutrient input due to human activities in catchment (Hutchinson, 1967; Patrick, 1970). In the present study of Lotus Lake though the diatoms dominated over green algae quantitatively as well as qualitatively Chlorophyceae was second dominant group with average density of 30.16 %. Further, significant seasonal variations recorded in the density of Chlorophyceae indicate their dependence on physico-chemical as well as biological components of the system (Table 4a.3). Among biological components of Lotus Lake, Chlorophyceae is positively correlated to Bacillariophyceae and Cyanophyceae at the level of 0.01, adding to the total density while negatively with the minor group Euglenophyta. However, among physical parameters AT as well as WC has negative effect whereas WT has no significant effect on Chlorophyceae. Water temperature of Lotus Lake, being located at higher altitude, fluctuates in comparatively narrow range (Chapter 1) and hence probably produce non signified effect on Chlorophyceae while Total solids ($p = 0.05$) with suspended particles ($p = 0.01$) prevent growth of Chlorophyceae and its dissolved components have no significant effect indicating that chemical components have less influence on Chlorophyceae. Further, CO_2 has negative influence ($P < 0.05$) while dissolved oxygen do influence chlorophyceae. Rather, the nutrients have significant negative relations as they are trapped by growing Chlorophyceae population. The alkaline nature of water body has been reported to promote the dense growth of Chlorophyceae (Gulati and Wurtz, 1980). The Lotus Lake remains alkaline all throughout the year. Chlorophyceaen phytoplankton order of Chlorococcalean is known to prefer inorganic nutrients providing alkaline pH and moderately high temperature (Krishnan, 2008) and thrive well in water rich in NO_3 than phosphates. Total hardness and transparency also influence Chlorophyceae density positively (Bhatt *et al*.,1999).

Species richness of Chlorophyceae varied non-significantly across the seasons between 3 and 6 with total 9 species. The green algae of Lotus Lake include genera *Ulothrix, Oedogonium, Bulbochaetae, Pediastrum, Eudorina, Spirogyra, Closterium, Staurastrum* and *Cosmarium*. Of these *Closterium, Staurastrum* and *Cosmerium* are considered as desmids which indicate good quality of water and absence of desmids is an indication of heavy pollution of water (Hosmani *et al*., 2002). Detailed study of Desmid flora would be useful in managing the pristine quality of the Lotus Lake. According to Hutchinson (1967) desmids (*e.g. Cosmarium*) are associated with oligotrophic freshwater and in these, they may form an important food source for herbivore fish. The food chain relations of endemic and endangered species of fishes may include specific phytoplankton species. Moreover, the dominance of Desmids over Chlorococcales (Pediastrum)- a group indicative of eutrophication (Rott, 1984) in the lake may be considered as a positive biological sign to suggest that the trophic characteristics of the system is still within control. Further, the different species of Chlorophyceae have differential preference for magnesium and phosphate for their growth and high calcium content and low pH values favour their growth (Munawar, 1974). Typical species of nutrient rich waters are *Mougeotia, Oocystis, Ulothrix, Spirogyra, Micractinium* (Sreenivasan *et al*., 1997). Among these genera *Ulothrix* and *Spirogyra* were recorded in Lotus Lake in low density. The algal community structures thus suggest that the system is still under natural control as is evidenced by the dominance of sensitive species. However, rare occurrence of tolerant species such as *Spirogyra, Ulothrix, Oedogonium* at some parts of the Lake requires to be monitored intensively.

Bacillariophyceae (Diatoms)

According to Telford *et al*. (2006) lentic Bacillariophyceae communities that show spatial variation in diversity and species composition cannot be solely driven by local environmental conditions but also determined by habitat availability. However, according to Fabricus *et al*. (2003) Diatom community distribution in a Lake is also determined by the combination of physical, chemical and biological factors which is reflected as their seasonal variations at Lotus Lake. At Lotus Lake this group appeared to be the most dominant group with two years average density of 44.3 % with maximum diatom density in the summer (Table 4a.1, Fig. 4a.2) and minimum in post-monsoon. High density of diatoms in summer is also reported by Hafsa and Gupta

(2009); Hulyal and Kaliwal (2009) and Ekhande (2010). Among the chemical parameters, pH and NO_3 are particularly reported to be closely related to diatom growth and some species show good potential as indicators of change in habitat (Owen *et al.*, 2004). The Lotus Lake remained alkaline throughout the study period and pH and temperature are positively significantly correlated with density of diatoms (Table 4a.3). Medium nutrient content with the alkaline pH might be the factors that favour the diatoms. Kamat (1965) has reported that higher pH is favourable for diatom growth. In the present study among the three nutrients NO_2 and NO_3 were negatively correlated while PO_4, non-significantly with the density of diatoms. Diatoms absorb phosphates in large quantities than their requirements. Further, density of diatoms is positively significantly correlated with the transparency of Lotus Lake as is also reported by Bhatt *et al*. (1999), and with hardness as is reported by Ekhande (2010) and Krishnan (2008).
In Indian climatic conditions rains disturb the distribution of plankton in general and result in decline in their density which was also recorded for the Lotus Lake during monsoon. Diatoms also need at least 2µmole silicate/l for successful development (Escavarage and Prins, 2002). According to Kobbia *et al*. (1992) dissolved silica is supplied to the lake by drainage water and is also generated by remineralization within lake. Though the silica of Lotus Lake was not estimated the dominance of diatoms indicates sufficient silica in the lake water.

Qualitative estimation of diatoms revealed 21 species that dominate the Lotus Lake. Wetzel (2001) reported that availability of distinct nutritional requirements favour one group over the other. Diatoms are ecologically diverse and colonize virtually all microhabitats in marine and freshwater systems. The study of diatoms in Lotus Lake revealed that maximum species richness of diatoms was in summer while minimum in winter probably higher temperature of summer favouring the growth. Though optimum temperature for diatoms is 18 - 30˚C (Palmer, 1980), many species can tolerate a range of temperature between 0.0˚C to 35 ˚C (Patrick, 1973). Since the surface water temperature fluctuations in Lotus Lake varied from 18.38 ± 0.15˚C to 22.2 ± 0.37˚C, temperature regime in the lake was favourable for diatoms.

Taxonomic indicators based on Diatom assemblages provide a useful estimate of ecosystem change and have been recommended as a standard mean in biological monitoring (Mc Cormick and Cairns, 1994) and Diatom composition gives more accurate and valid predictions as they react directly to pollutants (Dixit *et al*., 1992).

