CHAPTER 4
STUDY OF PLANKTON

INTRODUCTION

'Plankton' refers to those microscopic aquatic forms that swim in water with little or no resistance to the currents and live as free floating organisms suspended in open or pelagic waters. As reviewed by Battish (1992) plankton have been described by Hensen as early as (1887) as organic particles 'which float freely and involuntarily in the open water, independent of shores and bottom.

Plankton are of great importance as producers and also as food consumers in the natural purifier of polluted waters and sewage. However, some plankton form a harmful bloom under certain climatic conditions that may cause high mortality of the other aquatic organisms and pose a serious hazard in the water supply for domestic and industrial use. Because of their short life span, plankton respond quickly to environmental changes and hence their standing crop and species composition change with the change in quality of water. Many of them flourish, both in highly eutrophic as well as natural waters while few others are very sensitive to organic and chemical changes in water. Divided in two groups as phytoplankton –the autotrophs and zooplankton –the consumers, they are the important base line organisms of any aquatic body on which the aquatic ecosystem is built. Being autotropic, phytoplankton constitutes the basis of nutrient cycle. As primary producers, they play significant role in maintaining the equilibrium between biotic and abiotic factors. Because of their high species richness and sensitivity to environmental factors phytoplankton are widely used as important water quality indicators. According to Murphy *et al.* (2002) the main advantages of using phytoplankton in lake monitoring are: 1) They are primary producers and are directly affected by physical and chemical factors. Hence, changes in the status of phytoplankton community have direct implications on biointegrity of the lake ecosystem as a whole. 2) They generally have high reproductive rates and bear very short life cycles, making them valuable indicators for short term (impacts at scales of weeks and months. 3) They are good indicators of the trophic state of lake. 4) Their sampling is easy, inexpensive and creates minimal impact to resident biota. 5) Changes in their community composition can provide better scale assessment of changes due to ecological impact. One more advantage as per Netherland *et al.* (2009), is 6) Algal assemblages are sensitive to some pollutants like herbicides which may not visibly affect other aquatic assemblages and organisms at higher concentrations. Earlier workers have emphasized on the role of algal communities as reliable indicators of pollution (Patrick, 1950; Palmer, 1969; Nandan and Patel, 1985). Hence, in recent times, instead of considering a single species, algal communities and their dynamics are taken into consideration as indicators of pollution.

The second group of plankton – the Zooplankters are microscopic, free swimming animalcule components of an aquatic ecosystem that are primary consumers of phytoplankton. However, they themselves become the main food item of fishes and thus can also be used as indicators of the trophic status of a water body (Verma and Munshi, 1987). Thus, they play an integral role in transforming energy from producers to the consumers; from one trophic level to the next trophic level, ultimately leading to the fish production, which is mainly considered as the final product of aquatic environment (Singh, 2000b). The density, diversity and species richness of plankton are controlled by several physicochemical factors of the water (Nair *et al.*, 1983). Hence, both phyto- and zooplankton have been used quite frequently as indicators to observe and understand changes in the aquatic ecosystem under climatic or seasonal changes (Fevre-Lehoerff *et al.*, 1995; Beaugarand and Reid, 2000 and Li *et al.*, 2000). Hence, the present chapter deals both with phytoplankton and zooplankton diversity and density at the Yashwant Lake, the high altitude lake of mid Satpura range in North-West Maharashtra. For the convinience of discussion it has been divided as Chapter 4A-Phytoplankton and Chapter 4B Zooplankton.

MATERIAL AND METHODS

The plankton (both phytoplankton and zooplankton) along the periphery of Yashwant lake were collected during each biweekly visit at the three stations namely YLA, YLB and YLC. Ten litres 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 volume of sample was made to 100 ml. The samples were taken in separate vials and fixed in the field with 1 ml of 4 % formalin and 1 ml of Lugol's Iodine at the collection site. 10 ml of 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 litres of sample. Qualitative study of phytoplankton and zooplankton were carried out upto the genus/species level using the standard keys given by Edmondson (1963), Philipose (1967), Sarode and Kamat (1984), Battish (1992) and APHA (1998). Hence, species richness of each group of plankton is considered as number of species of each group observed per visit. The number of species present in a region may be considered as its 'species richness' a frequently used measure. Species richness can be correlated positively with some measures of ecological diversity (Hurlbert, 1971).

Both the groups of plankton *i.e.* the phytoplankton and the zooplankton are studied. The phytoplankton study includes five major groups the Cyanophyceae, Chlorophyceae, Bacillariophyceae, Dinophyceae and Euglenophyta, while the zooplankton study includes two main groups the Rotatoria and the Microcrustacea. The Microcrustacea are further represented as Cladocera, Copepoda and Ostracoda.

The data of the two years (from December-2006 to November-2008) was pooled and separated for three months and analysed for seasonal variations, with respect to winter (December, January, February), Summer (March, April, May), Monsoon (June, July, August) and Postmonsoon (September, October, November). Further, the Mean, Standard Error of Mean (SEM) 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 biotic factors as independent variables with the help of SPSS 7.5 for Windows. The P value for ANOVA is non significant if $P > 0.05$ (ns), Significant if $P < 0.05$ (*), Significantly significant (**) if $P < 0.001$ and highly significant if $P < 0.0001$.

4A. PHYTOPLANKTON

INTRODUCTION

The Phytoplankton-algae, of the open water ponds, lakes and large streams consist of a diverse assemblage of microscopic autotrophs. The phytoplankton are subdivided into two major groups euplankton and pseudoplankton. The euplankton are the permanent members of aquatic community and are by far the most important of the floating communities, while pseudoplankton are plankters, caught up accidentally in the water currents or washed into the habitat. Many of these forms have different physiological requirements, which may vary in response to physical and chemical parameters such as light, temperature and nutritional regime. The dominant genera in algal groups change not only spatially (vertically and horizontally within a lake) but also seasonally in response to seasonal changes in physical, chemical and biological conditions of the water body. Hence a general pattern of seasonal succession of phytoplankton of many lakes has been correlated with environmental factors. The precise reasons for many of these changes are not well known (Wetzel, 2001). In truly aquatic habitats, there is a range of microhabitats supporting comparable life forms whether the water is fresh or saline. These habitats are the rock surfaces on which epilithic algae grow, plant surfaces supporting epiphytic algae, sediments, such as sand with its epipsamic flora and silt/mud with its epipelic flora. These seasonally changing microhabitats, influence the phytoplankton communities seasonally. Hence, the study of phytoplankton distribution is important in understanding the ecology (because they are important source of fish diet) and their role as pollution indicator, as they project the trophic status of the water body (Naik and Neelkanthan, 1990). This heterogenous microscopic group include families Cyanophyceae, Chlorophyceae, Bacillariophyceae (diatom), Dinophyceae and Euglenophyta.

At present, altogether 41 functional freshwater phytoplankton groups are described world over with more or less precisely defined ecological demands (Padisak *et al.*, 2009). Further, field and laboratory evidences indicate that phytoplankton react rapidly not only to the climate but to the changes in nutrient loading. Therefore, they either mimic eutrophication by increasing phytoplankton production carrying capacity of ecosystem (Mooij *et al.*, 2005) or contribute to it by inducing phosphorus release from sediments and accelerating nutrient cycling (Pettersson *et al.*, 2003).

In general, Phytoplankton communities in lakes are dominants and subdominants. Several rare species may coexist with more abundant ones (Hutchinson, 1967). Though number of isolated studies have been carried out on various wetlands and natural ponds with reference to algae, the information is lacking from many regions. The main difficulty of using phytoplankton in lake monitoring is the time consuming taxonomic identification and the need for qualified specialists.

In the present study at Yashwant Lake that receives the southwest monsoon and has altitudinal effect, an attempt is made to find out the effect of season on phytoplankton community. The phytoplankton families represented at Yashwant Lake are:

1) Cyanophyceae

The Cyanophyceae (Blue green algae) have been among the most studied of all the planktonic groups. Previously classified as algae in the division Cyanophyta [Cyano (Greek = blue green)] or Myxophyceae [Myx (Greek = slime)], these organisms are now considered as true bacteria called cyanobacteria with simple prokaryotic cell structure. They occur in unicellular, filamentous or colonial forms and most of them are ensheathened with mucilagenous sheaths either individually or in colonies. The cyanobacteria are further classified as coccoid family Chroococcaceae (*e.g.* microcystis) and filamentous families Oscillatoriceae (*e.g. Oscillatoria*), Nostocaceae (*e.g. Anabaena*) and Rivulariaceae (*e.g. Gloeotrichia*). Bold (1973) named this group as Cyanochloronata which is considered more appropriate than Cyanobacteria or Cyanophyta. However, biochemical relationships of some selected organisms from various groups by Schwartz and Dayhoff (1978) have shown that from biochemical point of view 'blue greens' are quite distant from bacteria when their ferredoxin sequences, c-type cytochromes and 5s ribosomal RNA sequences are taken into consideration.

Members of Cyanophyceae family form calcareous concentrations in the form of carbon crystals on the stones *e.g. Chaetophora* colony. These concentrations can form greyish-white sandy deposits along the lake shores and even extend out as calcareous ooze into deeper water (Round, 1985). Heterocysts, unique to Cyanophyceae (except Oscillatoriaceae), are differentiated cells that are major sites of nitrogen fixation. Recent studies indicate that they show circadian rhythms and their capacity for photosynthesis and nitrogen fixation is regulated by biological clock, reset by light/ dark cues, at the level of gene expression (Golden *et al.*, 1997).

2) Chlorophyceae

The second family that was observed at Yashwant Lake is chlorophyceae. It belongs to the division Chlorophyta or the 'green algae', which are highly developed photoautotrophic organisms with simple morphology. Chlorophyta includes majority of algae particularly of fresh water environments. Three classes of green algae are now recognized, *viz.* Chlorophyceae, Prasinophyceae and Charophyceae. These algal classes are usually distinguished on the basis of their pigmentation, nature of food reserves, fine structure of plastids, chemical nature of the cell wall and the number, position and fine structural details of flagella in the motile stages (Krishnamurthy, 2000). The chlorophyceae are an extremely large and morphologically diverse group of algae that are almost totally fresh water in distribution. Most of these planktonic green algae belong to the orders Volvocales (*e.g. Eudorina, Volvox*) and Chloroccocales (*e.g. Pediastrum, Selenastrum*). Many members are flagellated or amoeboid, at least in the gamete stages in order Zygnematales and the Desmids (*Conjugales, Desmidiales*). Eutrophic lakes, especially in temperate region often have large summer growths of Chlorococcales (*e.g. Pediastrum, Chlorella*) and these become especially abundant in the small lakes and ponds. A few desmids (*e.g. Closterium, Cosmerium*) are characteristics of eutrophic lakes and these are important indicator organisms especially when the absence of the bulk of desmid species is taken into account (Round, 1985).

3) Bacillariophyceae (Diatoms)

The third group of phytoplankton observed at Yashwant Lake was the most important group of algae-the Bacillariophyceae (Diatom). Most species of Diatoms are sessile and associated with littoral substrata. Their primary characteristics are presence of silicified cell walls. Both unicellular and colonial forms are common among the diatoms. The group is commonly divided into the centric diatoms (*Centrals*), which have radial symmetry and the pennate diatoms (*Pennales*), that exhibit essentially bilateral symmetry. The Pennate diatoms are differentiated in four major groups: a) the Araphidineae which posses a pseudoraphe (*e.g. Asterionella, Fragillaria* and *Synedra*) b) Raphidioidineae, in which a rudimentary raphe occurs at the cell ends (*e.g. Actinelia* and *Eunotia*) c) The Monoraphidineae, which have a raphe on one valve and a pseudoraphe on the other (*e.g. Achnanthes* and *Cocconeis*) and d) Biraphidineae in which the raphe occurs on both the valves (*e.g. Amphora, Cymbella, Gomphonema, Nevicula, Nitzschia* and *Surirella*). These divisions are of more than taxonomic interest since distinct nutritional requirements favour the growth of one group over another (Wetzel, 2001). The diatoms in Littoral zone are important contributors of the primary production in shallow aquatic ecosystems (Wetzel, 1990). Some of the genera of diatoms are pollution tolerant. Palmer, (1980) stated that *Synedra acus, Gomphonema sp., Cyclotella sp.* and *Melosira sp.* are found in organically rich water and play an important role in water quality assessment and trophic structure. Diatoms are important in Paleolimnological studies to reconstruct the past eutrophication of lakes on basis of paleolimnological evidences (Taylor *et al.*, 2006).

4) Dinophyceae

The dinoflagellates, the fourth group at the Yashwant Lake, (Dinophyceae of the Phyrrophyta) are unicellular flagellated algae, many of which are motile. Although a few species are naked or without a cell wall (*e.g. Gymnodinium*), most of them develop a conspicuous cell wall that often is sculptured and bears large spines and elaborate cell wall processes (*e.g. Ceratium, Peridinium*). In both naked and armoured types, the cell surfaces have transverse and longitudinal furrows that connect and contain the flagella. Movements of flagella create water current for weak locomotion disrupting the chemical gradients at the cell surface (Wetzel, 2001). Among the dinoflagellate one example *Ceratium* shows phytoplanktonic cyclomorphosis by lengthening cellular extensions or horns as temperature increases from spring to mid summer (Hutchinson, 1967), a characteristic mainly shown by zooplankton. These may have adaptive significance as it reduces the rate of sinking out of the photic zone and help in monitoring seasonal changes.

5) Euglenophyta

The euglenophyta is the fifth and relatively smaller group of aquatic form occuring in the Yashwant Lake. When conditions are favourable, the euglenoids develop great profusion. Almost all of them are unicellular, lack a distinct cell wall and possess one, two or three flagella that arise from an invagination in the cell membrane. Most of euglenoids are pigmented. The unpigmented euglenoids are able to ingest solid particles (phagotrophic) and are treated as Protozoa. The pigmented ones are photosynthetic and facultatively heterotropic (Wetzel, 2001). This free swimming microalgal group of wide geographical distribution is found worldwide, occurring predominantly in small freshwater bodies, with high organic content (Round, 1985; Wetzel, 2001; Sandra *et al.*, 2007). Several species are known as indicators of organically polluted environments (Kaur *et al.*, 2001; Tiwari and Chauhan, 2006; Hafsa and Gupta, 2009; Nandan and Mahajan, 2003). Due to the significance of the euglenophyta as organic pollution indicator it is essential to document the information about them with their environmental preferences.

RESULTS

Total Phytoplankton

During the two year survey a total of 37 genera and 49 species of phytoplankton were identified at Yashwant Lake belonging to five taxonomic assemblages Bacillariophyceae (Diatoms), Chlorophyceae, Cyanophyceae, Dinophyceae and Euglenophyta.

The density of various groups of phytoplankton recorded in biannual percentage (Table 4A.1), in decreasing order was Bacillariophyceae (40.81 to 42.02 %) > Chlorophyceae (26.94 to 27.82 %) > Cyanophyceae (19.22 to 20.35 %) > Dinophyceae (8.62 to 8.77 %) > Euglenophyta (2.95 to 3.70 %).

Maximum densities of Total phytoplankton (Table 4A.2, Fig. 4A.1) were recorded in summer with 4500 ± 200.2 ind./L at YLC, followed by 4303 ± 168.6 ind./L at YLB and 3558 ± 204.8 ind./L at YLA. The density at the three stations decreased in monsoon to 1917 ± 227.7 ind./L, 2354 ± 299.7 ind./L and 2475 ± 311 ind./L at YLA, YLB and YLC respectively and were minimum in postmonsoon with 1745 ± 91ind./L, 1864 ± 115 ind./L, 2003 ± 120 ind./L at three stations respectively but started increasing in winter with 3099 ± 225 ind./L, 3345 ± 210 ind./L and 3552 ± 227 ind./L respectively. The total phytoplankton showed seasonal variations at $P < 0.0001$ at all the three stations.

The biannual % species richness of total phytoplankton of Yashwant Lake (Table 4A.3) also occurred in the same decreasing order as Bacillariophyceae (43.05 to 47.88 %) > Chlorophyceae (20.83 to 21.10 %) > Cyanophyceae (18.92 to 20.31 %) > Dinophyceae (8.0 to 9.72 %) > Euglenophyta (4.07 to 6.07 %).

Species richness of total phytoplankton also showed seasonal variations at all the stations (Table 4A.4, Fig. 4A.7) at $P < 0.0001$. Maximum species richness were recorded in summer at YLC (37.5 ± 0.4 no.of species) followed by YLB and YLA (32.17 ± 1.16, 30.17 ± 1.32 species). The species richness showed decreasing trend in monsoon and postmonsoon with non-significant difference among the three stations. In monsoon the species richness was 25.8 ± 1.1, 28 ± 0.7 and 30 ± 1.3 at YLA, YLB and YLC respectively, in post monsoon 21 ± 0.9, 22.17 ± 1.1 and 24.67 ± 1 while in winter minimum at 19.2 ± 1.8, 20.7 ± 0.9 and 22.3 ± 1.1.

When individual families are considered as per taxonomy it showed following trends.

1. Cyanophyceae (Blue Green Algae)

Blue green algae were third dominant quantitative component of the total phytoplankton with biannual percentage abundance 19.22, 20.35 and 19.45 % at YLA, YLB and YLC respectively (Table 4A.1).

The density of the blue green algae were maximum in winter with 761 ± 61.47 ind./L, 862 ± 35.57 ind./L and 902.7 ± 50.87 ind./L at the YLA, YLB and YLC respectively. (Table 4A.2, Fig. 4A.2). Density decreased in summer to 511.2 ± 36.24 ind./L, 696 ± 32.26 ind./L and 626.2 ± 17.02 ind./L at YLA,YLB and YLC respectively, and further declined in monsoon to 339 ± 42.38 ind./L, 425.7 ± 36 ind./L and 416.2 ± 43.58 ind./L at the three stations. Once the monsoon was over, non-significant increase was noted in postmonsoon with 372 ± 33, 433 ± 45 and 484 ± 36 /l respectively. The density of Cyanophyceae showed seasonal variations with $P< 0.0001$.

Total eight genera of Cyanophyceae (Annexture-I) were identified during the study. Mean biannual percentage of species richness of Cyanophyceae were 20.3, 19.74 and 18.92 % at the three stations YLA, YLB and YLC respectively (Table 4A.3).

Maximum species richness in summer that varied between 6.8 ± 0.1 species at YLC and 6.1 ± 0.3 species at YLA while at YLB it was 6.5 ± 0.22 (Table 4A.4, Fig. 4A.8). Species richnes decreased in monsoon to 5 ± 0.3, 5.3 ± 0.2, 5.7 ± 0.2 and at YLA, YLB and YLC respectively and was minimum in postmonsoon with 3.6 ± 0.2, 3.8 ± 0.3 and 4.2 ± 0.1 species respectively.

While in winter it increased to 4.6 ± 0.5, 4.8 ± 0.3 and 5 ± 0.3 species respectively.

2. Chlorophyceae (Green algae)

Chlorophyceae were second dominant quantitative component of total Phytoplankton abundance with average biannual percentage 27.82, 27.42 and 26.94 % at YLA, YLB and YLC respectively (Table 4A.1).

The densities of green algae were maximum in winter with non-significant differences among the three stations *i.e.* 1154 ± 62 ind./L, 1235 ± 62 ind./L and 1284 ± 59 ind./L at YLA, YLB and YLC respectively (Table 4A.2, Fig. 4A.3) that decreased non-significantly in summer to 753 ± 47 ind./L, 1014 ± 72 ind./L and 999 ± 58 ind./L and were minimum in monsoon with 456 ± 42 ind./L, 508 ± 62 ind./L and 531 ± 49 ind./L. The densities increased in post-monsoon between 508 ± 39 ind./L, 503 ± 45.56 ind./L and 561 ± 49 ind./L at YLA,YLB and YLC respectively.

Total ten genera of Chlorophyceae (Annexture-I) were identified during the study period at Yashwant Lake. It showed mean biannual percentage species richness as 20.83, 21.02 and 21.1 % at YLA, YLB and YLC respectively (Table 4A.3). Seasonal variations were recorded in species richness (Table 4A.4, Fig. 4A.9) with maximum species observed in summer (6.16 ± 0.3, 7 ± 0.3 and 7.6 ± 0.2 at YLA, YLB and YLC respectively). The species richness at the three stations declined in monsoon (5.5 ± 0.4, 5.8 ± 0.3 and 6.3 ± 0.2 respectively) and were minimum in postmonsoon with 3.5 ± 0.2, 4 ± 0.2 and 4.5 ± 0.2 and in winter with 4.8 ± 0.5, 5 ± 0.3 and 5.6 ± 0.2 respectively. The chlorophyceae density and species richness showed seasonal variations at $P < 0.0001$ at all the three stations.