Palmer (1969) has listed diatom taxa in decreasing order of emphasis with reference to pollution index. With reference to this, in the Lotus Lake water the tolerant species in decreasing order of emphasis were *Nitzschia, Navicula, Synedra, Melosira, Gomphonema, Fragilaria, Surirella, Cymbella* and *Pinnularia*. *Nitzschia* species is characteristics of organically rich waters (Richardson, 1968). Though many studies have investigated autecological status of indicator species (Taylor *et al*., 2007), few studies contribute to species optima of *Nitzschia species* and *Gomphonema sp.* However, the clean water diatom species *Amphora ovalis, Cymbella species* and *Pinnullaria species* were also recorded in Lotus Lake.

Euglenophyta:

Euglenophyta is the free swimming micro-algal group of wide geographical distribution found worldwide, occurring predominantly in small freshwater bodies with high organic content (Round, 1985; Wetzel, 2001) several species are known as indicators of organically polluted environment (Tiwari and Chauhan, 2006; Hafsa and Gupta, 2009). Due to the significance of the Euglenophyta as organic pollution indicator it is essential to document them with their environmental preferences.

Euglenophyta was the group represented in the lowest percentage density in the Lotus Lake water with annual average percentage density of only 3.7 %. When its seasonal variations are considered higher density of Euglenophyta were recorded in the Lake in post monsoon and lowest in the winter. Maximum euglenoids in post monsoon can be attributed to influx of rainwater which carries high amount of organic matter from the drainage. This probably creates temporarily suitable environment for euglenoids (Wetzel, 2001) in monsoon and continues favouring their growth till post monsoon. Euglenophyta are algae characteristics of environments rich in ammonia (Round, 1985).

Significant negative correlations of Euglenophyta density at the level of 0.01 are established with parameters like Cl, TDS, TH, Trans., while positive at 0.01 with NO_2, TSS and WC and at 0.05 with NO_3. The density of Euglenophyta is non-significantly correlated with Temperature, TS, Transparency, CO_2, DO, pH and PO_4. Negative correlation between density of euglenophyta and DO are reported by Heide (1982) stating that low DO is highly favourable to the growth of Euglenophyta. Positive correlation with nitrate and nitrite are also recorded by other authors (Krishnan, 2008, Ekhande, 2010).

In the Lotus Lake only four species of Euglenophyta belonging to two genera representing just 7.78 % of the total diversity of phytoplankton species were observed *Euglena gaumei* and *Euglena viridis* were most common in the monsoon and post monsoon. Presence of *Euglena sp* and *Phacus sp*, are a direct indication of beginning of pollution load because both these species in general, are considered to be dominant and tolerant genera of polluted ponds (Alam and Khan, 1996). However, Tiwari and Srivastava (2004) found *Euglena sp.*and *Phacus sp.* in industrially polluted as well as non-polluted waters in North India and also observed that these are the species with greater ecological amplitude to their occurrence in aquatic systems exhibiting varying levels of pollution load. Though the pollution indicator species were found in Lotus Lake their density and species richness were very poor, so for the proper management of this water body continuous monitoring will play a vital role.

In conclusion, Lotus lake supports good diversity and density of phytoplankton with Bacillariophyceae as most common group while Euglenophyta the least. The Lotus Lake is not yet polluted. But, in today's modern world, ecotourism is fast growing field and Toranmal area is one of the most favoured centre. If care is not taken Lotus Lake can soon undergo deterioration and develop into a deteriorated habitat.

CHAPTER 4B.

ZOOPLANKTON

INTRODUCTION

Zooplanktons are the microscopic, free-swimming animalcule components of an aquatic ecosystem. They are primary consumers of phytoplankton, present at various depths deciding their own niches in every type of aquatic environment. Inspite of having locomotory appendages, their movements are very limited and they are found floating freely in and around euphotic zone.

Zooplanktons, in turn, are the main food items of fishes and can be used as indicators of the trophic status of a water body (Verma and Munshi, 1987). They play an integral role in transforming energy from producers to the consumers, forming higher trophic level in the energy flow after phytoplankton. With the producers- the phytoplankton, these consumers play an important role in the transformation of energy from abiotic forms to the higher trophic levels ultimately leading to the fish production, which is considered as is the final product of an aquatic environment. Zooplankton, constitute important food source of many omnivorous and carnivorous fishes and also supply the necessary amount of protein for the rapid growth of larval fish (Rahman and Hussain, 2008). Being primary consumers, they are critical in maintaining aquatic food web foundation by being at the second level in aquatic environments (Licandro and Ibaney, 2000). The nutrient status and the physico-chemical parameters of water body play an important role in governing the production of plankton. Because of their short life cycle they respond quickly to changes in aquatic environment (*e.g.* water quality, such as pH, colour, taste, *etc*.) and are therefore used as indicator of overall health or condition of their habitat (Thrope and Covich, 1991; Carriack and Schelske, 1997). As zooplankton can pronounce the conditions of water body and can be used to assess overall lake health the relationship between the physico-chemical parameters of water and plankton are of great importance in management strategies of any aquatic ecosystem (Edward and Ugwumba, 2010). The qualitative and quantitative abundance of zooplankton in a lake are also important for successful aquaculture management, as they vary from one geographical location to other and even within similar ecological conditions (Boyd, 1982).

Zooplankton communities of freshwater belong to four main taxonomic groups the Rotifera, the Cladocera, the Copepoda and the Ostracoda. Most of zooplankton depend to a large extent on various bacterioplankton and phytoplankton for food. Many of the larger forms feed on smaller zooplankton, forming secondary consumer, while some of them are detritivore feeders, browsing and feeding on the organic matter particles attached to substrate or lying on the bottom sediment.

The investigations on the effect of seasonal variations in the physico-chemical variables causing variations in abundance and diversity of zooplankton (Davies *et al*., 2009), biomass dynamics (Zuykova *et al*., 2009), role of abiotic factors in community organization (Patrick, 1973; William and Joseph, 1991), diurnal vertical movements in fresh water zooplankton (Wetzel, 2001), monthly variations and depth wise abundance of zooplankton (Ali *et al*., 1985) and many other studies have highlighted importance of zooplankton studies of any water body to establish health status of the same. In understanding aquatic ecology anthropogenic activities in landscape has become essential (Stanley *et al*., 2005).

A large number of studies covering a wide variety of ecosystems and organisms, suggests that species richness in general tend to vary strongly with ecosystem production and habitat heterogenicity (Rosenzweig, 1995). This is particularly so with freshwater fauna (Zooplankton) which plays a key role in preservation and maintenance of ecological balance. Its basic study is inadequate and absolutely necessary in tropics with reference to seasonal fluctuations which are a well known phenomenon exhibiting biomodal oscillations with spring and autumn in the temperate lakes and reservoirs. These fluctuations are greatly influenced by the variations in the temperature along with many other factors (Wetzel, 2001).

Thus, Zooplankton being in the centre of aquatic food web, and influenced strongly by bottom-up and top-down processes, have often been used as models for ecological paradigms (Wetzel, 2001). Rate of Lake change (eutrophication) may best be determined through long term monitoring programmes which can assess the trophic conditions and also provide a baseline for present as well as future comparisons. Since zooplanktons are potentially valuable indicators of environmental changes, investigations on zooplankton are expected to be an integral part of such programmes. Quantitative information on actual and relative abundance (community composition) is expected to yield more indicator value than simply presence or absence of certain species (Gannon and Stemberger, 1978). Hence, in the present study of Lotus Lake, to establish a food chain/web and condition of the lake, zooplankton are also considered and their qualitative and quantitative seasonal variations and correlation with other biotic and abiotic parameters are evaluated in the present chapter.

RESULTS

In the Lotus Lake total 35 species of Zooplankton were recorded (Annexture III) which belong to three groups : Rotifera (20 species), Cladocera (9 species) and Copepoda (6 species).

Quantitatively and qualitatively these three groups administered same sequence as : Rotifera > Cladocera > Copepoda

A) Density of Zooplankton of Lotus Lake

1) Total Zooplankton

Among the three groups of zooplankton (*Viz*. Rotifera, Cladocera and Copepoda) the density of Rotifera dominated quantitative component of total zooplankton of the lake with two years average density of 41.7 %, followed by the Cladocerans with 32.5 % and Copepodes 25.8 % (Table 4b.1, Fig.4b.1). However, if Cladocera and Copepod are considered together as microcrustacea, the microcrustacea became dominant zooplankton group with 58.3 %. The density of total zooplankton administered significant seasonal variations ($P < 0.0001$ $F_{3\ 44}$ 73.62). Maximum density of the total zooplankton (Table 4b.2, Fig. 4b.2) were recorded in summer (2604 ± 49.23 /l) and minimum in postmonsoon (1258 ± 55.15 /l, while it was 1437 ± 92.34 /land 2024 ± 79.18 /l in winter and monsoon respectively.

2) Rotifera

With the most dominant quantitative component (41.7% density) (Table 4b.1, Fig.4b.1) in the Lotus Lake Rotifers exhibited significant seasonal variations ($P < 0.0001$, $F_{3\ 44}$ 97.05). Maximum density of rotifers (Table 4b.2, Fig. 4b.2) was recorded in summer (1218 ± 34.83 /l) which started decreased in monsoon (880.3 ± 49.21 /l,) through post monsoon (508.8 ± 23.06 /l) and reached to minimum density in winter (449.8 ± 33.19 /l).

3) Cladocera

The density of Cladocerans, the second dominant quantitative component (32.5 %) (Table 4b.1, Fig.4b.1) in the Lotus Lake, also showed significant seasonal variations

(P < 0.0001 $F_{3\ 44}$ 34.86). Their minimum density (Table 4b.2, Fig. 4b.2) was recorded in postmonsoon (408.3 ± 22.57 /l) which increased in winter (557.6 ± 36.46 /l) and reached to maximum in summer (765 ± 17.87 /l). In next season (monsoon), it declined to 644.3 ± 20.64 /l.

4) Copepoda

Copepod the third and lowest quantitative component (25.8 %) (Table 4b.1, Fig.4b.1) of zooplankton in the Lotus Lake also showed significant seasonal variations (P < 0.0001 $F_{3\ 44}$ 27.78). Minimum density of a Copepod (Table 4b.2, Fig. 4b.2) was recorded in post-monsoon (340.8 ± 17.74/l) which started increasing through winter (429.3 ± 30.85 /l) and reached to peak in summer (621.2 ± 18.52 /l).In monsoon, it decreased to 499.2 ± 20.18 /l.

B) Species richness of Zooplankton of Lotus Lake

1) Total Zooplankton

The species composition of total zooplankton occurred in decreasing order of dominance with two years species richness as Rotifera 49.2 % > Cladocera 28.9 % > Copepoda 21.9 % (Table 4b.1, Fig. 4b.3) and administered significant seasonal variations (P < 0.0001 $F_{3\ 44}$ 112.3).

Maximum species richness of total zooplankton (Table 4b.3, Fig. 4b.4) were recorded in summer (23.17 ± 0.27). It showed decreasing trend in the following seasons with 20.33 ± 0.41 and 14.33 ± 0.76 in monsoon and post monsoon respectively reaching to 10.75 ± 0.55 species in winter.

2) Rotifers

The Rotifers, registering major dominant qualitative component among the three groups of zooplankton with 49.2% (Table 4b.1, Fig.4b.3) two years percentage that varied significantly across the seasons (P < 0.0001, $F_{3\ 44}$ 149.3). Maximum species richness of Rotifers (Table 4b.3, Fig. 4b.4) were recorded in summer (13 ± 0.25) with decreasing trend in the following seasons with 10.92 ± 0.23 and 7.08 ± 0.58 in monsoon and post-monsoon respectively and minimum 2.75 ± 0.30 in winter.

3) Cladocera

Cladocerans the second dominant qualitative component with 28.9 % two years percentage average species richness showed significant seasonal variations (P < 0.0001 $F_{3\ 44}$ 20.45). Its maximum species richness occurred in summer (5.75 ± 0.21) and minimum in post monsoon (4.08 ± 0.14) while it was 4.58 ± 0.14 and 5.41 ± 0.15 in the winter and monsoon respectively (Table 4b.3, Fig. 4b.4).

4) Copepoda

Copepod, the last qualitative component among the three groups with two years percentage average species richness of 21.9 %, had maximum species richness (Table 4b.3, Fig. 4b.4) in summer (4.41 ± 0.14) and minimum in post-monsoon (3.16 ± 0.16), while it was 3.41 ± 0.14 and 4 ± 0.21 in the winter and monsoon respectively. Species richness of copepod also varied significantly across season ($P < 0.0001$ $F_{3\ 44}$ 10.88).