3. Bacillariophyceae

Bacillariophyceae (Diatoms) was the most dominant family in the Total Phytoplankton abundance with biannual percentage between 40.81 to 42.02 % at the three stations (Table 4A.1).

Maximum density of diatoms were recorded in summer with 1783 ± 96 ind./L, 2035 ± 57 ind./L and 2313 ± 122 ind./L at YLA, YLB and YLC respectively (Table 4A.2, Fig. 4A.4). Densities decreased in monsoon and showed variations at the three stations with 871 ± 122 ind./L, 1069 ± 172 ind./L and 1167 ± 194 ind./L respectively. The minimum density was recorded in postmonsoon with non-significant differences (516 ± 28 ind./L at YLA, 566.3 ± 19.37 ind./L at YLB and 587 ± 37 ind./L at YLC). The diatom densities increased in winter with insignificant differences among the three stations (1042 ± 100 ind./L at YLA, 1054 ± 91.96 ind./L at YLB and 1198 ± 120 ind./L at YLC).

24 species of diatoms (Annexture-I) belonging to 16 genera were recorded at Yashwant Lake. Biannual percentage of species richness of diatoms at YLA, YLB and YLC were 43.05, 45.42 and 47.88 % respectively (Table 4A.3).

Maximum species were recorded in summer with 15.6 ± 1.2, 16.8 ± 0.9 and 21.0 ± 0.3 at YLA, YLB and YLC respectively which started decreasing in monsoon with 12 ± 0.6, 14 ± 0.5 and 15 ± 0.9 to postmonsoon with 7.3 ± 0.9, 9 ± 0.5 and 10.8 ± 0.9 and were minimum during winter with 6.3 ± 0.7, 7.3 ± 0.6 and 8 ± 0.9 at YLA, YLB and YLC respectively (Table 4A.4, Fig. 4A.10). Both the density and species richness of Bacillariophyceae showed significant seasonal variations with $P < 0.0001$ at all the stations.

4. Dinophyceae

Representation of Dinophyceae was poor at YSL and it was fourth in position of total phytoplankton density. Its mean biannual percentage density varied around 8.62, 8.74 and 8.77 % at the three stations YLC, YLB and YLA respectively (Table. 4A.1).

Maximum density of dinophyceae (Table 4A.2, Fig. 4A.5) were recorded in summer with 468 ± 29 ind./L, 500 ± 55 ind./L and 511 ± 28 ind./L. A decrease was observed in monsoon and postmonsoon with small variations among the three stations. The density was 197.5 ± 24.41 ind./L and 142.8 ± 4.4 ind./L at YLA, 216.8 ± 35.63 ind./L and 162.8 ± 15.95 ind./L at YLB and 258 ± 37 ind./L and 182.5 ± 7.79 ind./L at YLC during monsoon and post monsoon respectively. Minimum densities of dinophyceae were recorded in winter with 96 ± 5 ind./L, 159 ± 43 ind./L and 129 ± 16 ind./L at YLA, YLB and YLC respectively with seasonal variation at the level $P < 0.0001$.

Species richness of Dinophyceae at Yashwant Lake was poor, and only 4 species belonging to two genera were recorded, putting them to fourth qualitative component. Biannual percentages of species richness of Dinophyceae were 9.72, 8.34 and 8% at YLA, YLB and YLC respectively (Table 4A.3).

Maximum species richness of Dinophyceae were recorded in post monsoon with 3.66 ± 0.2, 3.3 ± 0.2 and 3.5 ± 0.2 at YLA, YLB and YLC (Table 4A.4, Fig. 4A.11) respectively which decreased in winter to 2.3 ± 0.2, 2.16 ± 0.1 and 2.3 ± 0.2 and were minimum in summer with 1.5 ± 0.3, 1.16 ± 0.2 and 1.3 ± 0.2 species only. It increased nonsignificantly in monsoon to 1.8 ± 0.1, 2.0 ± 0.2 and 2.0 ± 0.0 at all the three stations.

5. Euglenophyta

The abundance of Euglenophyta was poorest hence it was last quantitative component of the total Phytoplankton density. Its biannual percentage densities were 3.34, 3.7 and 2.95 % at YLA, YLB and YLC respectively (Table 4A.1).

The densities of euglenophyta (Table 4A.2, Fig. 4A.6) were low at YLA with 45 ± 10 ind./L in winter, 42.50 ± 5.7 ind./L in summer, 53 ± 10.89 ind./L in monsoon but increased significantly in postmonsoon to 214.3 ± 15.69 ind./L. At YLB it was low at 35.17 ± 2.4 ind./L during winter and 57.5 ± 6.24 ind./L in summer but increased to 133.8 ± 2.84 ind./L in monsoon and was highest 205 ± 11.50 ind./L in post monsoon. However, at YLC it increased from 38.33 ± 1.97 ind./L of winter to 50.17 ± 1.16 ind./L of summer and 94.50 ± 15.39 ind./L of monsoon reaching maximum 186.8 ± 12.23 ind./L in postmonsoon with significant variations at $P < 0.0001$.

Biannual percentage species richness of Euglenophyta were 6.07, 5.45 and 4.07 % at YLA, YLB and YLC respectively (Table 4A.3). Maximum species richness was observed in postmonsoon with 2.8 ± 0.2, 2 ± 0 and 1.7 ± 0.2 respectively (Table 4A.4, Fig. 4A.12). It was 1 ± 0.2 to 1.33 ± 0.21and 1.16 ± 0.16 at the three stations in winter, while minimum 0.7 ± 0.2, 1 ± 0 and 0.8 ± 0.2 in summer. It increased in monsoon to 1.3 ± 0.2, 1.3 ± 0.2 and 1 ± 0 at YLA, YLB and YLC respectively.

When the correlation of total phytoplankton density with biotic and abiotic parameters of YSL is considered (Table 4A.5) it showed a positive correlation at the level of 0.01 with TDS, acidity, alkalinity, TH, TDZ and negative correlation with WC and NO_3^- at all the three stations while other parameters like AT, WT, TS, TSS, Transparency, CO_2, DO, NO_2^-, PO_4^{-3}, TDM and TDB either the positive or negative correlation at various levels at the three sites.

Table: 4A.1 Biannual Percentage density of different groups of Phytoplankton at Yashwant Lake during Dec. 2006 Nov. 2008

Stations	Cyano phyceae	Chloro phyceae	Bacillario phyceae	Dino phyceae	Eugleno phyta
YLA	19.22	27.82	40.81	8.77	3.34
YLB	20.35	27.43	39.75	8.74	3.7
YLC	19.45	26.94	42.02	8.62	2.95
Biannual percentage	19.67	27.39	40.86	8.71	2.9

Table: 4A.2 Seasonal Variations in density of different groups of phytoplankton (ind./L) at YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

Parameters	Stations with F value	Winter	Summer	Monsoon	Postmonsoon
Tot. Phy.	YLA $F_{3\ 20}$ 20.61	3099 ± 225.4	3558 ± 204.8	1917 ± 227.7	1745 ± 91.02
	YLB $F_{3\ 20}$ 26.69	3345 ± 210.4	4303 ± 168.6	2354 ± 299.7	1864 ± 115.6
	YLC $F_{3\ 20}$ 24.63	3552 ± 227	4500 ± 200.2	2475 ± 311.5	2003 ± 120.5
Cyano.	YLA $F_{3\ 20}$ 18.42	761.5 ± 61.47	511.2 ± 36.24	339 ± 42.38	372.5 ± 33.49
	YLB $F_{3\ 20}$ 30.98	862.7 ± 35.57	696.5 ± 32.26	425.7 ± 36	433.7 ± 45.39
	YLC $F_{3\ 20}$ 29.59	902.7 ± 50.87	626.2 ± 17.03	416.2 ± 43.58	484.3 ± 36.91
Chloro.	YLA $F_{3\ 20}$ 40.60	1154 ± 62.7	753.2 ± 47.12	456.2 ± 42.86	508.5 ± 39.82
	YLB $F_{3\ 20}$ 35.97	1235 ± 62.39	1014 ± 72.57	508 ± 62.02	503.5 ± 45.56
	YLC $F_{3\ 20}$ 44.26	1284 ± 59.11	999.2 ± 58.83	531.2 ± 49.84	561.7 ± 49.78
Bacill.	YLA $F_{3\ 20}$ 31.77	1042 ± 100.8	1783 ± 96.63	871 ± 122.9	516.3 ± 28.73
	YLB $F_{3\ 20}$ 36.06	1054 ± 91.96	2035 ± 57.76	1069 ± 172.6	566.3 ± 19.37
	YLC $F_{3\ 20}$ 30.28	1198 ± 120.6	2313 ± 122.3	1167 ± 194.3	587.8 ± 37.95
Dino.	YLA $F_{3\ 20}$ 72.64	96.50 ± 5.07	468.7 ± 29.82	197.5 ± 24.41	142.8 ± 4.438
	YLB $F_{3\ 20}$ 16.47	159 ± 43.35	500.8 ± 55.04	216.8 ± 35.63	162.8 ± 15.99
	YLC $F_{3\ 20}$ 45.65	129.3 ± 16.07	511.2 ± 28.20	258 ± 37.29	182.5 ± 7.792
Eugle.	YLA $F_{3\ 20}$ 63.80	45 ± 10.4	42.50 ± 5.784	53 ± 10.89	214.3 ± 15.69
	YLB $F_{3\ 20}$ 88.79	35.17 ± 2.04	57.50 ± 6.24	133.8 ± 2.84	205 ± 11.50
	YLC $F_{3\ 20}$ 46.39	38.33 ± 1.97	50.17 ± 1.167	94.50 ± 15.39	186.8 ± 12.23

Figure: 4A.1 Seasonal variation in density of total phytoplankton (/L) at Yashwant Lake during December 2006 to November 2008

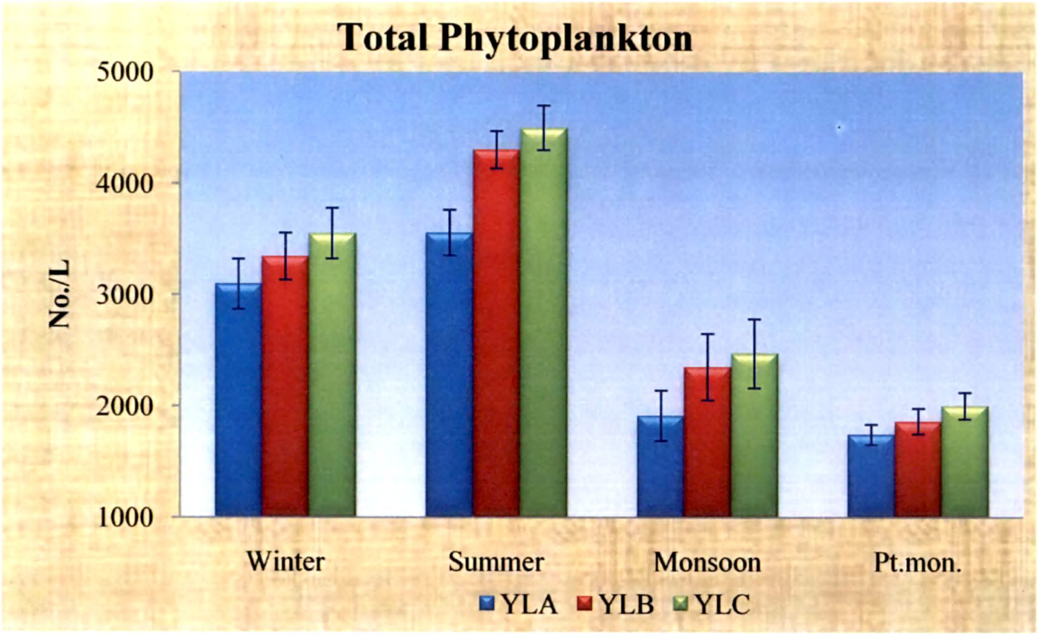


Figure: 4A.2 Seasonal variation in density of Cyanophyceae (/L) at Yashwant Lake during December 2006 to November 2008

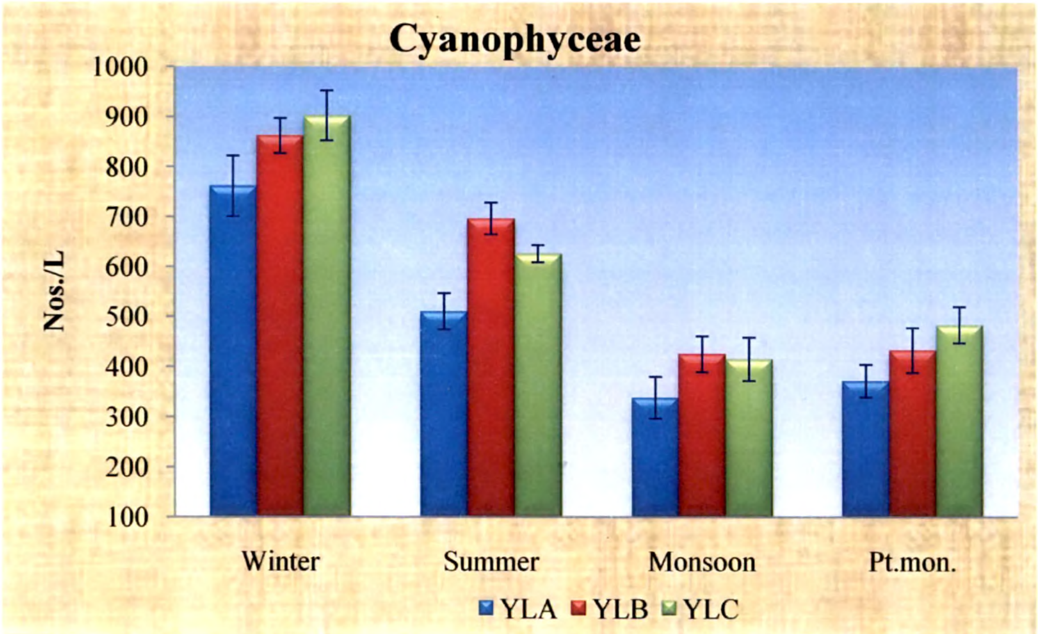


Figure: 4A.3 Seasonal variation in density of Chlorophyceae (/L) at Yashwant Lake during December 2006 to November 2008

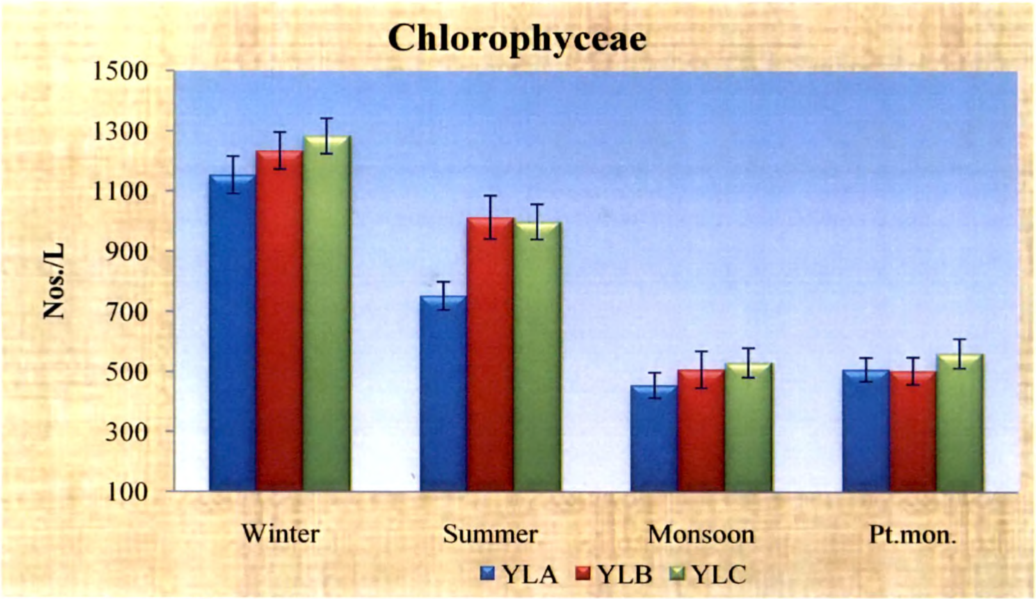


Figure: 4A.4 Seasonal variation in density of Bacillariophyceae (/L) at Yashwant Lake during December 2006 to November 2008

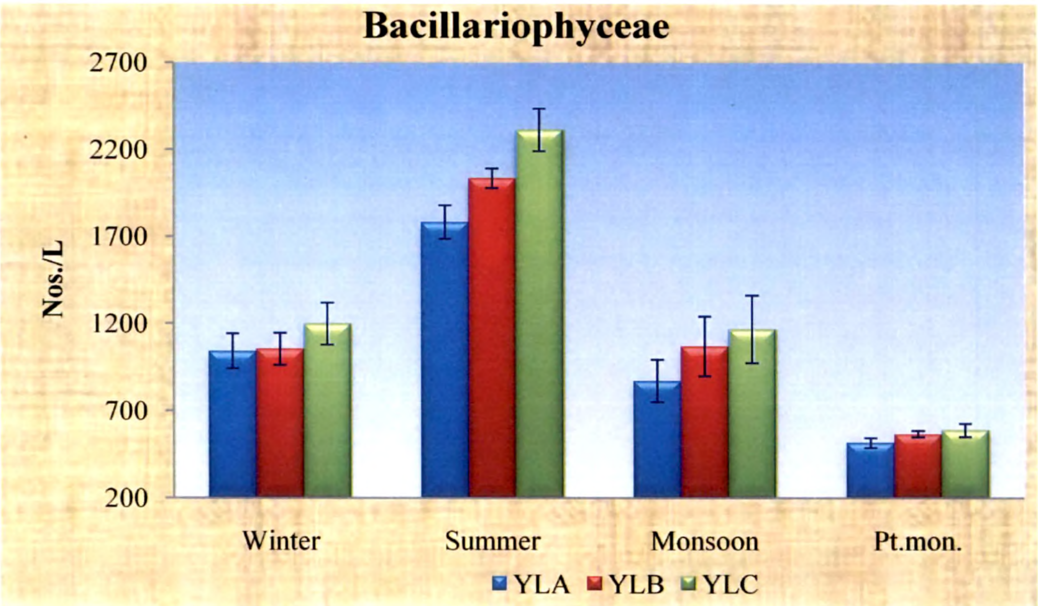


Figure: 4A.5 Seasonal variation in density of Dinophyceae (/L) at Yashwant Lake during December 2006 to November 2008

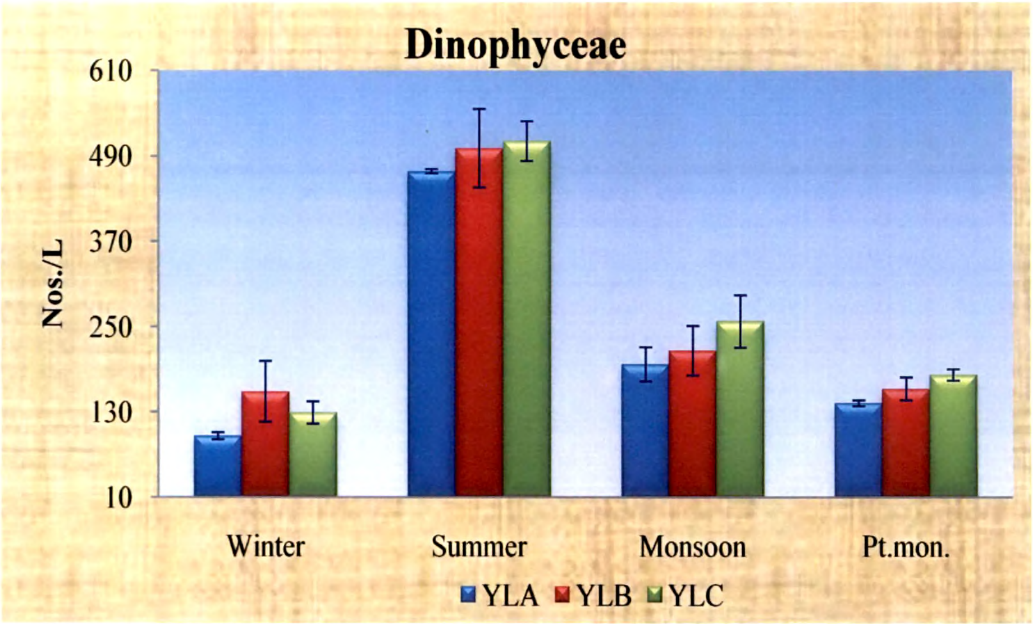


Figure: 4A.6 Seasonal variation in density of Euglenophyta (/L) at Yashwant Lake during December 2006 to November 2008