Pearson correlation of various abiotic parameters with zooplankton:

The density of total zooplankton along with three individual groups the Rotifers, the Cladocerans and the Copepods were correlated positively at the level of .01 with AT, WT, TS, TDS, CO_2, Cl^-, TH and pH, while negatively at the same level with WC. No significant correlation could be established with TSS, Trans, NO_2^- and NO_3^- whereas total zooplankton and Rotifer density were significantly negatively correlated with DO at .01 while with Copepod at .05 (two tailed). Density of total zooplankton and Rotifers were also positively correlated with PO_4^{-3} at 0.1 level (Table 4b.4 – details in chapter 1).

Table: 4b.1 Two Years Percentage density and species richness of different groups of Zooplankton at Lotus Lake during December 2006 to November 2008

Groups	Rotifera	Cladocera	Copepoda
Two Years Percentage density	41.7	32.5	25.8
Two Years Percentage species richness	49.2	28.9	21.9

Table: 4b.2 Seasonal Variations in density of different groups of Zooplankton (/l) at Lotus Lake during December 2006 to November 2008

Parameters	F value	Winter	Summer	Monsoon	Postmonsoon
Tot. zoo.	$F_{3\ 44}$ 73.62	1437 ± 92.34	2604 ± 49.23	2024 ± 79.18	1258 ± 55.15
Rotifera.	$F_{3\ 44}$ 97.05	449 ± 33.19	1218 ± 34.83	880 ± 49.21	508 ± 23
Cladocera.	$F_{3\ 44}$ 34.86	557 ± 36.46	765 ± 17.87	644 ± 20.64	408 ± 22.57
Copepoda.	$F_{3\ 44}$ 27.78	429 ± 30.85	621 ± 18.52	499 ± 20.18	340 ± 17.74

Table: 4b.3 Seasonal Variations in species richness (no. of species) of different groups of Zooplankton at Lotus Lake during December 2006 to November 2008

Parameters	F value	Winter	Summer	Monsoon	Postmonsoon
Tot. zoo.	$F_{3\ 44}$ 112.3	10.75 ± 0.55	23.17 ± 0.27	20.33 ± 0.41	14.33 ± 0.76
Rotifera.	$F_{3\ 44}$ 149.3	2.75 ± 0.3	13 ± 0.24	10.92 ± 0.23	7.08 ± 0.58
Cladocera.	$F_{3\ 44}$ 20.45	4.58 ± 0.15	5.75 ± 0.22	5.42 ± 0.15	4.08 ± 0.15
Copepoda.	$F_{3\ 44}$ 10.88	3.41 ± 0.15	4.42 ± 0.15	4 ± 0.21	3.16 ± 0.17

(Tot. zoo.-Total zooplankton)

Table: 4b.4 Pearson correlation of total zooplankton density with abiotic parameters of Lotus Lake during December 2006 to November 2008

Sr. No.	Parameter	Total zooplankton	Rotifers.	Cladocera.	Copepoda.
1	Atmospheric Temperature AT)	.750**	.830**	.531**	.606**
2	Water Temperature (WT)	.834**	.876**	.664**	.704**
3	Water Cover (WC)	-.801**	-.760**	-.716**	-.795**
4	Total Solids (TS)	.740**	.731**	.666**	.652**
5	Total Suspended Solids (TSS)	-.056	.021	-.130	-.154
6	Total Dissolved Solids (TDS)	.943**	.875**	.907**	.908**
7	Transparency	-.139	-.241	.001	-.003
8	Carbon Dioxide (CO_2)	.815**	.888**	.594**	.670**
9	Dissolved Oxygen (DO)	-.474**	-.566**	-.262	-.363*
10	Chloride	.872**	.839**	.797**	.810**
11	Total Hardness (TH)	.579**	.551**	.508**	.582**
12	pH	.832**	.889**	.632**	.700**
13	NO_2^-	-.063	.034	-.173	-.167
14	NO_3^-	-.237	-.258	-.167	-.202
15	PO_4^{-3}	.421**	.520**	.250	.254

** The pearson correlation is significant at the 0.01 level (two tailed)
*The pearson correlation is significant at the 0.05 level (two tailed)

Fig.: 4b.1 Two Years Percentage density of different groups of Zooplankton at Lotus Lake during December 2006 to November 2008

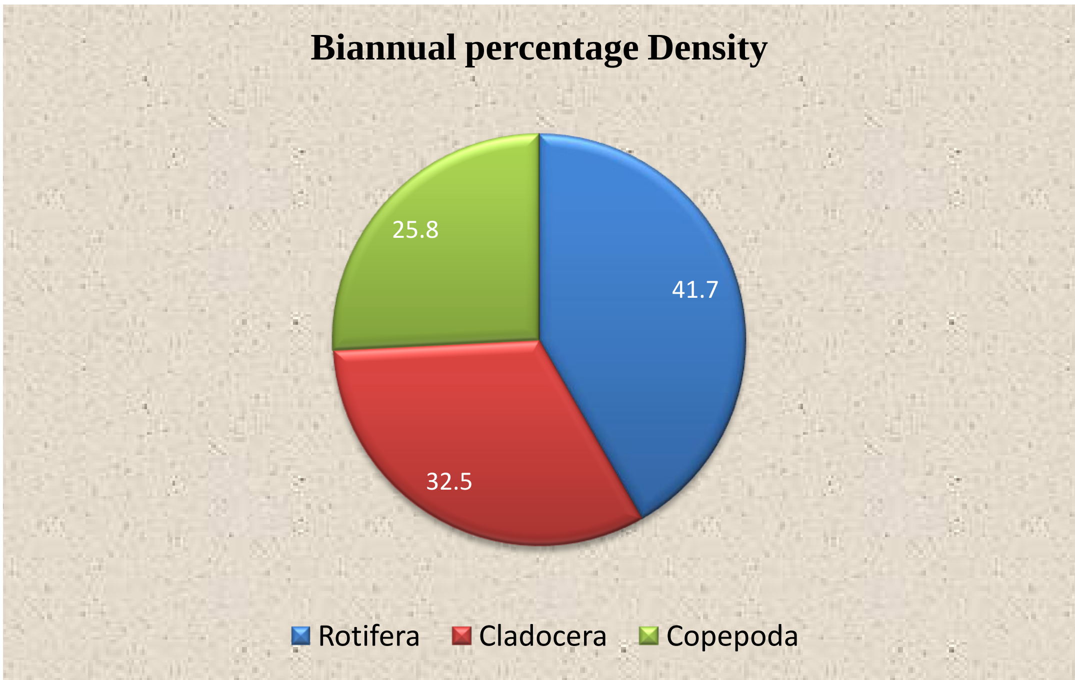


Fig.: 4b.2 Seasonal Variations in density of different groups of Zooplankton (/l) at Lotus Lake during December 2006 to November 2008

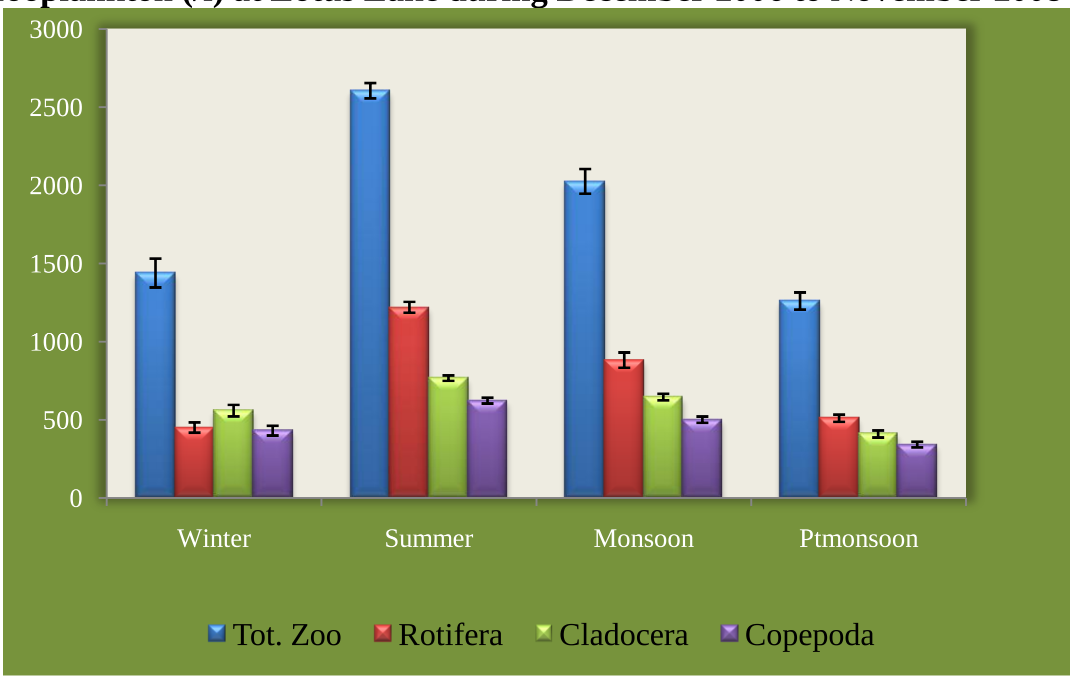


Fig.: 4b.3 Two Years Percentage species richness of different groups of Zooplankton at Lotus Lake during December 2006 to November 2008

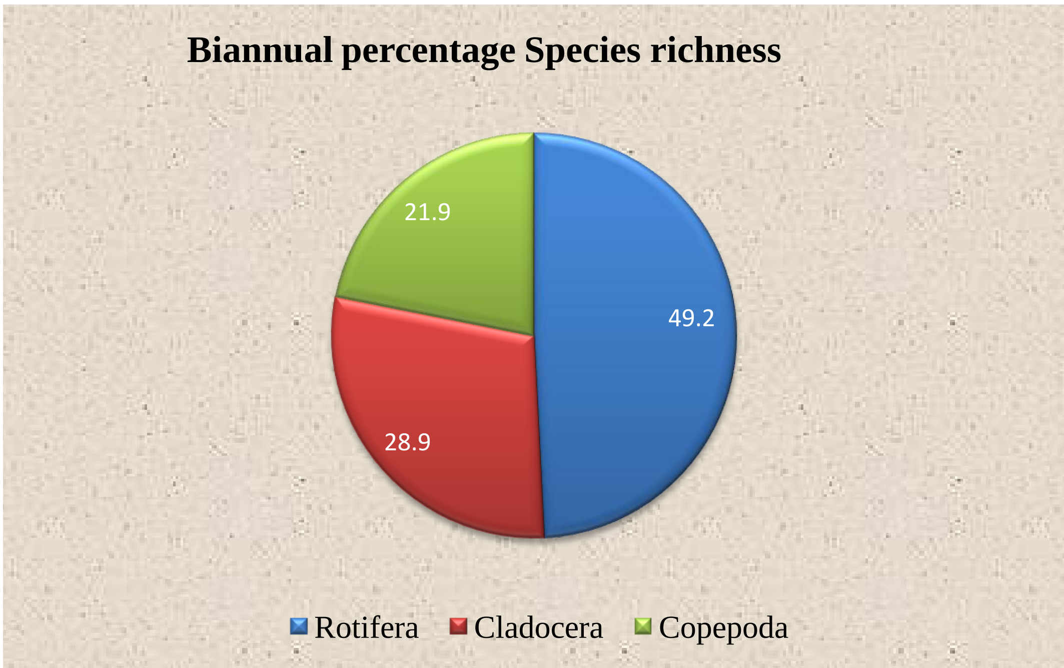
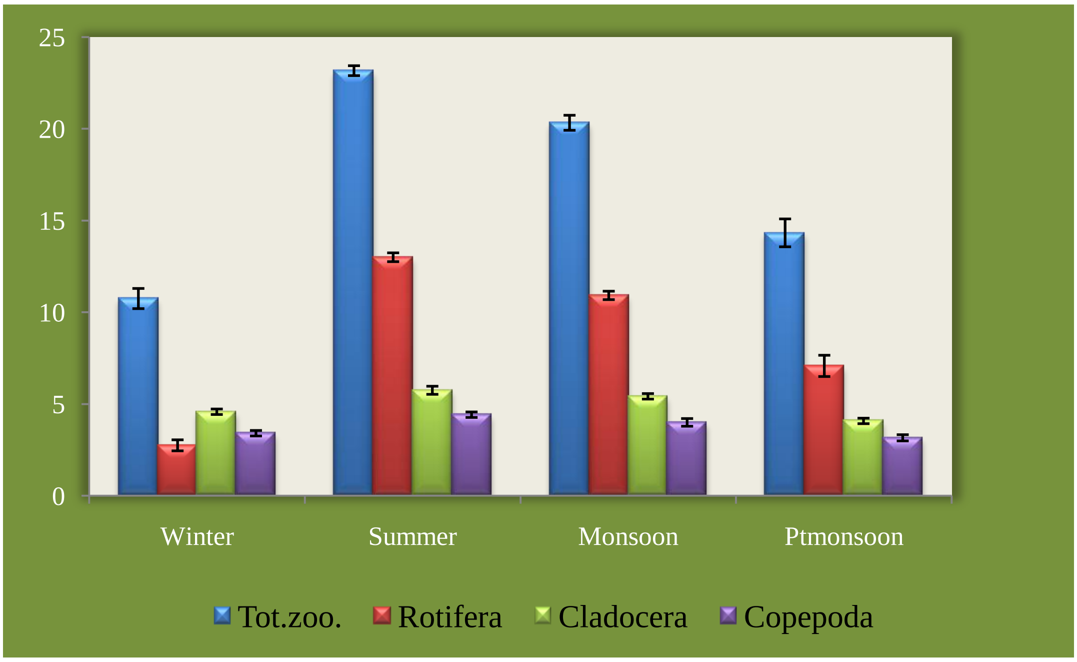