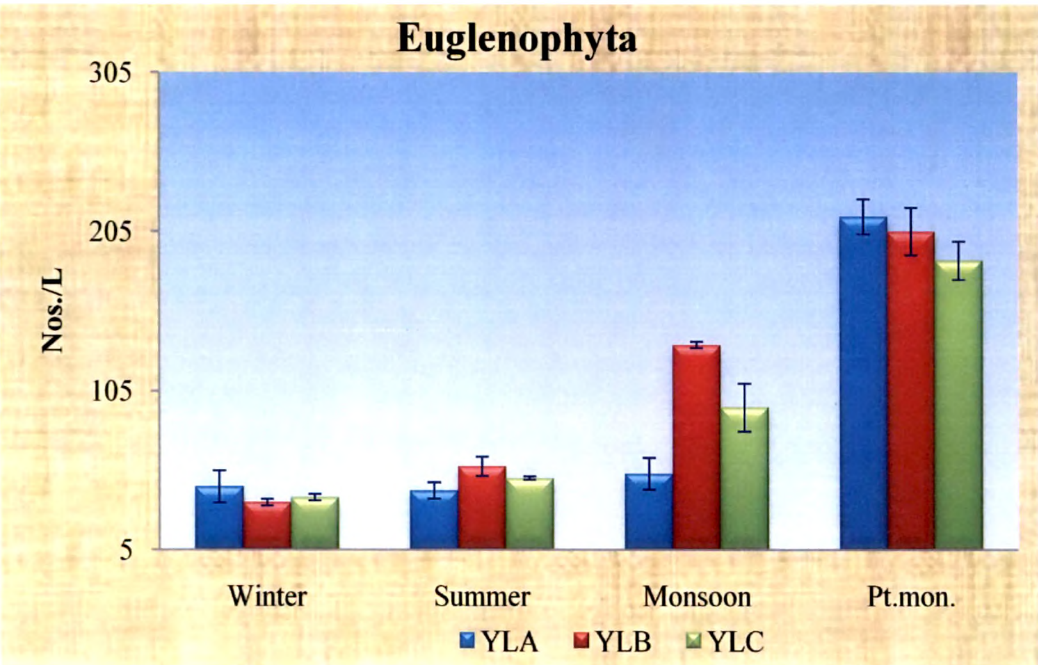


Table 4A.3 Biannual Percentage Species richness of different groups of Phytoplankton at Yashwant Lake during December 2006 to November 2008

Stations	Cyano.	Chloro.	Bacillario.	Dino.	Eugleno.
YLA	20.31	20.83	43.05	9.72	6.07
YLB	19.74	21.02	45.42	8.34	5.45
YLC	18.92	21.1	47.88	8	4.07
Biannual percentage	19.62	20.95	45.45	8.68	5.19

Table 4A.4 Seasonal Variations in species richness (no. of species) of different groups of phytoplankton at YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

Parameters	Stations	Winter	Summer	Monsoon	Postmonsoon
Tot. Phyto.	YLA $F_{3\ 20}$ 14.15	19.17 ± 1.77	30.17 ± 1.32	25.83 ± 1.10	21.0 ± 0.89
	YLB $F_{3\ 20}$ 27.62	20.67 ± 0.95	32.17 ± 1.16	28.0 ± 0.73	22.17 ± 1.13
	YLC $F_{3\ 20}$ 43.09	22.33 ± 1.14	37.50 ± 0.42	30.0 ± 1.29	24.67 ± 1.02
Cyano.	YLA $F_{3\ 20}$ 7.28	4.66 ± 0.55	6.16 ± 0.30	5.00 ± 0.36	3.66 ± 0.21
	YLB $F_{3\ 20}$ 17.35	4.83 ± 0.30	6.50 ± 0.22	5.33 ± 0.21	3.83 ± 0.30
	YLC $F_{3\ 20}$ 30.44	5.0 ± 0.25	6.83 ± 0.16	5.66 ± 0.21	4.16 ± 0.16
Chloro.	YLA $F_{3\ 20}$ 8.33	4.83 ± 0.54	6.16 ± 0.30	5.50 ± 0.42	3.50 ± 0.22
	YLB $F_{3\ 20}$ 15.13	5.0 ± 0.36	7.0 ± 0.36	5.83 ± 0.30	4.0 ± 0.25
	YLC $F_{3\ 20}$ 38.13	5.66 ± 0.21	7.66 ± 0.21	6.33 ± 0.21	4.50 ± 0.22
Bacill.	YLA $F_{3\ 20}$ 22.05	6.33 ± 0.76	15.67 ± 1.2	12.0 ± 0.68	7.33 ± 0.95
	YLB $F_{3\ 20}$ 38.54	7.33 ± 0.66	16.83 ± 0.94	14.0 ± 0.57	9.0 ± 0.57
	YLC $F_{3\ 20}$ 48.55	8.0 ± 0.89	21.0 ± 0.36	15.0 ± 0.96	10.83 ± 0.87
Dino.	YLA $F_{3\ 20}$ 15.56	2.33 ± 0.21	1.50 ± 0.34	1.83 ± 0.16	3.66 ± 0.21
	YLB $F_{3\ 20}$ 19.11	2.16 ± 0.16	1.16 ± 0.16	2.0 ± 0.25	3.33 ± 0.21
	YLC $F_{3\ 20}$ 23.67	2.33 ± 0.21	1.33 ± 0.21	2.0 ± 0.0	3.50 ± 0.22
Eugle.	YLA $F_{3\ 20}$ 19.95	1.0 ± 0.25	0.66 ± 0.21	1.33 ± 0.21	2.83 ± 0.16
	YLB $F_{3\ 20}$ 7.91	1.33 ± 0.21	1.0 ± 0.0	1.33 ± 0.21	2.0 ± 0.0
	YLC $F_{3\ 20}$ 5.18	1.16 ± 0.16	0.83 ± 0.16	1.0 ± 0.0	1.66 ± 0.21

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

Figure: 4A.7 Seasonal variation in species richness of total phytoplankton (no. of species) at Yashwant Lake during December 2006 to November 2008

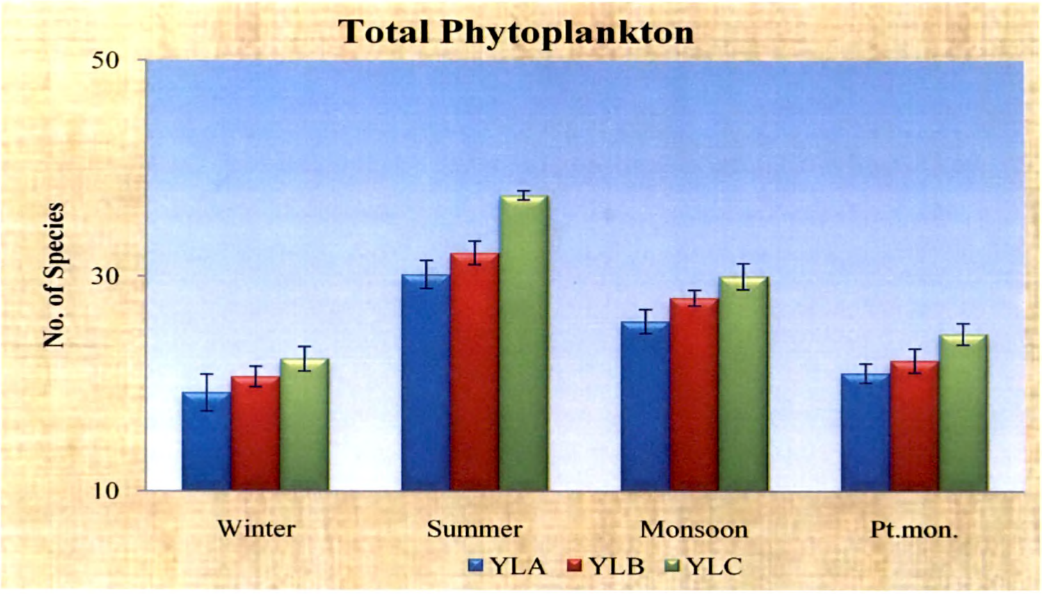


Figure: 4A.8 Seasonal variation in species richness of Cyanophyceae (no. of species) at Yashwant Lake during December 2006 to November 2008

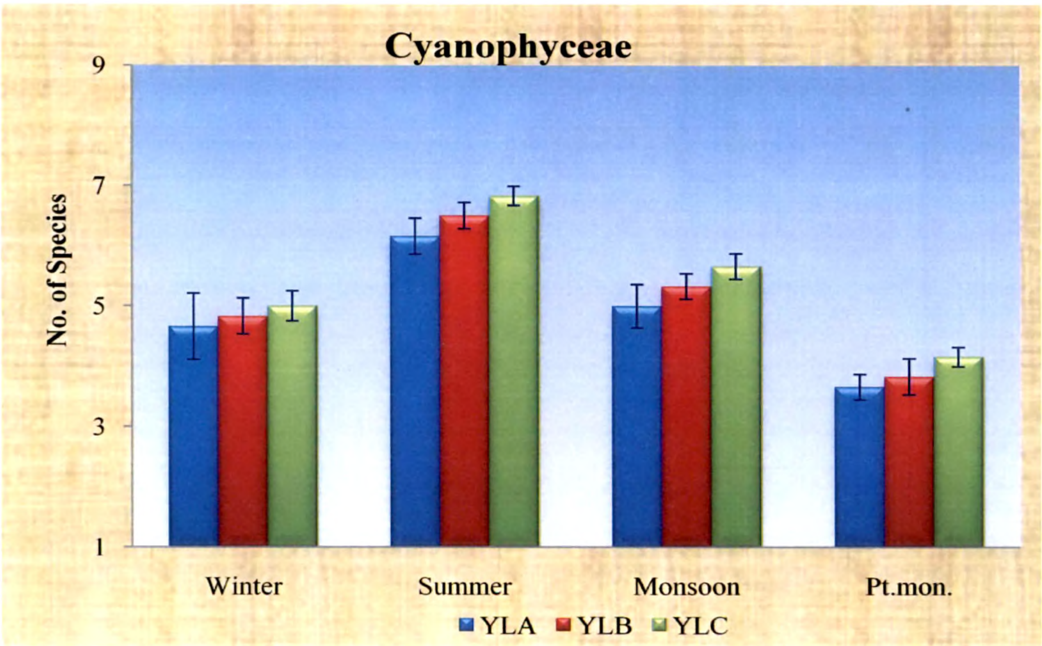


Figure: 4A.9 Seasonal variation in species richness of Chlorophyceae (no. of species) at Yashwant Lake during December 2006 to November 2008

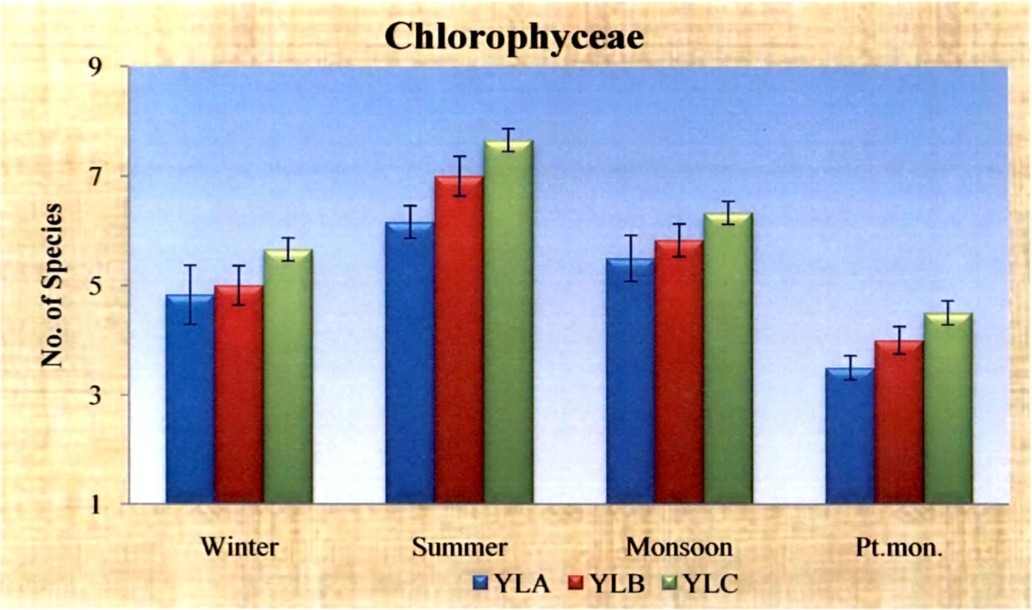


Figure: 4A.10 Seasonal variation in species richness of Bacillariophyceae (no. of species) at Yashwant Lake during December 2006 to November 2008

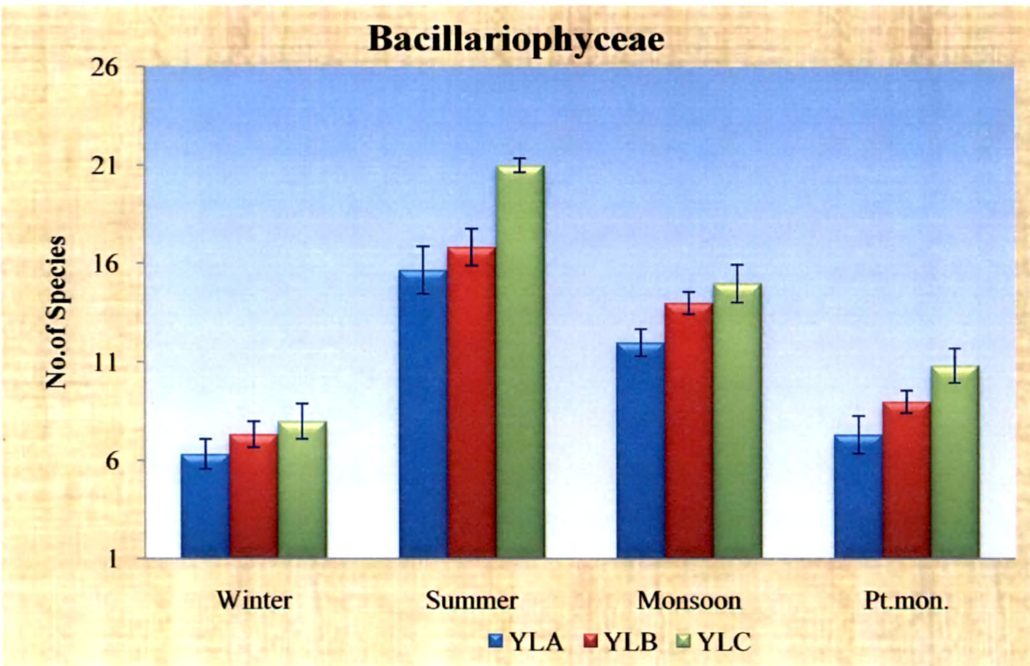


Figure: 4A.11 Seasonal variation in species richness of Dinophyceae (no. of species) at Yashwant Lake during December 2006 to November 2008

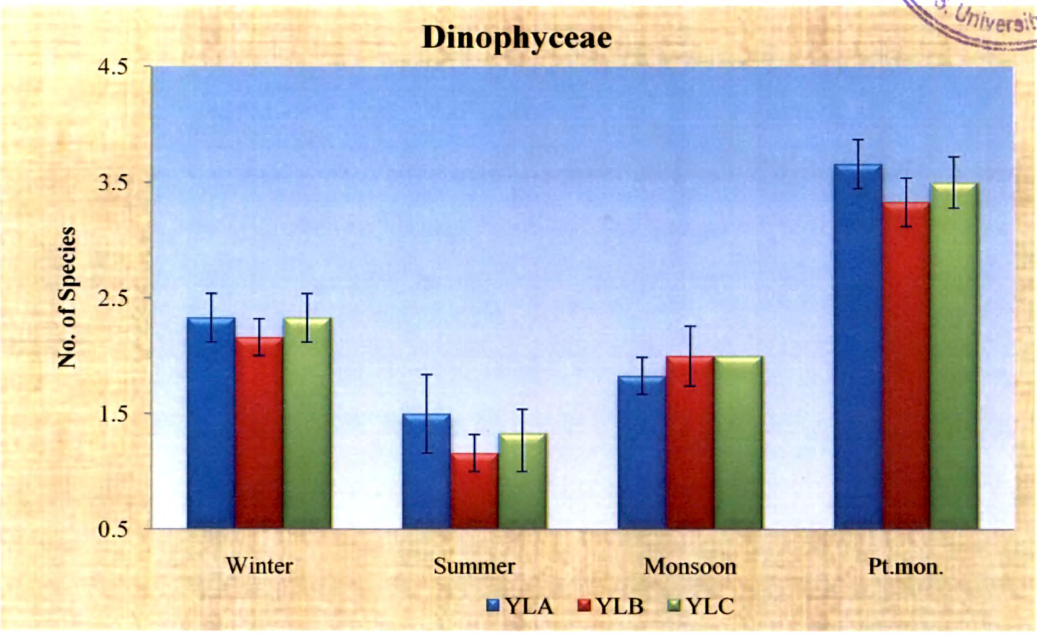


Figure: 4A.12 Seasonal variation in species richness of Euglenophyta (no.of species) at Yashwant Lake during December 2006 to November 2008

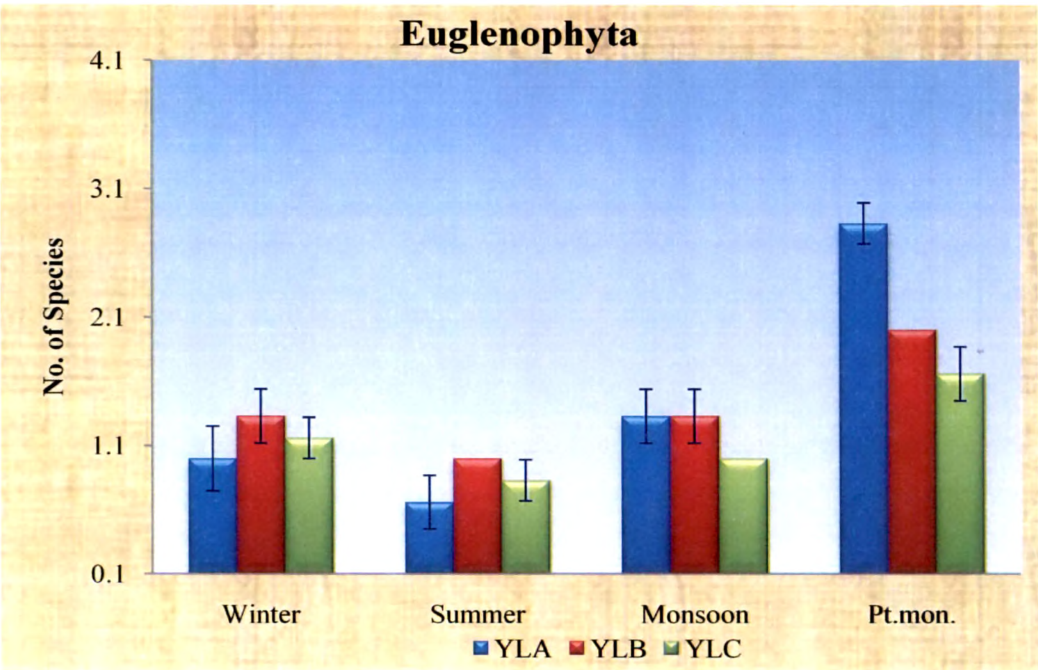


Table: 4A.5 Pearson correlation of Total Phytoplankton density with Biotic and Abiotic parameters of Yashwant Lake during December 2006 to November 2008

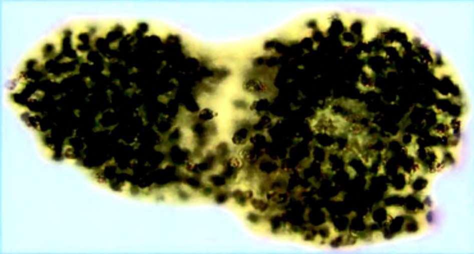
Sr. No.	Parameter	YLA	YLB	YLC
1	Ambient Temperature AT)	0.500 *	0.193	0.606**
2	Water Temperature (WT)	0.674**	0.313	0.762**
3	Water Cover (WC)	-0.885**	-0.693**	-0.930**
4	Total Solids (TS)	0.295	0.016	0.410*
5	Total Suspended Solids (TSS)	-0.511*	0.618**	-0.414*
6	Total Dissolved Solids (TDS)	0.752**	0.517**	0.820**
7	Transparency	0.229	0.549**	0.103
8	Acidity	0.761**	0.523**	0.854**
9	Alkalinity	0.732**	0.544**	0.832**
10	Carbon Dioxide (CO_2)	0.485*	0.179	0.555**
11	Dissolved Oxygen (DO)	-0.424*	-0.262	-0.448*
12	Chloride	0.860**	0.611**	0.933**
13	Total Hardness (TH)	0.703**	0.809**	0.728**
14	pH	0.686**	0.420*	0.783**
15	NO_2^-	-0.27	-0.494*	-0.107
16	NO_3^-	-0.587**	-0.819**	-0.600**
17	PO_4^{-3}	0.157	-0.269	0.291
18	Total Density Of Zooplankton (TDZ)	0.841**	0.635**	0.879**
19	Total Density of Mollusc (TDM)	-0.469*	-0.719**	-0.549**
20	Total Density of Birds (TDB)	-0.191	0.154	-0.264

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

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

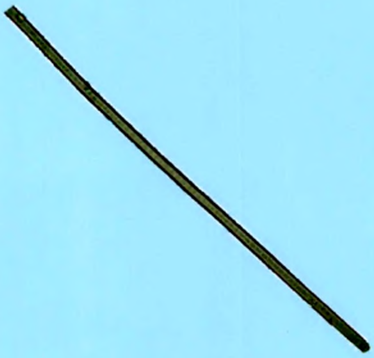
Plate No - 7

Some Representative Phytoplanktons of Yashwant Lake



1 : Microcystis viridis

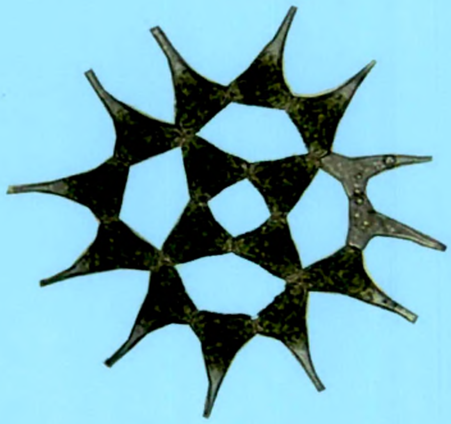
2 : Oscillatoria limosa



3 : Phormidium ambigum

4 : Bulbochaetae spp.

5 : Closterium attenuatum



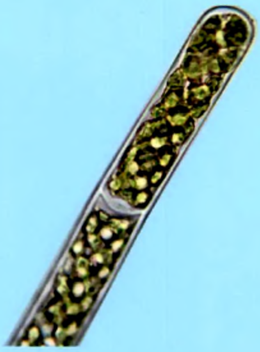
6 : Pediastrum simplex

Cyanophyceae - 1 to 3

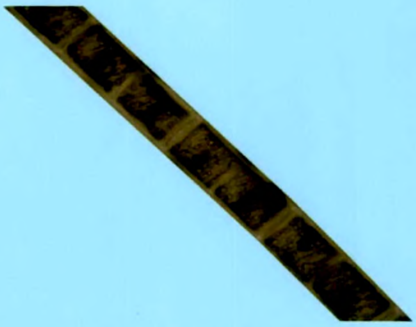
Chlorophyceae - 4 to 6

Plate No - 8

Some Representative Phytoplanktons of Yashwant Lake



7 : Spirogyra hyalina



8 : Spirogyra formosa

9 : Melosira islandica

10 : Synendra ulna

11 : Synendra acus

12 : Gyrosigma accuminatum

Bacillariophyceae - 7 to 12

Plate No - 9

Some Representative Phytoplanktons of Yashwant Lake

13 : Navicula cuspidata
(K.V. conspicua.)

14 : N. cupidada
(Kuetz V. major Meister)

15 : N. rhynchocephala

16 : Pinnularia interupta

17 : Pinnularia vidarbhensis

18 : Rhopalodia gibba

Bacillariophyceae - 13 to 18

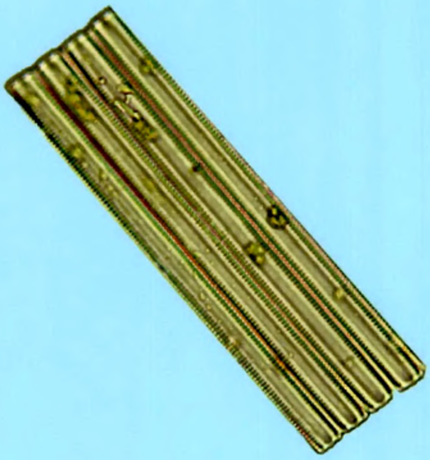
Plate No - 10

Some Representative Phytoplanktons of Yashwant Lake

19 : Nedium longiceps

20 : Surirella subsalsa

21 : Gomphonema gracile



22 : Fragilaria construens

Bacillariophyceae - 19 to 22

23 : Peridinium spp.
Dianophyceae

24 : Phacus longicauda
Euglenophyta

DISCUSSION

Phytoplankton forms the basic link of food chain between abiotic and biotic factors in the aquatic ecosystem as the metabolic activities of these organisms depend on the physicochemical factors of the aquatic environment. The quality and quantity of phytoplankton and their seasonal successional patterns have been successfully utilized to assess the quality of water and its capacity to sustain heterotrophic communities. Virtually all the dynamic features of lakes such as colour, clarity, trophic state, zooplankton and fish production depend to a large degree on the phytoplankton (Goldman and Horne, 1983).

Biodiversity conservation seeks to maintain the human life support system provided by nature and the living resources essential for development. As far as water reservoirs in India are concerned three distinct plankton pulses are reported which coincide with southwest post-monsoon (September-November), winter (December-February) and summer (March-May) (Sugunan, 2000). First the South-West Monsoon (June-August) flushing disturbs and often dislodges the standing crop of plankton. However, the destabilizing effects does not wean away immediately (as dam outlets are closed), and the allochthonous nutrient input favours some plankton growth in postmonsoon *e.g.* (Euglenophyceae). Second, as the post-monsoon merges into winter, the turbulence decreases and water becomes clean, the phytoplankton community progresses through a series of succession to culminate in a peak Cyanophyceae and Chlorophyceae. Third, at the end the summer plankton maxima coincide with the drastic drawdown, bringing the deep, nutrient rich areas into the fold of tropholytic zone. High temperature, bright sunlight and rapid tropholytic activities also accelerate the multiplication of phytoplankton during summer (Bacillariophyceae and Dinophyceae).

Phytoplankton forms a dominant quantiative component of plankton as compared to zooplankton throughout the present study as is also observed by Sugunan (1989); Krishnan *et al.* (1999); Goswami and Goswami (2001).

However, Sharma and Sharma (2008) have reported zooplankton as the dominant component as compared to that of phytoplankton.

Total Phytoplankton

Maximum density of phytoplankton noted at Yashwant Lake in summer may be attributed to maximum photoperiod and higher temperature as is reported to invigorate growth of the aquatic autotrophs (Vyas and Kumar, 1968; Murugavel and Pandian, 2000; Sunkad, 2002; Hujare, 2005). The role of photoperiod and temperature in determining density of phytoplankton has been documented as early as 1940 by Bhardwaja. Further, as the water level decreases in summer under Indian climatic conditions, the phytoplankton aggregates resulting in their increased density. pH is also a factor that influences plankton density. The higher pH (alkaline pH) is favourable for the growth of phytoplankton (Hujare, 2005). At Yashwant Lake temperature and pH both were positively correlated with total density of phytoplankton (Table 4A.5). An opposing situation occurs during postmonsoon when the water level and water cover are highest, plankton get more distributed resulting in decline in their density. In addition the short photoperiod and lower temperature of higher altitude may not be much favourable to phytoplankton density. However, once the lake is stabilized the productivity increases resulting in higher density compared to monsoon. When compared with phytoplankton density of other water bodies like reservoirs in plains of Maharashtra (More and Nandan, 2000; Jawale and Patil, 2009), tropical reservoirs in Brazil (Cleber and Giani, 2001) and Kavery river (Mathivanan *et al.*, 2007) the density of phytoplankton at YSL was distinctly lower.

Calcium is an important part of plant tissue, as it increases the availability of other ions and reduces the toxic effects of NO_2^- (Manna and Das, 2004). As per the present study Calcium in the form of Total hardness may be playing a vital role in the growth of phytoplankton resulting in significant positive correlations in total phytoplankton density with total hardness. When the correlation with various parameters is considered the same correlation is established at the three stations mainly for the parameters which show effects of mixing in water, while the influence of difference in the substratum and surrounding area is noted for those chemical parameters on which biota depends (Table 4A.5). Further, present results showed significant positive correlation between abundance of phytoplankton and zooplankton, while negative correlation was observed in case of molluscs and birds with significant and non significant values respectively.

Species richness

Sharma and Durve, (1985) have stated that the most undesirable feature of eutrophication is the change in the lake flora from diatoms (Bacillariophyceae) and greens (Chlorophyceae) to the blue greens (Cyanophyceae) that are favoured by increased nutrients. In the present study the sequence of percentage density and species richness in decreasing order were Bacillariophyceae > Chlorophyceae > Cyanophyceae > Dinophyceae > Euglenophyta (Table 4A.1) indicating no traces of eutrophication.

This is supported by the representation of various species belonging to the five families studied. Of the total 49 species of phytoplankton recorded, 24 belonged to bacillariophyceae, 10 to chlorophyceae, 8 to cyanophyceae, 4 to dinophyceae and 3 to euglenophyta (Annexture- I).

The maximum species richness of total phytoplankton (Table 4A.4) recorded in summer was mainly due to the dominance of diatoms (51 to 55 %) followed by members of Chlorophyceae and Cyanophyceae. As far as microhabitats are concerned the diatoms completely dominated the epipelic community all throughout the year. During summer the increase in thermal stability of water column coincides with moderate nutrient depletion. However, there are species that are favoured by mixing in water and higher nutrient concentration. Many factors are known to be regulated by phytoplankton or under external control may minimize competition, allowing the coexistence of many species in stable environment (Nico, 2003). The species richness of total phytoplankton showed decrease with the onset of monsoon that changed to postmonsoon when plankton get distributed, reaching minimum species richness in winter when temperature and photoperiod are minimum. In short the exogenous factors such as addition of rain water and silt may tend to disrupt equilibrium dynamics in monsoon while stable conditions of water in summer with change in temperature and photoperiod influence phytoplankton positively. The overall balance is consistent with the existence of phytoplankton community oscillating along a continuum, from equilibrium to non-equilibrium.

1. Cyanophyceae (Blue Green Algae)

Cyanophyceae, a rich plankton community with well marked serial succession, is the hallmark of Indian reservoirs. Blue green algae form the mainstay of the manmade lakes (Singh, 1960; George, 1961; Nandan and Patel, 1984). According to these authors, the overwhelming presence of *Microcystis aeruginosa* in Indian reservoirs is remarkable as several species of phytoplankton are known to regulate growth of other species of phytoplankton. In the Yashwant Lake maximum density of blue green algae was observed in winter. However, the algal bloom of *Microcystis* observed by these authors is not applicable for YSL as no significant algal bloom was noted here.

Tucker and Loyd (1984); Hegde and Sujata (1997) and Naik *et al.* (2005) have stated that moderately high temperature supports the growth of blue green algae. Thus, water temperature plays an important role in the periodicity of blue-green algae (Hutchinson, 1967; Rai, 1978; Nandan and Patel, 1984). The same effects of water temperature on blue green algae were noted during late winter and early summer at all the stations of Yashwant Lake (Table 4A.2). The effect of temperature in general on algal growth can not be separated from the effects of light, as both the factors are interrelated in photosynthesis. Kopczynska (1980) has shown the combined effects of light and temperature on the growth of algal flora in general. In present study, the abundance of total algal flora was greater in summer while blue green alga were maximum in winter. There is probably no definate correlation between cyanophyceae and temperature and pH of water. There are considerable differences of opinion regarding the effect of pH on abundance of algal flora. However, the pH of Yashwant Lake was alkaline throughout the study period with maximum in summer and minimum in winter (Chapter 3). The individual cyanobacterial species have considerable specializations and are intolerant of a high degree of environmental variability (Padisak and Reynolds, 1998). Though the abundance was low in summer in present study maximum eight species of blue green algae were recorded from Yashwant Lake. These species are *Microcystis viridis*, *Aphanocapsa biformis*, *Spirulina subtillissma*, *Oscillatoria limosa*, *Phormidium ambiguum*, *Lyngbya limnetica*, *Nostoc spongiaeformae* and *Anabaena sp.*

In India the bloom of *Microcystis aeruginosa* are common and permanent blooms have been reported in many temple tanks in south India. The factors like warm temperature and high nitrogen and phosphorus contents, promote such abundant growth (Desikachary, 1959). *Microcystis aeruginosa* is the best single indicator of pollution (Philipose, 1960). Moderate temperature in the summer with higher nitrate and phosphate levels may be the reason for temporary *Microcystis* bloom. The species of *Microcystis* are objectionable not only because they create oxygen demands, but also some of them release toxic substances which kill fish and other animal life (Prescott, 1948). The blue green algae like *Anabaena* produces neurotoxins the contact irritants that were originally thought to be produced only by genera *Oscillatoria.* However, the presence of *Oscillatoria* and *Anabaena* in present study indicates beginning of biological pollution at Yashwant Lake raising an alarm to the future status of the Lake. Mischke and Nixdorf (2003) have noted that few Oscillatoriaceae species can tolerate the combination of intermittent nutrient deficiency and low light conditions, such conditions are produced by the frequent but irregular mixing, and they build up very dense population that increases turbidity. The steady state period of winter is a self induced habitat, in which competitors fail because of low light conditions combined with effective exploitation of nutrient resources by the dominant Cyanobacteria. Whereas, in summer though the transparency is moderate no cynobacteria (Oscillotoria) could dominate against higher density of other plankton.

The *Anabaena* and *Nostoc*, have the general ability to fix the atmospheric nitrogen (Nico, 2003). These pollution indicator species were recorded with other indicator species like *Microcystis*, *Anabaena* and *Oscillatoria* in present study but their population were low indicating that the water is not yet polluted. Temporary bloom of *Oscillatoria* and *Microcystis* may be present in summer when temperature and CO_2 were high and O_2 low (Table 4A.2) indicating moderate deterioration due to evaporation and concentration. Tiwari and Chauhan (2006) have recorded maximum *Oscillatoria, Nostoc, Anabaena* and *Microcystis* in summer at higher temperature and high CO_2 and low Oxygen levels.

2. Chlorophyceae (Green algae)

Chlorophyceae the free living phytoplankton, is mostly confined to shallow waters and attached to the submerged plants or found in moist soil. Maximum density of this green algae was observed in winter when temperature and photoperiod are low at YSL (Table 3.1). Studies have been made by many workers on the distribution and abundance of chlorophyceae (Jyoti *et al.*, 1990; Huddar, 1995; Islam *et al.*, 2001). In the present study as noted for other groups the minimum density of chlorophyceae in monsoon may be attributed to the dilution effect due to the rains as well as drifting of algae along with the water. Like Cyanophyceae the maximum density of Chlorophyceae was recorded in winter and low during summer indicate that their contribution is low in increase in total plankton density of summer. The chlorophyta is the second dominant group recorded at the Yashwant Lake which is concur with the predominance of the diatoms over the green algae noted by Baruah *et al.* (1993) and Krishnan *et al.* (1999). In contrast to this, Yadava *et al.* (1987); Goswami and Goswami (2001) and Sharma (2009) recorded chlorophyta dominance over diatoms. ANOVA registered seasonal variations ($P < 0.0001$) in the density of Chlorophyceae across the seasons. This density of

Chlorophyceae was negatively correlated with CO_2, NO_2^-, NO_3^-, PO_4^{-3}, TS, TSS and positively correlated with total density of phytoplankton, TH and Transparency at YLB where the substratum is muddy.

Gahotri *et al.* (1980) have recorded higher percentage of chlorophyceae in alkaline waters which has been proved true in the present study too. According to Gulati and Wurtz-Schuiz (1980) the alkaline nature of water body promotes the dense growth of chlorophyceae. The Yashwant Lake remains alkaline all throughout the year (Table 3.3). The green algae of Yashwant Lake includes genera *Ulothrix, Oedogonium, Bulbochaetae,* Closterium, *Cosmerium, Staurastrum, Eudorina, Pediastrum and Spirogyra* (Annexture-I). 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), while according to Zutshi, (1975), Saify *et al.*, (1986) and Hujare, (2005) an excess of eutrophication of water body increases the number of chlorophyceae both qualitatively and quantitatively. Thus, the YSL has potential to undergo eutrophication.

According to Standards I S 10500: 1991- Annexture-I, the species of *Coelastrum, Oocystis, Scendesmus, Zygnema, Chlamydomonas, Chlorella, Spirogyra, Tribonema* and *Closterium* are found in polluted waters. Of these only *Spirogyra* and *Closterium* were found in YSL in low density, this indicate that the water is not much polluted.

3. Bacillariophyceae (Diatoms)

The Bacillariophyceae (Diatoms) are also being used increasingly as indicators of environmental changes, including studies of past climatic changes (Smol and Cumming, 2000; Wim *et al.*, 2007). The environmental factor such as physico-chemical and biological factors influence the abundance and species richness of diatoms, which is reflected in their seasonal variations. Maximum diatom density were recorded in summer at all the three stations as is also reported by Sunkad (2002); Hujare (2005); Hulyal and Kaliwal (2009); Hafsa and Gupta (2009) and Jawale and Patil (2009) when the temperatures are high in Indian climate. The temperature has been reported as the most important factor affecting diatom growth positively (Pearsall, 1932; Yoshitake and Imahori, 1980). In addition George, (1961) observed that the high pH value promotes the growth of algae in general while Kamat (1965) reported that it is favourable for abundant growth of diatoms. As discussed to Chlorophyceae for Bacillariophyceae also alkaline pH is favourable (Table 3.3). Diatoms are reported to absorb phosphates in large quantities than their requirements (Rutner, 1963 and Munawar, 1970). Philipose (1960) has reported direct relation of phosphate with diatoms. In present study, minimum to moderate phosphate were recorded in winter and summer respectively when the diatom populations were moderate to maximum. In additions Nitrates have also been given the prime importance in diatom ecology (Patrick, 1948, Rao, 1955). Nitrate is also considered as the main controlling parameter in the periodicity of diatoms. However, in the present study the diatom density is negatively correlated with the nitrate at all the three stations (Annexture 5a, b and c). This needs further investigation in relation to other abiotic and biotic parameters.

In addition to summer peak, a winter peak is also recorded for diatoms by George (1966); Patil (2005); Nandan and Magar (2007) and Sharma (2009) in their annual studies. However, in present seasonal study a steady increase from winter to summer has been noted at the higher altitudinal Lake. The effect of rains in distributing the plankton in general and resulting decline in their density stands true for diatoms too. However, Pennak (1949, 1955) did not find any regular diatom pulse throughout the year.

Dissolved silica has a specific role in diatom growth and adequate silica supply is essential for bacillariophyceae in general. Dissolved silica is supplied to the lake by drainage water (Kobbia *et al.*, 1992; Gad, 1992) and is also generated by remineralization within the lake. The relative importance of these processes is not yet known. In the present study the silica is not estimated, but high density of diatoms is indicative of sufficient silica content of Yashwant Lake.

The diatoms of Yashwant Lake were represented by 24 species belonging to16 genera (Annexture- I) which dominated in density atleast for three seasons. This indicate availability of their distinct nutritional requirements at YSL that favours one group over other as indicated by Wetzel (2001). Further, the diatoms are positively correlated with the density of total phytoplankton indicating their dominance among all the phytoplankton communities. Patrick (1973) concluded that many species of diatoms can tolerate a temperature range from 0.0 to 35°C. The study of Yashwant Lake indicates that this group of species are found abundantly when water temperature fluctuated between 18.75 ± 0.3 °C of winter to 22 ± 0.4 °C of summer.