Fig.: 4b.4 Seasonal Variations in species richness (no. of species) of different groups of Zooplankton at Lotus Lake during December 2006 to November 2008



DISCUSSION

Total Zooplankton Density

Zooplanktons, the heterotrophic animals floating in water, constitute an important food source for many species of aquatic organisms. This probably explains why there is so much fascination in the study of structure and dynamics of zooplankton populations of lakes (Goldman and Horne, 1983). The zooplankton community composition in shallow lakes is influenced in addition to water chemistry and hydrobiology (Moss, 1994; Hampton and Gilbert, 2001) also by predation. A growing data of water body documents seasonal variations in the abundance of tropical zooplankton (Robinson and Robinson, 1971; Hulyal and Kaliwal, 2009) as is also administered at Lotus Lake where significant seasonal variations ($P < 0.0001$, $F_{3\ 44}$ 73.62) in zooplankton density are noted. The proximal physical factors that regulate population of zooplankton in tropical lakes are affected by seasonal fluctuations and by short term, unpredictable climate changes (Lewis, 1983) while the limnological features of tropical lakes are strongly affected by rain and wind which cause mixing as well as stratification in water. Strong winds and intense rainfall following episodes of hot weather lead to the formation of multiple thermoclines, while heavy precipitation promotes nutrient runoff from the watershed. Together with high average temperatures and intense solar radiation, these factors are reported to support high productivity in tropical lakes (Talling and Lemoalle, 1998).

The warm summer surface water temperature (Gilloly, 2000) and alkaline pH (Jakson, 1961) preferred by the zooplankton are also noted for Lotus Lake (22.16 ± 0.21 ˚C and pH 8.45 ± 0.09) hence their higher density and diversity during the said period. The water temperature, pH and total phytoplankton of Lotus Lake are significantly positively correlated (Table 4b.4) with total density of zooplankton. The abundance of zooplankton can also be linked with the development of phytoplankton, the producers, as their concentration also increases along with the rising water temperature (Mitrofanova, 2000; Chapter 2). The higher density of phytoplankton of Lotus Lake in summer created a favourable niche for herbivorous zooplankton, thus increase in the density of these primary consumers. This in turn increased the density of secondary consumer zooplankton increasing total zooplankton density.

The density of total zooplankton was negatively significantly correlated with water cover of Lotus Lake. The maximum density of total zooplankton in summer may be attributed to higher rate of evaporation which decreases water cover and the zooplankton get concentrated. Opposing conditions are noted in post monsoon when density of zooplankton was minimum when the water cover and the water level were maximum. During monsoon due to good southwest monsoon rains in this semiarid zone of Maharashtra, the water cover and level start increasing distributing the zooplankton in wider area and decreasing their density. The influx of rain water in Lake is known to bring about dilution effect (Chapman, 1972; Deshkar, 2008; Ekhande, 2010), as well as nutrients in the lake which help in buildup of zooplankton density (Michael, 1969) by winter compared to post-monsoon. However, lower temperature (18.38 ± 0.15˚C) at higher altitude probably restricts zooplankton growth in winter.

The standing crop of Lotus Lake is also assumed to be related to various degrees to variables such as macrophytes, *etc*. The low water levels in summer results in emergence of macrophytes that serve as hiding places and new niches to the various zooplankton species (Beklioglu and Moss, 1996). At Lotus Lake too, higher species richness is noted in summer when water level is low. Conversely, , comparatively higher water level of winter prevents emergence of macrophytes and reduces niches for zooplankton together with the lower temperature. At the low temperature some of the species also enter into diapause condition (Wetzel, 2001) further decreasing the zooplankton density. However, the members of all the three groups were represented throughout the study period in all the seasons irrespective to their lower or higher species richness.

Several species of zooplankton are known to show habitat overlap (Patricia, 1975). This can occur due to two mechanisms, first by resource partitioning when certain species pair can co-occur to a great degree by utilizing different food resources available in the same environment in which they occur. Second, by selective predation where certain competitors, the superior competitors, are preyed upon more effectively. The competitive balance is thus shifted in favour of an inferior competitor, allowing both species to coexist in the system. The presence of representatives of all groups in all the seasons at Lotus Lake indicates co-occurrence of various species which needs to be further investigated. It is likely that the zooplankton have evolved for millions of years with this variety of food and remained obvious to it. Sufficient density of total phytoplankton (Chapter 4a) recorded throughout the study period may be responsible for productivity of the Lotus Lake which supports variety of zooplankton species.

Rotifera

Rotifera is a group of primary freshwater invertebrates that plays a pivotal role in many freshwater ecosystems (Wallace *et al*., 2006). They are ubiquitous, occurring in almost all types of freshwater habitats, from large permanent lakes to small temporary puddles. Their ubiquity and abundance advocate their importance as one of the three main groups of freshwater zooplankton in limnological studies together with the Cladocera and Copepod, and as organisms used in mass aquaculture (Segers, 2007). Rotiferans because of their less specialized feeding habits, parthenogenic reproduction and high fecundity (Sampaio *et al*., 2002), form a prominent group among the zooplankton of a waterbody irrespective of the trophic status. They respond more quickly to the environmental changes and hence are frequently used as indicator of changes in water quality (Gannon and Stemberger, 1978).