Palmer, (1969) has listed the taxa in decreasing order of emphasis with reference to pollution index. In the present study some of these pollution tolerant species were also observed in the order of density as follows: *Nitzschia, Navicula, Synedra, Melosira, Gomphonema, Fragilaria, Surirella, Cymbella, Pinnularia.* Similar taxa were also recorded by Nandan and Mahajan, (2007) at Suki Dam, Maharashtra. It is general observation that *Cymbella, Fragilaria species, Gomphonema* are commonly found in organically rich waters while according to Richardson, (1968) *Nitzschia* species is characteristic of organically rich waters. However, the clean water diatom species *Amphora ovalis, Cymbella sp., Pinnularia sp.* were also observed in the waters of YSL. This indicates that though not yet polluted, YSL- if care is not taken may get polluted in near future as it is having potential for deterioration and eutrophication under the influence of pollution and anthropogenic pressures.

It has been recently shown for lentic diatom communities that spatial variation in diversity and species composition cannot be solely driven by local environmental conditions but is also determined by habitat availability (Telford *et al.*, 2006) in other words potential habitat is available at YSL.

4. Dinophyceae

The distribution of dinoflagellates in relation to major chemical characteristics shows that, while some species are widely tolerant and ubiquitous, especially among species of *Ceratium* and *Peridinium,* most dinoflagellate species have restricted ranges with respect to calcium, pH, dissolved organic matter and temperature (Taylor and Pollingher, 1987). These two genera of dinophyceae *Ceratium* and *Peridinium* were recorded at Yashwant Lake. Dinophyceae, a sub-dominant quantitative component of phytoplankton, was at fourth position in algal group abundance (Table 4A.1) with 8.62 % (at YLC), 8.74 % (at YLB) and 8.77 % (at YLA). Temperature plays an important role in the periodicity of dinoflagellate (Fritch, 1935). Here also the abundance of dinophyceae is positively correlated with temperature. Asexual resting stages or cysts are known to undergo considerable periods of diapauses in winter decreasing their density (Loeblich and Loeblich, 1984). For example in *Ceratium*, the autumn decline of summer populations in temperate regions, results in the production of overwintering cysts. Emergence from benthic cysts can result in an exponential increase in the planktonic cells in the ensuing spring and summer (Heaney *et al.*, 1983; Pollingher *et al.*, 1993). However, in tropics Zafar (1967); and Singh and Swaroop (1979) reported that the dianoflagellates are also abundant in winter. Hasle (1954) reported that the cells show diurnal vertical migration that concentrate in the uppermost 5 m belt but migrate further towards the surface during the day time, often collecting around 2 m depth. The dianoflagellates are also reported to move against water movement and show a negative reaction to light around noon (Blasco, 1978). This can be the reason for lower dinophyceae at YSL.

5. Euglenophyta

Euglenophyta has been considered a significant group in the study of the phycological flora. However, studies concerning both the occurrence of euglenophyta and environmental variables are still scarce (Philipose, 1982). In the present study of Yashwant Lake the abundance of euglenoids showed seasonal variation attributed to temporal variation in physico-chemical parameters. Maximum density of euglenophyta was recorded in post-monsoon, as is also reported by Hafsa and Gupta (2009). As asserted by Round, (1985), Euglenophyta are algal characteristic of environments rich in ammonia. The values of nitrate were also maximum to moderate in monsoon and postmonsoon respectively at Yashwant Lake. According to Duttagupta *et al.*, (2004); Bhuiyan and Gupta (2007) and (Munnawar, 1970a,b) Iron, Calcium and Magnesium play a great role in stimulating and maintaining Euglena blooms. Drastic reduction in the population of euglenophyta in winter has been attributed to the use up of essential nutrients during their bloom and bust period in postmonsoon (Duttagupta *et al.*, 2004).

As compared to other classes of algae, the members of euglenoid were least in number *i.e.* 3, which belonged to the genera *Euglena* and *Phacus*. Among the three stations, the abundance and species richness of euglenophyceae were higher at YLA, which has maximum anthropopressure due to washing and bathing activities as well as use the area for casual and holy occasions. Though found in small number Euglenophyta is probably better adapted to anthropopressure as is reported by Yusoff and Patimah (1994); Sandra *et al.* (2007). According to these authors Euglenoids are found most often in shallow water rich in organic matter. Pollution indicator species of euglenoid are found in Yashwant Lake, however quantitatively (2.95 to 3.34 %) and qualitatively they were poor as compared to other group of algae. The density and diversity of Euglenophyta also support the warnings that YSL is having potential for eutrophication and if the care of anthropopressures is not taken it may get polluted leading to eutrophication as is observed in many lake system including those at higher altitudes.

4 B. ZOOPLANKTON

INTRODUCTION

Zooplankton are minute heterotropic organisms in water bodies that are present at various depths in 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 eutrophic zone. Compared to phytoplankton, zooplankton have short life span and they respond more quickly to environmental changes than phytoplankton and are easier to identify. Zooplankton form an important link in the dynamic ecosystems of estuaries, bays, rivers and lakes. By their heterotrophic activity zooplanktonic organisms transport the organic material of primary and secondary production. The study of fresh water fauna especially zooplankton, even if of a particular area, is extensive and complicated due to environmental, physical, chemical and geographic variations involving ecological, extrinsic and intrinsic factors (Majagi and Vijaykumar, 2009).

Zooplanktons are known to support the economically important fish population and are the major mode of energy transfer between phytoplankton and fish (Howick and Wilhm, 1984). Hence, they are the excellent indicators of the status of a lake and occupy a pivotal position in the food web and top down feedback mechanisms (Christoferson *et al.*, 1993; Jeppensen *et al.*, 1999). Various studies have been conducted world wide with reference to the species richness, distribution of copepod and cladocera and their relation to hydroperiod (Dagmar *et al.*, 2006), comparison of zooplankton diversity of two fresh water wetland ecosystems of Goa Das *et al.* (2005), seasonal distribution of the population structure of zooplankton in connection with physicochemical parameters Sarkar and Chaudhary (1999). Hence, Zooplankton communities of numerous reservoirs, lakes and shallow water bodies have been used as indicators for the status of the lake (Christoferson *et al.*, 1993; Jeppensen *et al.*, 1999; Ramchandra *et al.*, 2002) and related with the concentration of total nitrogen, total phosphorus, algal biomass and the density and size of individuals (in the Central American lakes, Giselle and Bruce, 2007). The variability observed in the distribution of zooplankton is due to abiotic parameters (*e.g.* climatic or hydrological limitation) and biotic parameter (predation, competition) or combination of both (Roff *et al.*, 1988; Christou, 1998; Escribano and Hidalgo, 2000; Beyst *et al.*, 2001). Hence, the use of zooplankton for environmental characterization of water body is potentially advantageous as the quality of water affects the species composition, abundance, productivity and physiological conditions.

Zooplankton communities of fresh water belong two major groups Rotifera and the Microcrustaceans. Latter is further divided into three main taxonomic groups the - Cladocera, Copepoda and Ostracoda. Majority are abundant in shallow areas of reservoirs, but only few species are abundant in open waters. They occupy an intermediate position in the food webs, many of them feed on algae and bacteria and in turn are fed upon by numerous invertebrates and fishes. The dominance of zooplanktonic rotifers, cladocerans and copepods in shallow water bodies varies according to the degree of organic pollution (Verma and Munshi, 1987). The four groups studied at YSL are as follows.

ROTIFERA

Rotifera, also called Rotatoria or wheel animalecules is group of small, usually microscopic, pseudocoelomate animals which have been variously regarded either as a class of phylum Aschelminthes, or as a separate minor phylum. They are ubiquitous, occurring in almost all types of fresh water habitats, from large permanent lakes to small temporary puddles and feed on algae and bacteria. Being prey for plankton feeders, Rotifers play a crucial role in many freshwater ecosystems. They are permanently and obligatorily connected to aquatic habitats in all active stages, only their resting stages are draught resistant (Hendrik, 2007). Rotifer distribution and diversity is influenced primarily by deteriorating quality of water in freshwater ecosystems and secondarily by eutrophication and salinization. The nutrients, primary production, temperature, abundance of predators and competitors, and potential food resources are important factors influencing the structure of rotifer community (Devetter and Sed'a, 2003).

Most rotifers are not free floating, but are sessile and associated with littoral substrata. Population of rotifers is highest in association with submerged macrophytes, especially plants with richly divided leaves. In such conditions the densities may reach upto 25,000 per litre (Edmondson, 1944, 1945, 1946) and *vise a versa* with reduced sites of attachment and presumably less protection from predation, their density is low (Wetzel, 2001). Even though most rotifers commonly exhibit maximal densities in early summer, in temperate regions they show wide range of temperature tolerance (Berzens and Pejler, 1989). Various rotifer taxa serve as useful bioindicators of water quality of environments within the limits of Limnosaprobity. Their ability to colonize diversified aquatic and semi-aquatic biotopes and inherent quality to build up substantial densities within short time- intervals make them ideal for ecological considerations as well as valuable tool for population dynamic studies.

MICROCRUSTACEAN

Littoral and limnetic habits of various freshwater ecosystems are colonized by microcrustacea, which include Cladocerans, Copepods and Ostracods. As said earlier they invariably form an integral link of aquatic food webs, serve as valuable fish food organisms and contribute notably to secondary productivity in freshwater environments. In natural habitats wherein external influences of pollution are absent or at least low, members of this group constitute a sizable population. Hence, microcrustacea are included in routine limnological studies (Sharma and Sharma, 2009). Several papers have been published on rotifer diversity and density, however this literature provides limited information on their ecology, ecosystem diversity and role in aquatic productivity because of inadequate analysis of their communities. These authors have recorded that water temperature, rainfall, specific conductivity and dissolved oxygen show significant influence on species richness and abundance of microcrustaceans. Wolfgang (2003) during his investigation of drinking water reservoir-

Saidenbach (Germany) between 1975-1990, reported biomass decline in the total microcrustacean due to top down effects and because of increase in stocks of both native planktivorous fishes and non-native carps over the years. However, Eitam *et al.*, (2004) reported microcrustaceans richness to be related to pond permanence and not to surface area, where hydroperiod, conductivity, vegetation and wetland size, all seem to be determinants of microcrustacean fauna. The microcrustacean group as further divided into 3 groups: Cladocera, Copepoda and Ostracoda.

CLADOCERA

Cladocerans (water fleas) are primary freshwater small sized (0.2 – 6 mm) brachiopod crustaceans inhabiting pelagic, littoral and benthic zones. The cladocera are found in all sorts of fresh waters with higher densities in lotic than lentic systems. The shallow weedy backwater of lake, where water level is fairly permanent, harbour a great variety of species than does any other kind of locality. Here, they also act as the link in the food chain. Most of them are herbivorous, feeding on phytoplankton and in turn, are preyed upon by certain invertebrates and fish, thus, involved in the transfer of energy from primary producers to secondary and tertiary consumers within the aquatic food web (Dodson and Frey, 2001). They inhabit diverse habitats and are at times exposed to great variety of harsh and extreme environmental conditions.

A high diversity of cladocerans can be found in the littoral zone of stagnant waters, as well as temporary water bodies. Cladocerans especially Daphnia are important model organisms in both basic and applied research, (Venkataraman, 1990, Yousuf, *et al.*, 1983, Rane, 2002). The Canonical Correspondence Analysis of cladocerans and environmental variation in the cladoceran species has shown strong positive correlation between size of cladocerans and vegetation cover (Dagmar *et al.*, 2006). These authors have concluded that the presence of fish seems to play a minor role in shaping species richness in Donana wetlands. Cladoceran actively select their food, with preference for large particles, and are unselective filter feeders (Claes *et al.*, 2004). It has been reported that the life history strategies of tropical and temperate cladoceran taxa differ in response to several abiotic (temperature, light and oxygen saturation percentage) and biotic factors (predation and inter and intra-specific competition).

The water fleas (the cladocerans) are important component of the fauna of freshwaters; particularly significant in the food web of stagnant waters (Forro *et al.*, 2007). Most species are filter feeders and usually reproduce by cylindrical parthenogenesis. Thus their population are mainly dominated by females. However, sexually produced diapausing eggs are common and resistant to desiccation and other unfavorable conditions, and may even survive passage through the digestive track of birds (Figuerola *et al.*, 2003). Thus, birds are important propagules for their passive dispersal. Cladocerans have also gained certain economic importance as they are widely used in aquaculture and these large filter feeding planktonic species have an indirect economic impact as important fish food or phytoplankton controlling group.

COPEPODA

Copepods are minute (0.3 to 2.5 mm) crustaceans laking a distinct shell fold and having a simple median eye. They pass through a series of naupliar stages during their development. The three suborders of free living copepods found in fresh and other inland water bodies are the same as those found in marine waters-the Calanoid, the Cyclopoida and the Harpacticoida.

Geoff and Danielle (2007) have reported zoogeographic distribution of 2,814 species of copepods from fresh waters. They also studied key human related issues, such as role of copepods as vectors for human parasites and the losses caused by parasitic copepods in commercial aquaculture. Statistically most of the copepod assemblages of the natural marshes (marismas) have been shown to have strong positive relation to Axis 1 and 2 in Canonical Correspondence Analysis ordination (Dagmar *et al.*, 2006) indicating their positive association with hydroperiod, size and vegetation cover. The presence of copepods has been reported to improve the feeding condition of Daphnia-Cladocera (Claes *et* *al.*, 2004) because during copepod larvae grazing, the nutrients released are taken by phytoplankton which favours the population of Daphnids.

A number of studies have demonstrated that most of adult cyclopoid copepods are carnivorous and their predatory activities play a significant role in the population dynamics of other copepods (Confer, 1971). Various, adult Cyclops prey heavily on naupli of Diaptomus species and its own species, while some species are herbivorous which feed on a variety of algae ranging from unicellular algae to long strands of filamentous species. Cyclomorphosis, the means of rapid, evasing swimming movements is lacking in copepods (Kerfoot, 1980), hence they can not defend themselves better from invertebrate predator compared to most rotifers and cladocerans.

OSTRACODA

The Ostracoda are small bivalved crustaceans found in all the types of aquatic environments; both marine and fresh water including heavily polluted areas. They are more abundant in shallow water bodies where weeds or algae are abundant. Like other groups they also play important role in transforming the energy from producers to consumers in aquatic food web (Chakrapani *et al.*, 1996). The carapace of Ostracoda is made up of low magnesium calcite that fossilizes well in lake sediments, preserving information about the past lake environment (Griffith and Holmes, 2000).

Species richness and abundance of Ostracods are greatest in lake water saturated with $CaCO_3$ and highest numbers of species are found in lakes with moderate conductives, which has been reported to determine the presence or absence of species within the water body (Griffith and Holmes, 2000). Factors influencing Ostracod distribution include lake depth, water temperature and dissolved ion concentration (Mourguiart and Carbonel, 1994). High salinity appears to influence Ostracod species abundance and high ion concentrations can cause certain species to be excluded from some lakes (Forester, 1983). Thus, diversity, abundance and seasonal fluctuations of Ostracods have been linked with water quality. The assessment of Ostracods in four lakes of

Mysore city have shown influence of Water Quality Index (WQL) on species diversity, abundance and seasonal fluctuations of Ostracods (Padmanabha and Belagali, 2008). The assessment by them indicates that increase in water quality index decreases the population density of Ostracod but increases species diversity.

The presence and absence of certain organisms can be used to determine the condition of water. The productivity of aquatic animals directly depends on physico-chemical features of water. Hence, the knowledge of abundance, composition and seasonal variations of aquatic communities can help in planning successful management of a water body. Among the biotic components phytoplanktons and zooplanktons both are good indicators of fluctuations in water body as they are strongly affected by environmental variations in water quality and responds quickly to the same. Hence, qualitative and quantitative studies of zooplankton were also carried out at Yashwant Lake.

RESULTS

Seasonal variations in the density of total zooplankton for two years of investigations are presented in Table 4B.2, Fig.4B1. Seasonal variations are considered as total zooplankton, and then further divided in four groups *i.e.* rotifer, and microcrustacea that includes cladocera, copepod and ostracoda. Total 44 species of zooplankton belonging to 26 genera were identified from the surface water of the reservoir. Of these nine genera belonged to rotifera (24 species), ten genera to cladocera (11 species), four genera to copepod (6 species) and three genera to ostracoda (3 species). Seasonal variations in species richness of total zooplankton (no. of species) includes species richness of above said four groups (Table 4B.4, Fig. 4B.7).

DENSITY

A. Total Zooplankton

The abundance of total zooplankton includes four quantitative components and their abundance show significant seasonal variations. The sequence of abundance of various zooplankton group in decreasing order were recorded as Rotifera (35.27 to 36.82 %) > Cladocera (31.97 to 33.20 %) > Copepodes (24.53 to 26.17 %) > Ostracoda (4.9 to 5.5 %), (Table 4B.1).

Maximum density of total zooplankton (Table 4B.2, Fig. 4B.1) were recorded in summer. At YLC it was (2967 ± 59.7 ind./L), it was lower at YLB (2827 ± 59.03 ind./L) and lowest at YLA (2607 ± 56.02 ind./L). The density of total zooplankton decreased in monsoon with 2607 ± 118 nos. /L, 2333 ± 138.4 ind./L and 2173 ± 133.3 Ind./L. at YLC, YLB and YLA respectively and decreased further in post-monsoon to 1327 ± 68.05 ind./L, 1567 ± 90.28 ind./L and 1620 ± 88.09 ind./L. at YLA, YLB and YLC respectively. During the winter density increased to 1447 ± 137.6 ind./L, 1667 ± 174.9 ind./L and 1787 ± 187.8 ind./L at YLA, YLB and YLC respectively. Total zooplankton density showed significant seasonal variation at $P < 0.0001$ at all the three stations.

1. Rotifers

When separate groups are considered Rotifera was the dominant group among the four groups of zooplankton with 36.29 % biannual average density (Table 4B.1). Percentage density of Rotifera at YLA, YLB and YLC was recorded as 31.97 %, 33.20 % and 33.14 %.

Maximum density of rotifers (Table 4B.2, Fig. 4B.2) were recorded in summer. At YLA, it was 1158 ± 41 ind./L while at YLB and YLC it was nonsignificantly higher with 1180 ± 77.8 and 1340 ± 53.42 ind./L respectively. The density at all the stations decreased in monsoon and varied with 783 ± 76 ind./L at YLA, 973.3 ± 86.82 ind./L at YLC and 900 ± 85.01 ind./L at YLB. In post-monsoon it further decreased to 395 ± 28 ind./L at YLA, 483.3 ± 39.47 ind./L at YLB and 500 ± 59.1 ind./L at YLC. The density was almost maintained in winter when it was 444.5 ± 63 ind./L at YLA, 400 ± 61.97 ind./L at YLB and 493.3 ± 79.11 ind./L at YLC with $P < 0.0001$.

2. Microcrustacea

The microcrustacea includes the three groups: Cladocera, Copepoda and Ostracoda. Microcrustaceans as a whole had biannual average density of 63.76%. According to site distribution, YLB has 64.65 % of total microcrustacean followed by YLC with 63.16 % and YLA with 63.04 %. The total density of microcrustacea showed significant seasonal variations compared to rotifers and dominated throughout the study period. Its maximum densities were recorded in summer, with higher densities 1449 ± 17.59 ind./L at YLA , 1647 ± 28.13 ind./L at YLB and 1633 ± 24.04 ind./L at YLC (Table 4B.2, Fig. 4B.3). The density decreased in monsoon and varied between 1390 ± 62.23 ind./L at YLA, 1603 ± 54 ind./L at YLC. It was 14.33 ± 57.89 ind./L at YLB. Thereafter it was minimum in post-monsoon and altered within the range of 930 ± 53.81 ind./L at YLA and 1120 ± 58.42 ind./L at YLC. At YLB it was 1083 ± 57.14 ind./L. The density increased nonsignificantly in winter with 995.5 ± 78.28 ind./L, 1273 ± 113.8 ind./L, 1293 ± 112 ind./L at YLA, YLB and YLC respectively with significant seasonal variations at $P < 0.0001$.

2a. Cladocera

The cladocera was second dominant group among the four groups of zooplankton studied with 32.77 % biannual average density (Table 4B.1). Percentage density of Cladocera were 31.97 % at YLA, 33.20 % at YLB and 33.14% at YLC. It showed significant temporal variations with $P < 0.0001$.

Maximum density of cladocerans were also recorded in summer with 742.8 ± 13.63 ind./L., 853.3 ± 24.59 ind./L and 886.7 ± 12.59 ind./L at YLA, YLB and YLC respectively (Table 4B.2, Fig. 4B.4). The densities lowered in monsoon and ranged from 675 ± 29 ind./L at YLA, 713.3 ± 34.9 ind./L at the YLB and 826.9 ± 8.43 ind./L at YLC. Minimum densities were recorded during post-monsoon with 459.8 ± 26.17 ind./L , 570 ± 30 ind./L and 600 ± 34.25 ind./L at YLA, YLB and YLC respectively. In winter the densities increased nonsignificantly to 535 ± 50.93 ind./L, 653.3 ± 60.81 ind./L and 663.3 ± 58.06 ind./L at the three stations respectively.

2b. Copepoda

Copepoda were third quantitative component in domination of the total zooplankton. Its biannual average density was 25.55 % (Table 4B.1). The percentage density of Copepods varied from 26.17 % at YLA to 25.95 % at YLB and 24.53 % at YLC.

Highest densities of copepoda were recorded in summer. It was maximum at YLB (660 ± 8.94 ind./L) while minimum at YLA (599 ± 14.67 ind./L) and 606.7 ± 21.71 ind./L at YLC (Table 4B.2, Fig. 4B.5). It decreased in monsoon with nonsignificant differences among the three stations with 562.5 ± 3846 at YLA, 553.3 ± 31.69 at YLB and 600 ± 46.19 ind./L at YLC. Minimum densities were recorded in post monsoon, where YLA had 405.8 ± 25.84 ind./L, YLB had 420 ± 24.77 and YLC had 453.3 ± 22.31 copepods/L. Non-significant increase was noted in winter to 407.7 ± 32.42 ind./L, 546.9 ± 51.29 ind./L and 543.3 ± 50.18 ind./L at YLA, YLB and YLC respectively.

2c. Ostracoda

The density of ostracoda at all the three stations of Yashwant Lake were very poor and formed the smallest component of total zooplankton density. The biannual percentage density of Ostracoda was 5.29 %. The percentage density of Ostracoda varied from 4.90 % to 5.50 % and 5.49 % at the three stations respectively (Table 4B.1).

Contrary to all the zooplankton, maximum density of Ostracoda were recorded in monsoon. It was 152.2 ± 11.24 ind./L, 166.7 ± 12.29 ind./L and 206.7 ± 12.29 ind./L at YLA, YLB and YLC respectively (Table 4B.2, Fig. 4B.6). The densities decreased in post-monsoon and were 65.17 ± 14.02 ind./L, 93.3 ± 8.43 ind./L and 66.67 ± 8.43 ind./L at YLA, YLB and YLC respectively. It was recorded at minimum level in winter for YLA and YLB 52.83 ± 5.03 ind./L, 73.33 ± 6.66 ind./L respectively, but was higher than monsoon with 86.17 ± 12.29 ind./L at YLC. The density of Ostracoda almost doubled in summer to 106 ± 16 ind./L, 133.8 ± 8.43 ind./L at YLA, YLB while increased to 133.3 ± 28.6 ind./L at YLC. Significant seasonal variations were recorded in density of Ostracodes with $P < 0.0001$.

Rotifer density is positively correlated at the level of 0.01 with acidity, alkalinity, atmospheric temperature, Chloride, Carbon-dioxide, pH, Phosphate, TDS, TS, TSS and WT and negatively correlated at the same level with WC and DO among all the physico-chemical parameters studied at all the three stations (Table 4B.5). Among biotic parameters it is again positively correlated at 0.01 level with Bacillariophyceae, Cladocera, Dinophyceae, Ostracoda, SRTP, SRTZ and TDZ, while negatively with Euglenophyta, SRB and TDB (Annexture 5a, b, and c).

Table: 4B.1 Biannual average percentage of density of various groups of zooplankton at Yashwant Lake during Dec.2006 to Nov. 2008

Stations	Rotifer	Microcrustacea	Cladocera	Copepoda	Ostracoda
YLA	36.80	63.04	31.97	26.17	4.90
YLB	35.27	64.65	33.20	25.95	5.50
YLC	36.82	63.16	33.14	24.53	5.49
Biannual percentage	36.29	63.76	32.77	25.55	5.29

Table: 4B.2 Seasonal Variations in density of various groups of zooplankton (No. of individuals /Litre) at YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

Parameters	Stations with F value	Winter	Summer	Monsoon	Postmonsoon
Total zooplankton	YLA $F_{3\ 20}$ 33.21	1447 ± 137.6	2607 ± 56.02	2173 ± 133.3	1327 ± 68.05
	YLB $F_{3\ 20}$ 22.91	1667 ± 174.9	2827 ± 59.03	2333 ± 138.4	1567 ± 90.28
	YLC $F_{3\ 20}$ 27.50	1787 ± 187.8	2967 ± 59.70	2607 ± 118.8	1620 ± 88.09
Rotifer	YLA $F_{3\ 20}$ 40.04	444.5 ± 63	1158 ± 41	783.3 ± 76	395 ± 28
	YLB $F_{3\ 20}$ 28.60	400 ± 61.97	1180 ±77.80	900 ± 85.01	483.3 ± 39.47
	YLC $F_{3\ 20}$ 33.29	493.3 ± 79.11	1340 ± 53.42	973.3 ± 86.82	500 ± 59.1
Microcrustacea	YLA $F_{3\ 20}$ 21.39	995.5 ± 78.28	1449 ± 17.59	1390 ± 62.23	930.8 ± 53.81
	YLB $F_{3\ 20}$ 11.24	1273 ± 113.8	1647 ± 28.13	1433 ± 57.89	1083 ± 57.14
	YLC $F_{3\ 20}$ 13.50	1293 ± 112	1633 ± 24.04	1603 ± 54.08	1120 ± 58.42
Cladocera	YLA $F_{3\ 20}$ 15.30	535 ± 50.93	742.8 ± 13.63	675.3 ± 29.7	459.8 ± 26.17
	YLB $F_{3\ 20}$ 8.87	653.3 ± 60.81	853.3 ± 24.59	713.3 ± 34.90	570 ± 30
	YLC $F_{3\ 20}$ 15.23	663.3 ± 58.06	886.7 ± 12.29	826.7 ± 8.433	600 ± 34.25
Copepoda	YLA $F_{3\ 20}$ 12.09	407.7 ± 32.42	599.0 ± 14.67	562.5 ± 38.46	405.8 ± 25.84
	YLB $F_{3\ 20}$ 8.90	546.7 ± 51.29	660 ± 8.944	553.3 ± 31.69	420 ± 24.77
	YLC $F_{3\ 20}$ 3.58	543.3 ± 50.18	606.7 ± 21.71	600 ± 46.19	453.3 ± 22.31
Ostracoda	YLA $F_{3\ 20}$ 13.26	52.83 ± 5.036	106.7 ± 16.19	152.2 ± 11.24	65.17 ± 14.02
	YLB $F_{3\ 20}$ 20.53	73.33 ± 6.667	133.3 ± 8.433	166.7 ± 12.29	93.33 ± 8.433
	YLC $F_{3\ 20}$ 12.99	86.67 ± 12.29	133.3 ± 28.60	206.7 ± 12.29	66.67 ± 8.433

Figure: 4B.1 Seasonal Variations in density of total zooplankton (no. of individuals/L) at YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

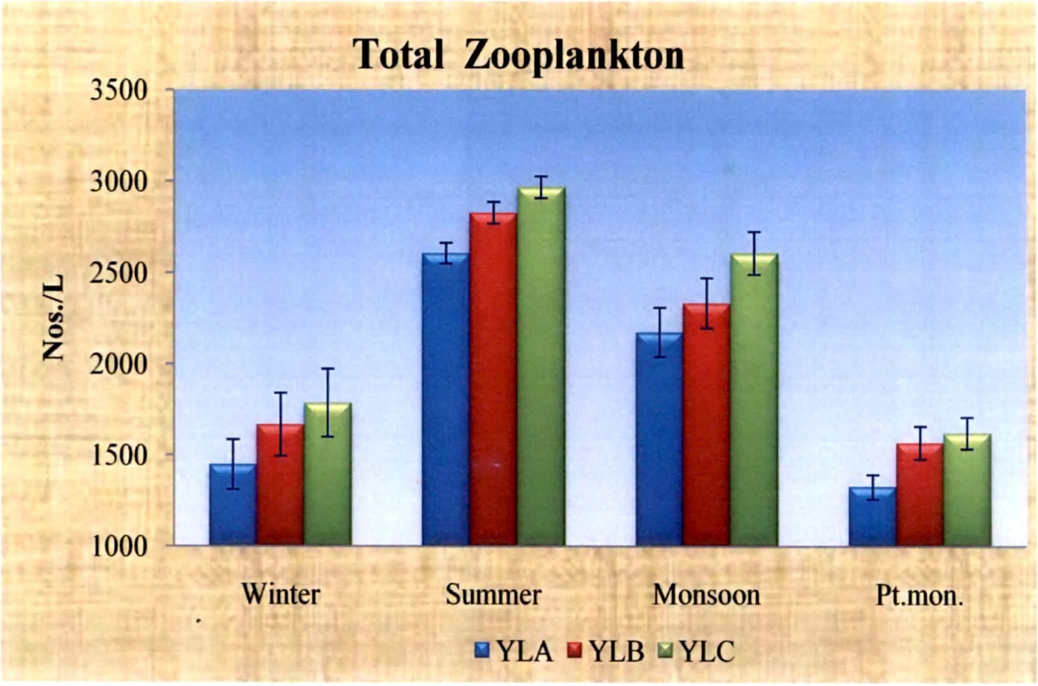


Figure: 4B.2 Seasonal Variations in density of Rotifers (no. of individuals/L) at YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

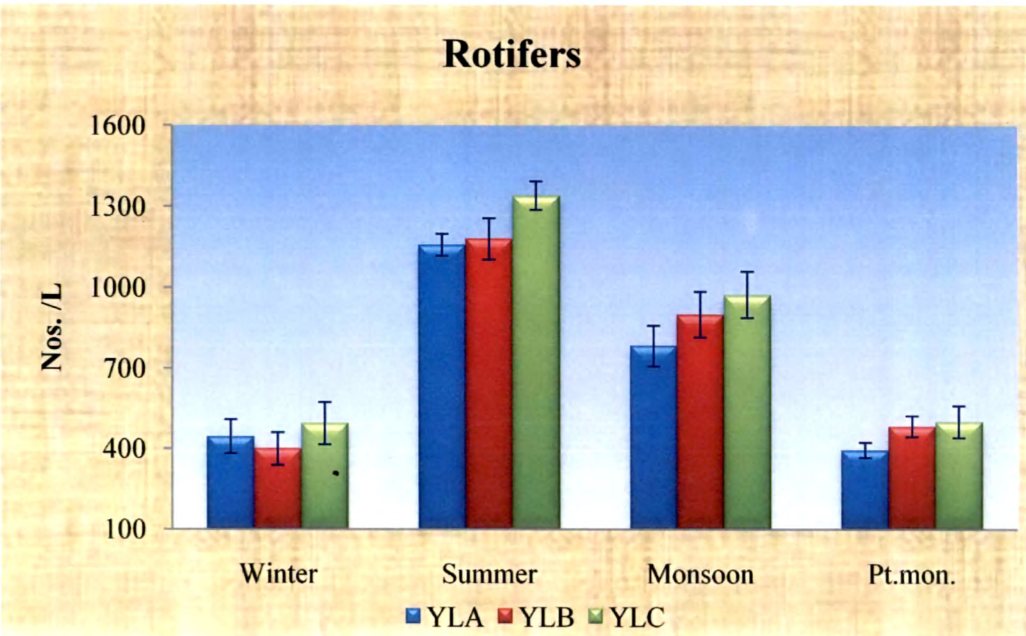


Figure: 4B.3 Seasonal Variations in density of Microcrustacea (no. of individuals/L) at YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

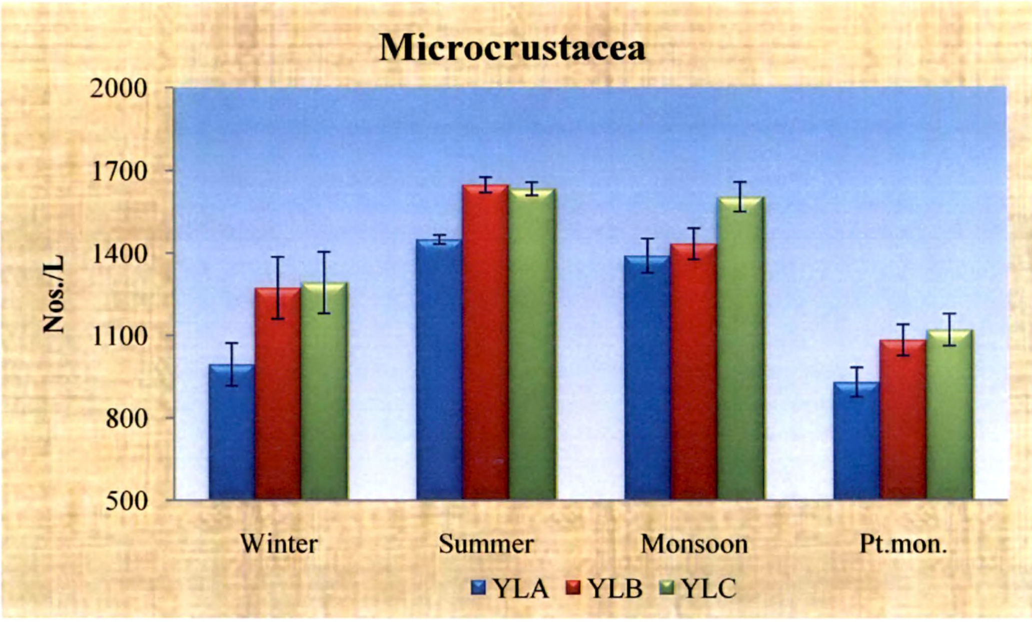


Figure: 4B.4 Seasonal Variations in density of Cladocera (no. of individuals/L) at YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

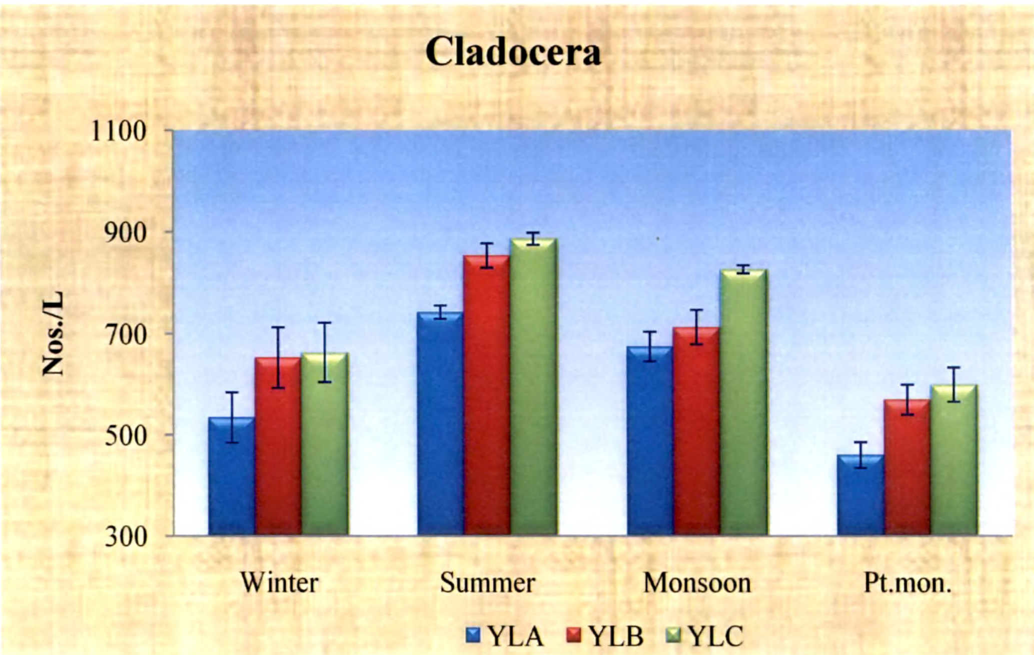


Figure: 4B.5 Seasonal Variations in density of Copepoda (no. of individuals/L) at YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

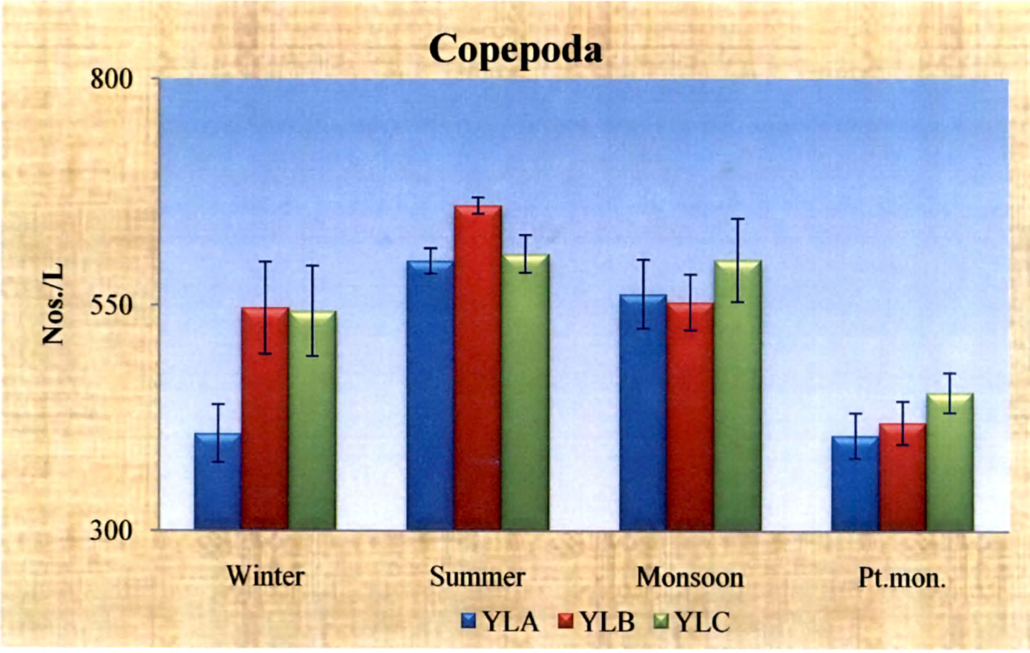
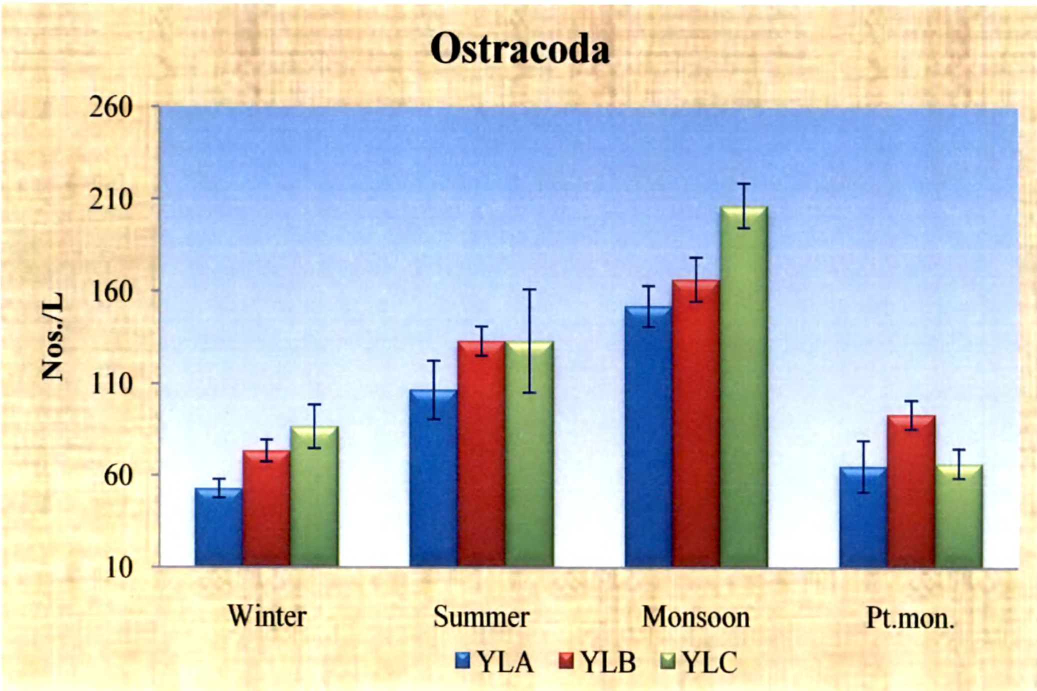


Figure: 4B.6 Seasonal Variations in density of Ostracoda (no. of individuals/L) at YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008



SPECIES RICHNESS

B. Total Zooplankton

As said earlier total 44 species belonging to 26 genera and of zooplankton taxa were identified during the two year study period, comprising four taxonomic assemblages Rotifera, Cladocera, Copepoda the common forms, and Ostracoda a poorly represented group (Annexture- II).