In the present study of Lotus Lake rotifer density administered significant seasonal variations ($F_{3\ 44}$ 97.05) with maximum density in summer while minimum in winter. The survival and reproductive rate of Rotifers are related strongly to the quality and abundance of food (Edmondson, 1946; Baker, 1979). Temperature, in addition to its effects on the rate of development of egg also influences the rates of biochemical reactions, feeding, movement, longevity and fecundity of Rotifers (Edmondson, 1946). It has been identified as one of the main environmental gradient that structures the Rotifer assemblages is the temporal gradient (Bruno *et al*. 2005). At Lotus Lake surface water temperature in summer was 22.16 ± 0.21 which probably favours the reproductive rate of Rotifers and results in its higher density.

In present study, Rotifer density was significantly positively correlated with the density of total phytoplankton (Table 4b.4). Phytoplankton is important food resource for Rotifers (Devetter and Sed'a, 2003). Hujare (2005) reported that high temperature, photoperiod and intensity of sunlight during summer accelerated growth of phytoplankton which are some of the limiting factors that have been correlated with the growth and abundance of Rotifers. The macrophytes and the littoral vegetation exposed during summer, create ideal habitat for the Rotifers and hence Rotifer composition, abundance and frequency may be expected to be high (Basinska and Kuczynska-Kippen, 2009). Further, the water cover of Lotus Lake was negatively correlated with the density of zooplankton. Due to low water cover in summer the Rotifers get concentrated and hence high density. Contrary to this higher water cover in winter distributed the Rotifers and lowered their density. In addition, Rotifers are also known to undergo diapause in unfavourable conditions such as lower temperature of winter (Schroder, 2005) extending over a period of several weeks or months, this can further decrease their density. Dormant eggs accumulate in the sediments and hatch when their environment becomes favourable, generally from cold, dark and anaerobic to relatively warm, light and aerobic conditions (Gilbert, 1995). At Lotus Lake, located at higher altitude in Satpura range of North Maharashtra, temperature fall in winter with simultaneous decline in photoperiod creating an unfavourable environment for the Rotifers. Moderate density of Rotifers recorded in the monsoon and post-monsoon coincides with the influx of rain water that disturbs the equilibrium of the water body. The main food of herbivorous Rotifers is phytoplankton, of which population is disturbed by the incoming rain water that increases TS and TSS simultaneously with low light conditions caused because of cloudy skies. Probably a shortage of food is created. High water inflow has been associated with reductions in the zooplankton density and biomass along with a consequent decrease in chlorophyll concentration, mainly because of the high input of suspended solids (Hart, 2004).

Although, both the internal and the external variables determine the structure of plankton communities in reservoirs, physical variables generally show predominant influence (Wilk-Wozniak and Pociecha, 2007). The greater stability of these physical variables allows biotic variables to become the principal factors in the regulation of structure of a community (Naselli-Flores and Barone, 1997). Results based on Principal component analysis (Jorge *et al*., 2009) have shown that temperature, DO and pH have strong effects on the Rotifer species and has explained that about 70 % of the variations occur in zooplankton communities. Temperature increase has been related to an increase in the Rotifer diversity. Same was true with reference to species richness of Rotifers at Lotus Lake which was significantly positively correlated with the temperature and pH.

In the present investigation of Lotus Lake twenty species of Rotifers belonging to nine genera were recorded. Maximum fourteen species of Rotifers were found to co-occur in summer. Studies have been carried out on the ability of certain groups of closely related species to coexist in the same area utilizing the same pool of resources (Maria, 1974; Culver, 1972). Among various genera of Rotifers, the *Brachinous* was found to be dominant followed by *Keratella*. Most common species of Rotifers observed in the Lotus Lake were *B. caudatus, B. qudridentatus, B. fulcatus, B. caliciflorus. K. tropica* and *Filinia longiseta*, but other genera such as *Lacana, Monostyla* and *Trichocera* were not rare. The genus *Lacane* and *Trichocera* both noted at Lotus Lake have been shown to provide large contribution in terms of abundance and richness in macrophyte associated littoral habitat (Green, 2003). Rotifers are typically littoral but few species are purely pelagic (Kuczynska-Kippen, 2000). This is probably a consequence of the spatial heterogeneity of littoral habitats, which allows them to sustain themselves as a greater diversity of forms (Pennak, 1966; Basinska and Kuczynska-Kippen, 2009).

The Rotifers exhibit high population turnover rate in nature. Hilbricht-Ilkowska (1967) reported an average turnover for *K. cochlearis* to be 38 times in 200 days. Rotifers respond more quickly to the environmental changes than crustaceans and appear to be more sensitive indicators of changes in water quality (Gannon and Stemberger, 1978). *Brachinous* and *Keratella* are the species observed in both eutrophic and mesotrophic lakes (Dadhich and Saxena 1999), while *Trichocera* and *Filina* are likely to occur in eutrophic environment (Rutner – Kolisko, 1974).
When comparing the species composition of the rotifer coenosis of Lotus Lake with that of other high altitude tropical Lakes, no true cold-water species are found, while quite a few warm water taxa occur. Clearly, the altitude (1000 m amsl) at which Lotus lake is located does not support cold water fauna.

Cladocera

Cladocera, commonly known as water fleas, constitute one of the major groups of animals of great economic importance in fresh water ecosystem. They are also widely used in aquaculture as large filter feeding cladoceran species have an indirect economic impact as important fish food or phytoplankton controlling group.

However, these animals are also intermediate hosts of some parasites that can potentially pose a threat to human health (Forro *et al*., 2007).

In the present study the cladoceran formed second dominant quantitative component with two years average density of 32.5 % and showed significant seasonal variations. Minimum density of cladocerans in postmonsoon can be related to the highest water cover, with which it is significantly negatively correlated. As discussed earlier the high water cover and level distribute the plankton and reduce the density in post-monsoon. In monsoon and post-monsoon maximum variability in limnological characteristics is expected to interfere the rate of reproduction and lead to the low density. Food supply also plays a vital role in the density of cladocera (Singh, 2000). In post monsoon, the density of total phytoplankton which also forms major food for the cladocerans was lower while in the summer it was maximum. The density of phytoplankton and cladocerans were significantly positively correlated. In summer the rising temperature increases the density of algae, detritus as well as bacteria, the major food for cladocerans, that ultimately leads to increase in overall density of cladocerans. Further, in the present study cladoceran density was significantly positively correlated with the temperature that increases the rate of moulting and brood production of cladocerans, while rising food supply results in increase in the number of eggs per brood (Wetzel, 2001). Lower temporal variability during dry season (summer) is also reported to favour the density of zooplankton in general (Fabio, 2008). Significant positive correlation of density of cladocera with AT, WT, Cl^-, CO_2, pH, TDS, TH, TS and total zooplankton density, and negatively significant correlation with water cover indicates variable influence of biotic and abiotic factors on cladoceran density.