The species richness showed variations among the seasons. The percentage species richness of various zooplankton groups at Yashwant Lake showed same inclination as that of density] with Rotifers 55.36 % to 56.83% > 25.04 to 26.34 % Cladocerans > 11.39 to 12.8 % Copepoda > 5.62 to 6.12 % Ostracods (Table 4B.3).

Maximum species richness (Table 4B.4, Fig. 4B.7) was recorded in summer at all the three stations. At YLC it was maximum 35 ± 0.5 species whereas at YLA it was minimum 29 ± 0.96 species and at YLB it was 33 ± 0.9 species. Though it decreased in monsoon the decrease was more pronounced at YLB and YLC (28.38 ± 1.85, 30.8 ± 1.01 species each), compared to YLA (27 ± 1.06 species). In post-monsoon the species richness was 19 ± 1.48, 21 ± 1.21 and 24.5 ± 1.38 species at YLA, YLB and YLC respectively. Minimum species richness was observed in winter that differed between 15 ± 0.89, 17.17 ± 1.35 and 18.8 ± 1.01 species at YLA, YLB and YLC respectively.

1. Rotifera

The group rotifera appeared to be dominant qualitative component of total zooplankton species richness with 56 % biannual average species richness (Table 4B.3). The percentage species richness at the three stations ranged from 55.36 % at YLB to 56.02 % at YLA and 56.83 % at YLC. Out of 44 species of zooplankton noted at Yashwant Lake 24 species were rotifers.

Maximum species richness of rotifers was recorded in summer with 17.67 ± 0.66 species, 19.5 ± .67 species and 21.17 ± 0.74 species at YLA, YLB and YLC respectively (Table 4B.4, Fig. 4B.8). In monsoon, the species richness varied within 15 to 18 species with mean species richness 15.5 ± 0.99 at YLA, 15.67 ± 1.47 at YLB and 17.33 ± 0.8 species at YLC. In post-monsoon it was 11.17 ± 0.83 at YLA, 12.33 ± 0.95 at YLB and 15.5 ± 0.95 at YLC. Minimum species richness was recorded in winter with 6.16 ± 0.94, 7.33 ± 1.17 and 8.33 ± 1.05 at YLA, YLB and YLC respectively.

2. Microcrustacea

The major component of total zooplankton species richness that includes three groups viz. Cladocera, Copepoda and Ostracoda was represented by twenty species at Yashwant Lake with biannual average species richness percentage of 43.92 (Table 4B.3). The sitewise percentage species richness was 43.97 % at YLA, 44.63 % at YLB and 43.16 % at YLC.

Highest microcrustacean species richness (Table 4B.4, Fig. 4B.9) were recorded in summer at YLC (13.67 ± 0.42) and YLB (13.17 ± 0.4) whereas comparatively lower at YLA (11.33 ± 0.42). In monsoon, it varied from 11.67 ± 0.3 at YLA, 12.67 ± 0.42 at YLB and 13.5 ± 0.34 at YLC. Minimum species richness was recorded during post-monsoon at all the three stations ranging from 7.83 ± 0.74 at YLA, 8.66 ± 0.61 at YLB and 9.0 ± 0.63 at YLC. The species richness were non-significantly higher in winter, with 8.66 ± 0.21, 9.83 ± 0.3 and 11.17 ± 0.3 at YLA, YLB and YLC respectively. It showed significant seasonal variations with $P < 0.0001$.

2a. Cladocera

Cladocera formed second dominant qualitative component of total zooplankton at Yashwant Lake with 11 species and 25.83 % biannual average percentage at all the three stations (Table 4B.3). Its individual percentage species richness at the three sites were 25.04 % for YLA, 26.34 % for YLB and 26.13 % for YLC.

Maximum species richness of Cladocerans were observed in summer with marginal variations among the three stations. 11.3 ± 0.42 species were observed at YLA, 7.83 ± 0.3 at YLB and 8.6 ± 0.21species at YLC (Table 4B.4, Fig. 4B.10). In monsoon, it ranged from 7.3 to 11.6 with 11.67 ± 0.3 at

YLA, 6.83 ± 0.47 at YLB and 7.33 ± 0.21 at YLC. Minimum species richness were recorded in post-monsoon which varied from 7.83 ± 0.74 at YLA to 5 ± 0.25 species at YLB and 5.33 ± 0.21 at YLC respectively. The species richness increased in winter and reached to 8.66 ± 0.21, 6.5 ± 0.22 and 7.33 ± 0.33 at YLA, YLB and YLC respectively.

2b. Copepoda

Copepods were the third qualitative component of zooplankton. Out of 44 species of total zooplankton, six species belonged to Copepods with biannual average percentage of 12.14% (Table 4B.3). The percentage species richness at all the three stations were 12.80 % at YLA, 12.24 % at YLB and 11.39 % at YLC. Species richness of Copepods showed significant seasonal variations with $P < 0.0001$ at all the three stations.

Similar to the above two groups maximum species richness of Copepods were also recorded in summer with 3.66 ± 0.21, 4 ± 0 and 3.83 ± 0.16 at YLA, YLB and YLC respectively (Table 4B.4, Fig. 4B.11). In monsoon, it varied between 2.8 to 3.3 with 2.83 ± 0.3 at YLA, 3.16 ± 0.16 at YLB to 3.33 ± 0.21 at YLC. In post-monsoon, the copepod species richness was minimum as well as same at all the three stations with 2.16 ± 0.16 species. In winter, the species richness showed a marginal increase and were recorded as 2.8 ± 0.1 at two stations YLA and YLB and 3.1 ± 0.1 at YLC.

3. Ostracoda

Species richness of Ostracoda at Yashwant Lake was poor with only three species and biannual average percentage 5.92% (Table 4B.3). Percentage species richness of Ostracods varied between 6.12 % at YLA, 6.04% at YLB and 5.62 % at YLC. Ostracod species richness showed seasonal variations at $P < 0.0001$.

Contrary to the other three groups maximum ostracods (Table 4B.4, Fig. 4B.12) were recorded in monsoon with minor variations amongst the three stations (2.66 ± 0.21, at YLA and YLB to 2.83 ± 0.16 species at YLC). It declined in post-monsoon (1.5 ± 0.5 species) at all the three stations. Minimum in winter 0.33 ± 0.21, 0.5 ± 0.22 and 0.6 ± 0.21 species at YLA, YLB and YLC respectively as they were not observed all the visits and increased non-significantly in summer with 1.1 ± 0.0, 1.33 ± 0.21 and 1.16 ± 0.16 at YLA, YLB and YLC respectively.

Table: 4B.3 Biannual avarage percentage of species richness of various groups of zooplankton at Yashwant Lake during Dec.2006 to Nov. 2008

Stations	Rotifer	Microcrustacea	Cladocera	Copapoda	Ostracoda
YLA	56.02	43.97	25.04	12.80	6.12
YLB	55.36	44.63	26.34	12.24	6.04
YLC	56.83	43.16	26.13	11.39	5.62
Biannual percentage	56.07	43.92	25.83	12.14	5.92

Table: 4B.4 Seasonal variations in Species richness no. of species of various groups of zooplankton at YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

Parameters	Stations with F value	Winter	Summer	Monsoon	Postmonsoon
Total zooplankton	YLA $F_{3\ 20}$ 26.49	15.00 ± 0.894	29.00 ± 0.9661	27.00 ± 1.065	19.00 ± 1.483
	YLB $F_{3\ 20}$ 34.47	17.17 ± 1.352	33.00 ± 0.9661	28.33 ± 1.856	21.00 ± 1.211
	YLC $F_{3\ 20}$ 46.85	18.83 ± 1.014	35.00 ± 0.5774	30.83 ± 1.014	24.50 ± 1.384
Rotifer	YLA $F_{3\ 20}$ 34.26	6.167 ± 0.945	17.67 ± 0.6667	15.50 ± 0.991	11.17 ± 0.8333
	YLB $F_{3\ 20}$ 21.67	7.333 ± 1.174	19.50 ±0.6708	15.67 ± 1.476	12.33 ± 0.9545
	YLC $F_{3\ 20}$ 35.80	8.333 ± 1.054	21.17 ± 0.7491	17.33 ± 0.802	15.50 ± 0.9574
Micro- -crustacea	YLA $F_{3\ 20}$ 16.35	8.66 ± 0.21	11.33 ± 0.42	11.67 ± 0.3	7.83 ± 0.74
	YLB $F_{3\ 20}$ 23.42	9.83 ± 0.3	13.17 ± 0.4	12.67 ± 0.42	8.66 ± 0.61
	YLC $F_{3\ 20}$ 24.69	11.17 ± 0.3	13.67 ± 0.42	13.5 ± 0.34	9 ± 0.63
Cladocera	YLA $F_{3\ 20}$ 21.67	8.66 ± 0.21	11.33 ± 0.42	11.67 ± 0.3	7.83 ± 0.74
	YLB $F_{3\ 20}$ 12.55	6.500 ± 0.223	7.833 ± 0.3073	6.833 ± 0.477	5.00 ± 0.2582
	YLC $F_{3\ 20}$ 30.91	7.333 ± 0.333	8.667 ± 0.2108	7.333 ± 0.210	5.333 ± 0.2108
Copepoda	YLA $F_{3\ 20}$ 7.76	2.833 ± 0.166	3.667 ± 0.2108	2.833 ± 0.307	2.167 ± 0.1667
	YLB $F_{3\ 20}$ 27.89	2.833 ± 0.166	4.00 ± 0.0	3.167 ± 0.166	2.167 ± 0.1667
	YLC $F_{3\ 20}$ 15.29	3.167 ± 0.166	3.833 ± 0.1667	3.333 ± 0.210	2.167 ± 0.1667
Ostracoda	YLA $F_{3\ 20}$ 9.55	0.3333 ± 0.21	1.00 ± 0.0	2.667 ± 0.210	1.500 ± 0.5627
	YLB $F_{3\ 20}$ 12.46	0.5000 ± 0.22	1.333 ± 0.2108	2.667 ± 0.210	1.500 ± 0.3416
	YLC $F_{3\ 20}$ 12.12	0.6667 ± 0.21	1.167 ± 0.1667	2.833 ± 0.166	1.500 ± 0.4282

Figure: 4B.7 Seasonal Variations in Species richness (no. of species) of Total Zooplankton at YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

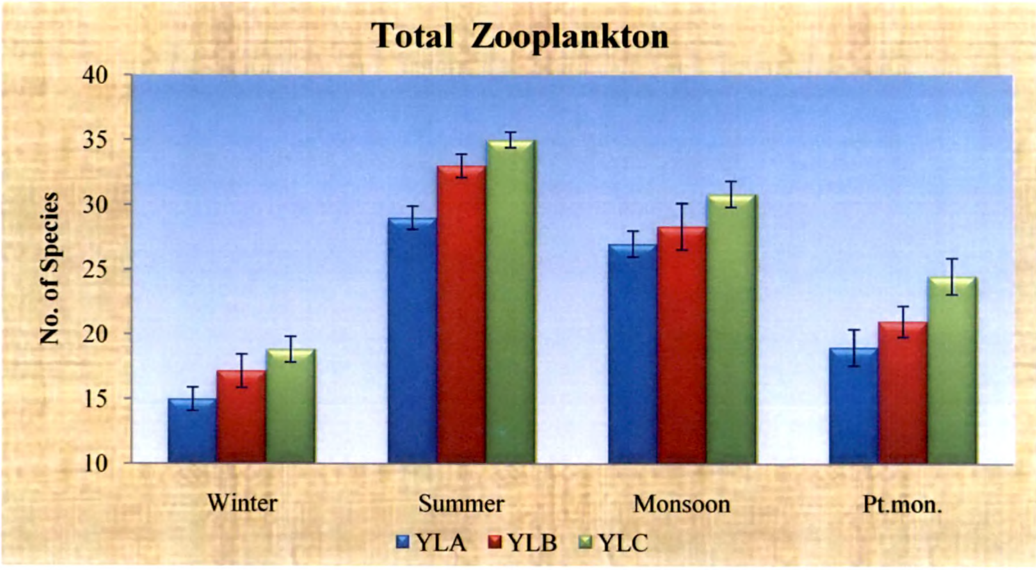


Figure: 4B.8 Seasonal Variations in Species richness of Rotifers (no. of species) at YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

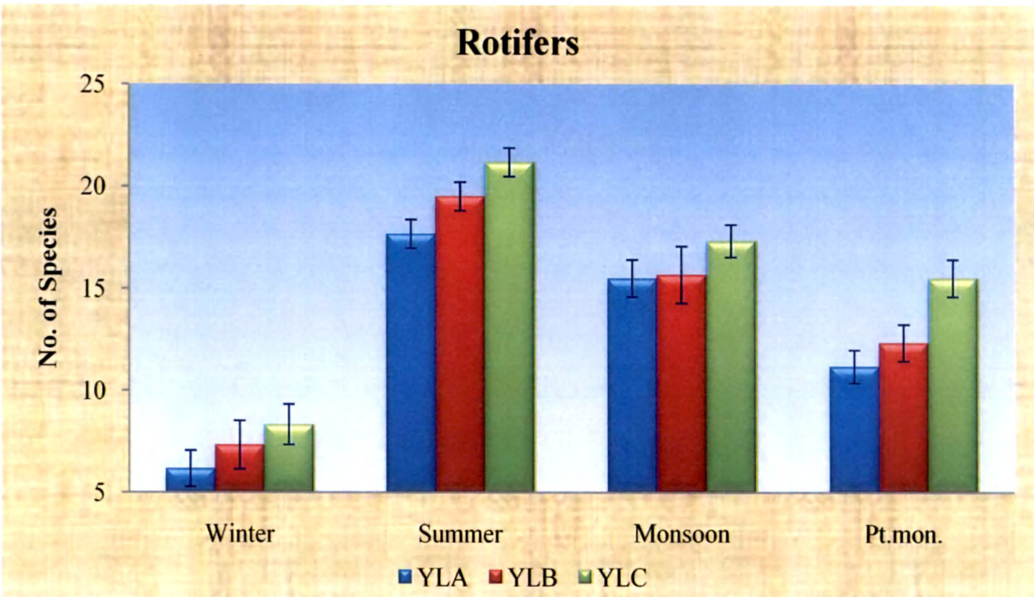


Figure: 4B.9 Seasonal Variations in Species richness of Microcrustacea (no. of species) at YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

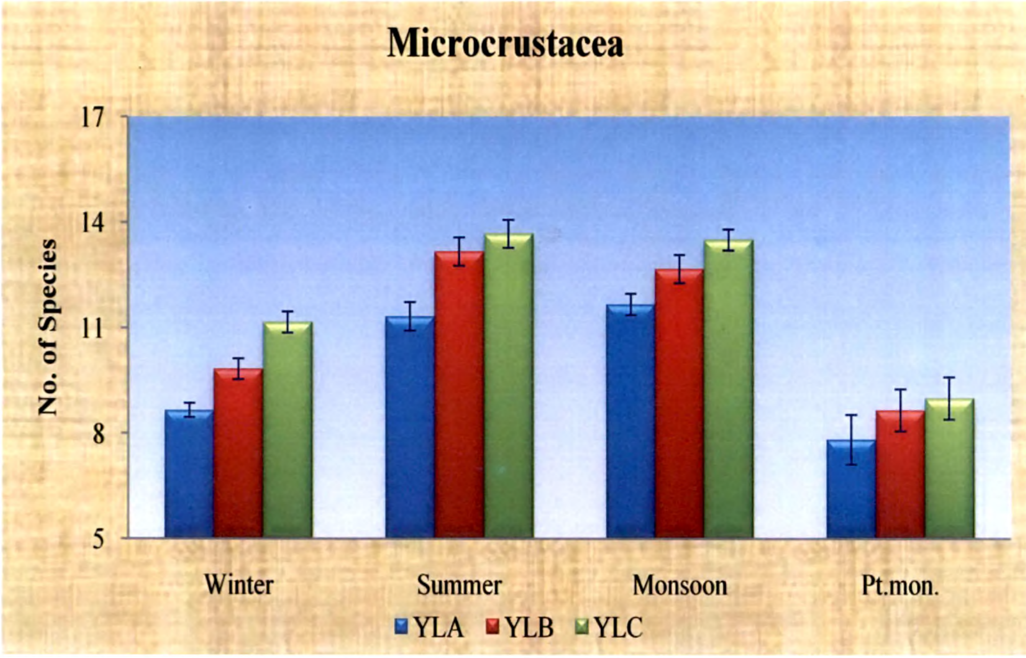


Figure: 4B.10 Seasonal Variations in Species richness of Cladocera (no. of species) at YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

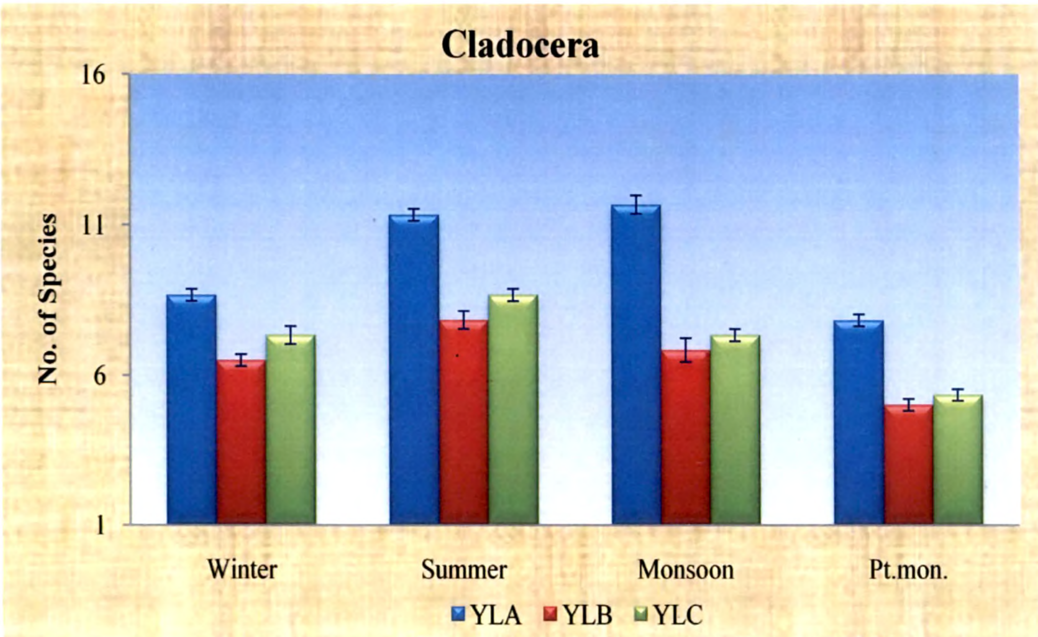


Figure: 4B.11 Seasonal Variations in Species richness of Copepoda (no. of species) at YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