With respect to species richness also this group appeared second dominant component in the Lotus Lake with two years average percentage species richness of 28.9 %. The seasonal succession of the cladocera is quite variable, both among species and within a species living in different lake conditions (Wetzel, 2001). Some species are perennial and overwinter in low population densities as adults (Parthenogenetic females) rather than dormant eggs. Cladoceran species richness varied significantly across the season ($P < 0.0001$, $F_{3\ 44}$ 20.45).

Total nine species of cladocera were recorded in Lotus Lake. Maximum species richness was recorded in summer while minimum in post monsoon (Table 4b.3). The seasonality within cladoceran life histories depends upon the environmental conditions (Wetzel, 2001) such as temperature on that effects species distribution, body size and abundance (Stockwell and Johannsson, 1997). In winter when temperature is low, low population of perennial and a near absence of aestival cladocerans is a common phenomenon among cladocerans (Wetzel, 2001). In present study also moderate species richness of cladocera was observed in winter. Thus, rising temperature and increasing food supply from algae, detritus and bacteria in summer, favour increase in cladoceran populations. The diversity of cladocerans in the Lake can also be related to macrophyte . Among various cladocerans *Cydorus* species is usually associated with macrophytes, periphyton or sediment (Wisniewski-Santos *et al*. 2002) while four taxa *Moina, Ceriodaphnia, Macrothrix and Diaphanosoma* are predominantly herbivorous typically found in tropical water bodies (Dodson and Frey, 2001). These taxa were also recorded in the Lotus Lake. *Moina* was observed throughout the year. This species is 'eurgplastic' as it can tolerate wide range of temperature (Patil and Panda, 2003). *Ceriodaphnia cornuta* was observed for about seven months from April to October while *Diaphanosoma sarsi, Simocephalus vetulus, Macrothrix spinosa* and *Claydorus spp* were the species better represented in the samples of the Lotus Lake and their occurrence was also for about seven months. Of these all species *Diaphanosoma* and *Chydorus* the pollution tolerant species (Mahajan, 1981) occurred in Lotus Lake with lower populations.

Copepoda

Copepod is also an ecologically and economically important group of zooplankton. Free living copepods can be voracious predator. One of which *Mesocyclop* species is important as biological control agent against larvae of mosquito in tropical countries (Geoff and Daniell, 2007). Copepods prefer more stable environments and generally are regarded as pollution sensitive taxa (Das *et al*., 1996). They are excellent food for zooplanktivorous fishes and their nutritional value is also very high (Watanabele *et al*., 1993). The moderate density of copepods in Lotus Lake is an asset which may be explored for pisciculture. The productivity of lakes generally tends to be very high, particularly in tropical regions, during low water periods (summer). Planktonic crustaceans are commonly abundant during these periods but experience severe decline during high water periods of inundation when inorganic suspended particles are high and phytoplankton production low (Junk and Robertson, 1997; Rey 2011).

As noted for other groups at the Lotus Lake, the water cover was significantly negatively correlated with the copepod density. The high water level and cover in the monsoon and post monsoon spreads the copepods causing their lowest density in post monsoon while the low water cover and level during summer concentrates the copepods and increases their density. The effect of dilution and concentration are also observed by Chauhan (1993) and Chapman (1972). Rapid increase in population sizes can result both from high birth rates associated with decreasing turbidity for some period following inundation and from the hatching of dormant eggs. As discussed for other groups of zooplankton lower densities of cyclopoid copepods in winter may be associated with the diapauses either at the egg stage or in the copepodite stages with or without encystment (Maier, 1994). WT, DO, light intensity and day length are believed to be associated with the initiation and termination of diapauses (Smyly, 1973). In winter the temperature of water is low in the sub-tropical higher altitude Lotus Lake and the availability of food is also expected to be low. This can affect fertility of females and mortality of adults as shown by Edmondson (1965) and Patil and Panda (2003). Swar and Fernando (1980) have pointed out that food is one of the vital factors which control zooplankton population. As said earlier the maximum phytoplankton density which forms food for herbivorous copepods as well as indirectly for the carnivorous copepods was recorded in the summer at Lotus Lake, probably favouring growth of herbivorous Copepods. Goswami and Selvakumar (1977) have also reported positive correlation of copepods with phytoplankton.

Copepod diversity of Lotus Lake was comparatively poor as only six species were recorded. Among these, five species belonged to cyclopoid family (*Macrocyclops spp*, *Cyclops spp. Mesocyclops leuckartii*, *Mesocyclops hyalines* and *Ectocyclops sp.*) and one *Diaptomus spp*. belonged to calanoid family. Maximum species richness was observed in summer while minimum in post monsoon.

Copepods reproduce all throughout the year. This was evidenced by the presence of the larval forms, nauplii and copepodite, and the appearance of number of oviparous individuals in all the months in the water samples from Lotus Lake. The results are well corroborated with the view of Rey *et al*., (2011). Previous studies (Kasprzak and Koschel, 2000) have used copepod abundance and occurrence as efficient bioindicators of higher trophic levels. Eutrophication leads to decrease in the percentage of calnoid copepod, while promotes the development of cyclopoid copepod. Though amongst the two the cyclopoid copepod were dominant in Lotus Lake, with reference to physico-chemical parameter studied (Chapter 3), the lake is not found to be polluted so the cyclopoid population may be considered as of natural occurrence.

In addition to long-term environmental programs, we need to improve paleolimnological methods. Some plankton preserve well in sediments while others do not. Analysis of these remains is useful in determining eutrophication rates (Hrbacek, 1969).

In conclusion, as said in earlier chapters Lotus Lake is least polluted lake. It supports good density and diversity of zooplankton that can maintain the balanced ecosystem. Looking at the increasing tourist load in recent days good management practices are required to maintain the balanced ecosystem of Lotus Lake in Toranmal area of Western Satpuda mountain range in North Maharashtra.