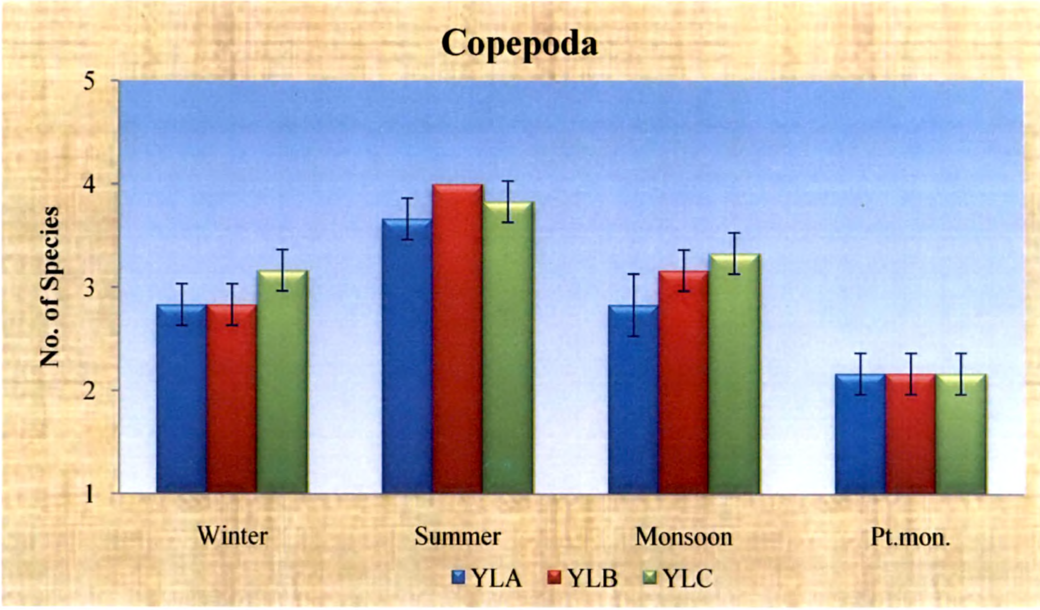


Figure: 4B.12 Seasonal Variations in Species richness of Ostracoda (no. of species) at YLA, YLB and YLC of Yashwant Lake during November 2006 to December 2008

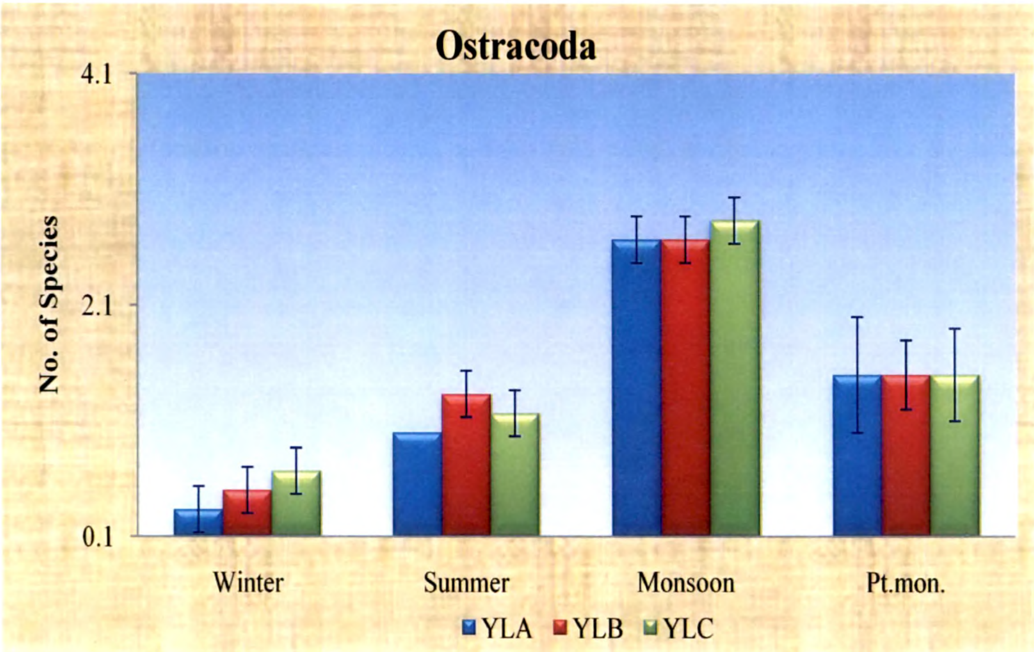


Table: 4B.5 Pearson correlation of total zooplankton density with abiotic parameters, total phytoplankton, molluscs and birds at YLA, YLB and YLC of Yashwant Lake during December 2006 to November 2008

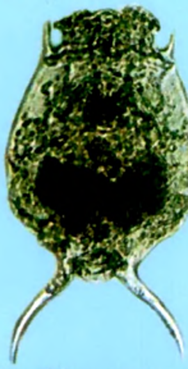
Sr.No.	Parameter	YLA	YLB	YLC
1	Acidity	.928**	.951**	.986**
2	Alkalanity	.837**	.870**	.950**
3	AT	.805**	.787**	.845**
4	Chloride	.955**	.958**	.971**
5	CO_2	.787**	.791**	.801**
6	DO	-.614**	-.642**	-.597**
7	NO_2^-	.461*	.276	.304
8	NO_3^-	-.143	-.349	-.275
9	pH	.899**	.899**	.911**
10	PO_4	.605**	.515*	.597**
11	WT	.855**	.782**	.888**
12	TSS	-.027	.118	-.039
13	TDS	.944**	.934**	.942**
14	WC	-.925**	-.926**	-.905**
15	TH	.374	.375	.411*
16	Trans.	-.266	-.211	-.340
17	TS	.716**	.716**	.713**
18	TDP	.841**	.635**	.879**
19	TDM	-.121	-.279	-.209
20	TDB	-.636**	-.623**	-.634**

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

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

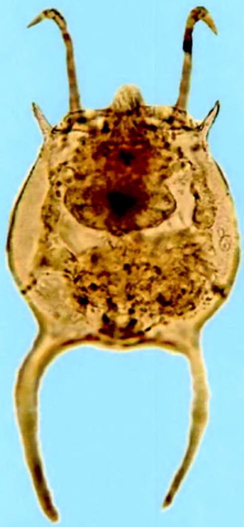
Plate No - 11

Some Representative Zooplanktons of Yashwant Lake



25 : Brachionous caudatus

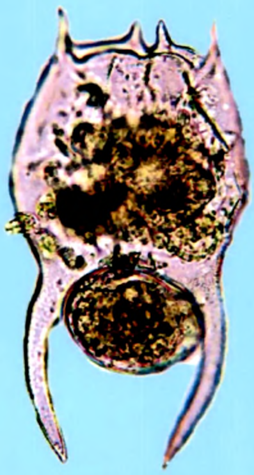
26 : B. quadridentatus



27 : B. fulcatus

28 : B. diversicornis

29 : B. plicatilis



30 : B. forficula

Rotifers - 25 to 30

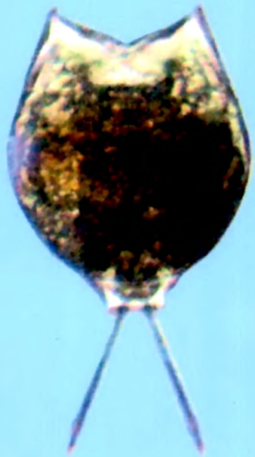
Plate No - 12

Some Representative Zooplanktons of Yashwant Lake

31 : B. calyciflorus

32 : Keratella tropica

33 : K. cochlearis



34 : Lacane luna

35 : Lacane ohioensis

36 : Monostyla bulla

Rotifers - 31 to 36

Plate No - 13

Some Representative Zooplanktons of Yashwant Lake

37 : Filinia longiseta

38 : Filina opoliensis

39 : Trichocerca spp.

40 : Rotaria neptunia

41 : Testudinella mucronata

Rotifers - 37 to 41

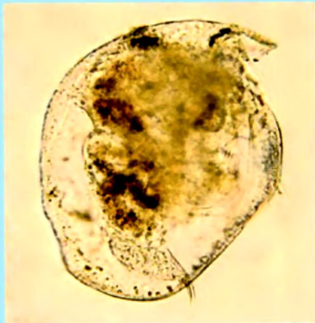
42 : Ceriodaphnia cornuta

Cladocera

Plate No - 14

Some Representative Zooplanktons of Yashwant Lake

43 : Alona rectangula



44 : Indialona ganpati

45 : Moina spp.

Cladocera - 43 to 45

46 : Mesocyclops spp.

47 : Ectocylops spp.

Copepoda - 46 to 47

48 : Eucypris spp.

Ostracoda

DISCUSSION

Density of total zooplankton

Zooplankton play a functionally important role in aquatic systems by consuming phytoplankton and bacteria and then releasing nutrients back in the ecosystem or by serving as prey for transferring nutrients to higher trophic levels (Hillbricht, 1977). The Zooplankton community composition in shallow water systems are not only influenced by predation (Donald *et al.*, 2001; Hampton and Gilbert, 2001) but also by, water chemistry and hydrology (Moss, 1994). Of the hydrology, the hydroperiod and water cover are the major physical factors responsible for formation of the various ecological communities (Shurin, 2000). According to Pennak (1946) and Bonecker and Lansac-Toha (1996) plankton are abundant during the slow water current, while rise in water brings about a sharp decline in their density. In the present study, at the higher altitudinal lake in the semi arid-zone of Maharashtra, India, the water level and the resultant water cover have proven to be the important factors in regulating the density of the plankton. Here at YSL, highest zooplankton density was noted during summer when the water level declines and the zooplankton get concentrated and *vice a versa* lowest during post-monsoon when the water level was high and plankton get distributed. Deshkar (2008) has made similar observations at irrigation reservoirs and village ponds at the plains of semi-arid zone of Gujarat. These regions depend on annual rainfall for their water requirement. When there is good rainfall during monsoon, the water level and the resultant water cover are maximum during the following post-monsoon (Chapter 3). During monsoon and post-monsoon the plankton get distributed in water which can lead to the decline in their density per litre. The influx of rain water is known to bring about dilution effects (Chapman, 1972; Davis, 1976). Further, turbidity can also cause death of plankton during rainy season leading to their lowest abundance (Michael, 1969; Sharma and Sahai, 1988) and, lower water temperature of winter probably also causes low abundance of zooplankton. Compared to post-monsoon a slow rise in total zooplankton density is noted at Yashwant Lake during winter an effect of stabilizing water level. Thus, the seasonal variations in total density of zooplankton were significant ($P < 0.0001$) at Yashwant Lake and a positive correlation is noted between water temperature and zooplankton density at the level of 0.01 (Table 4B.5). Sparrow (1966) and Vasisht (1968) have also shown a positive relationship between zooplankton population and water temperature.

Species richness of total zooplankton

In accordance to the density, the maximum species of total zooplankton were also observed in summer while minimum in winter at all the three stations (Table 4B.4). According to Mayagoitia *et al.*(2000) as observed in the semi-arid zone of temperate region (Spain), the rise in water level leads to the loss of macrophytes and hence loss of species leading to decline in species richness. The low water levels in summer, result in the emergence of macrophytes that serve as hiding places and new niches to the zooplankton (Beklioglu and Moss, 1996). The minimum species richness during winter may be attributed to low temperature in the semi-arid region of Maharashtra as well as higher altitude. Additionally the low species richness can also be attributed to the short photoperiod, less food production and low food availability to the herbivorous zooplankton species. At lower temperature, some of the species may enter into diapause condition (Wetzel, 2001) further declining species richness. After studying zooplankton composition of nineteen water bodies of Haveri district, Kudari *et al.* (2005) have also reported that maximum species richness occurs in summer. During this season, the absence of inflow of the water brings about stability to the water body and increases the food availability due to the organic matter production because of decomposition. The above factors contribute for high species diversity in summer.

The species richness of various zooplankton groups at YSL occurred in the decreasing order as Rotifera > Cladocera > Copepoda > Ostracoda. Here it is observed that the density and the species richness of various groups of zooplankton have similar tendency in their dominance as is also noted by Kudari *et al.* (2005) and Kiran *et al.* (2007).

1. ROTIFERA

Rotifer was the richest group at YSL with 24 species (Annexture-II), which accounts for 57 % of total zooplankton. It is known to dominate several water bodies (Neves *et al.,* 2003). This pattern is common in tropical and subtropical freshwaters irrespective of being a lake, pond, reservoir, river or stream (Neves *et al.,* 2003).

The rotifer community structure depends on a variety of environmental factors that include biological parameters, such as predation or competition, as well as various physico-chemical factors (Anna and Natalia, 2009). With the help of Canonical Correspondence Analysis (CCA), Bruno *et al.* (2005) have identified two main environmental gradients that shape up the rotifer assemblage, a temporal gradient- mainly related with the temperature and a eutrophic gradient. When the mercury goes down during extreme environmental conditions of winter the rotifers are also known to undergo diapauses (Schroder, 2005). This is the season when rotifer density was low at YSL too. However the increase in the density of rotifers in summer corresponds to decrease in water level that concentrated rotifers in shallow waters. Further, the littoral vegetation exposed during summer creates an ideal habitat for growth of the rotifers (Anna and Natalia, 2009; Pejler, 1995). Thus, Maximum numbers of rotifers seen during summer indicates the influence of temperature supported by positive correlation at 0.01 level (Table 4B.5) between temperature and rotifer density. This observation is corroborated by Kaushik and Sharma (1994); Sinha and Sinha (1983) and Singh (2000b). High temperature, duration of the day lenght intensity of sunlight during summer and accelerating phytoplankton are some of the limiting factors that have been correlated with the growth and abundance of rotifers (Alireza, 1995; Hujare, 2005). Bacterioplankter and phytoplankton are important food resources for rotifers (Devetter and Sed'a, 2003). In the present investigation the rotifer density is positively significantly correlated with total phytoplankton density (Table 4B.5) too.

The seasonal pattern in the rotifer communities is difficult to interpret, although with the abundance there is a tendency for increase in rotifer species richness during summer (Bruno *et al.*, 2005). As said earlier, in the present investigation, the rotifers dominated YSL with total maximum 24 species in summer. Among various genera of rotifers, *Brachionus* was the most dominant genus followed by *Keratella* in Yashwant lake throughout the study period (Annexture-II). The genus *Keratella* also contribute to significant fraction of rotifer population in the Yashwant lake with 3 species. Among these *Keratella tropica* was numerically higher than *Keratella cochlearis*. According to Goel and Chavan (1991), the species of genus *Keratella* and genus *Brachionus* are the pollution tolerant species and indicate accumulation of organic matter. Dadhich and Saxena (1999) have reported abundant population of *Brachionus* in both eutrophic and mesotrophic lakes. Among the other genera, genus *Trichocera* and some species of genus *Filina* noted at YSL are reported to occur in eutrophic environment (Ruttner-Kolisko, 1974) while genera *Lecane* and *Trichocera* have been shown to provide large contributions in terms of abundance and richness in macrophyte associated habitats (Green, 2003). Further, *Testudinella* is considered to be littoral genus (Pontin, 1978). All these genera were recorded in YSL water (Annexture- II). As said earlier for phytoplankton (Chapter 4A) the diversity of zooplankton also indicates potential for eutrophication at Yashwant Lake.

When the three different stations of YSL were considered more species were noted at station YLC which has good macrophyte coverage compared to station YLA and YLB. Kuczỳnska-Kippen (2000) stated that the rotifers are typically littoral and that few species are purely pelagic. This is probably a consequence of the spatial heterogeneity of littoral habitats, which allows them to sustain themselves as a greater diversity of forms. The macrophyte habitats are usually richer in terms of rotifer taxa than euplanktonic (pelagic) environments (Green, 2003). At station YLA which has a pelagic environment, *Keratella* sp. dominated. George (1961) reported that these loricate forms prefer water of higher alkalinity as is noted for YSL (Chapter 3).

The variations in correlation among the three stations noted with reference to biotic components like Chlorophyceae, Euglenophyta, Copepod and Cyanophyceae, Ostracods and Molluscs and among physico-chemical parameters with TH, TSS (Annexture Va, Vb and Vc) may be associated with difference in the microhabitat available at the three stations *i.e.* rocky shore with human disturbances at station YLA, machrophytes with forest on the neighbouring land at station YLB and macrophytes with agriculture land at station YLC.

Rotifers are considered as ideal indicators of water quality assessment (Berzens and Pejler, 1989). More work is still required to designate regional indicator species from different parts of India. It is presumed that rotifers utilize the nutrients as well as phytoplankton more rapidly to build up their population. This may be the reason for the worldwide distribution of rotifers (Pennak, 1978).

2. MICROCRUSTACEA

Littoral and limnetic habitats of various freshwater ecosystems are colonized by microcrustacea which includes Cladocera, Copepodes and Ostracoda. At all the three stations of Yashwant Lake the total density of zooplankton was mainly due to microcrustaceans. As expected the Crustacean density was high during summer when the water level is minimum in the semi-arid region of Maharashtra, India. As water level recedes, the resultant emergent macrophytes serve as hiding places for these microcrustaceans (Beklioglu and Moss, 1996). Further, during post-monsoon, in Yashwant Lake, water continues to arrive on one side through streams and leave via spillway creating a somewhat lotic condition. This condition is less preferred by the crustaceans (Baranyi *et al.,* 2002) and thereby the crustacean density was lowest during post-monsoon. Group wise variations in microcrustacean densities and diversities were noted at all the three stations of YSL.

2a. CLADOCERA

Cladocerans also show seasonal fluctuations (Kaushik and Sharma 1994; Sharma and Sharma 2009). As noted for rotifers, the maximum density of Cladocera was also recorded in summer and minimum in post-monsoon that can be correlated with water level/ cover. It has been reported that the density and biomass of Cladocerans is primarily determined by food supply (Wright, 1954; Singh, 2000b). With rising temperature in summer the food supply in the form of algae, detritus and bacteria is available which leads to an increase in Cladocerans population. In addition the overwintering adults or resting eggs of Cladoceran also become active as the temperature increases resulting in faster rate of moulting and brood production with increase in food supply that can results in rise in the number of eggs per brood (Wetzel, 2001). Quadri and Yousuf (1978) have also reported that the temperature is the primary factor affecting the occurence and distribution of Cladocerans. In present study the Cladoceran density is significantly positively correlated with total density of phytoplankton and water temperature as well as water cover (Annexture Va, Vb and Vc). The minimum population of Cladoceran in post-monsoon may be attributed to the dilution factor.

The seasonal succession of the Cladocera is quite variable, both among species and within a species that live in different lake conditions. Some species are perennial and overwinter in low population densities as adults (parthenogenetic females) rather than as resting eggs (Wetzel, 2001).

Cladocerans constitute important links in limnetic as well as benthic food chains *eg. Daphnia* and *Moina.,* while *Diaphanosoma,, Chydorus, etc.* are indicators of eutrophication (Mahajan, 1981). The most frequent cladocerans at YSL were *Diaphanosoma* species, *Ceriodaphnia cornuta* and *Moina micrura.* In littoral zone, the members of family Chydoridae represented major component. These organisms are usually associated with macrophytes, periphyton or sediment (Wisniewski-Santos *et al.,* 2002). Of these the *Cydorus* species was frequently recorded at station YLB and station YLC where the macrophytes are maximum in numbers but rarely at station YLA with rocky bottom.

The effect of temperature on Cladocerans has implication from the viewpoint of species distribution, body size and abundance (Stockwell and Johannsson, 1997). Most temperate water bodies contain Cladoceran genera like *Daphnia* and *Basmina* among herbivore taxa and *Leptodora* and *Cercopagic* among predatory taxa (Dumont and Negrea, 2002). In contrast tropical water bodies typically contain genera *Moina, Ceriodaphnia*, *Macrothrix* and *Diaphanosoma* all of which are predominantly herbivorous taxa (Dodson and Frey, 2001). These four genera of tropics were also recorded in the Yashwant lake (Annexture-II) the higher altitude lake.

The other parameters of the present study showed that the reservoir is of a better quality (Chapter 3) although there is a need of continuous monitoring to maintain quality of the water. The results indicate that the maximum number of genera occurred during summer than in post-monsoon. Among Cladoceran zooplanktonic population in general, low population of perennial species and a near absence of aestival species in winter are common. In present investigation moderate species richness is recorded in winter.

As noted for Rotifers, Cladoceran density is also positively correlated at the level of 0.01 with various physicochemical parameters except AT, NO_2^-, TH and Transparency and correlated variously with biotic component at the three stations with respect to their microhabitats according to substratum, vegetation and anthropopressures.

2b. COPEPODA

As noted for other groups, and also reported by Chauhan (1993); Chapman (1972); Govind (1978) the effect of water level was seen on Copepod density with minimum density in post-monsoon when they get distributed and maximum in summer when they get concentrated in shallow waters. Further, the life cycle of limnetic cyclopoid copepods is determined by water temperature, photoperiod, food availability and predation too (Wetzel, 2001). Hence, higher water temperature in summer may also be favorable for the growth and reproduction. In summer nutrients get concentrated increasing the productivity and also food availability in the form of phytoplankton (Goswami and Selvakumar, 1977). Phytoplanktons are positively correlated with copepod abundance at YSL. Most cyclopoid copepods are carnivorous and influence the population dynamics of the other copepods by predation. They also influence their own dynamics by cannibalism, especially of juveniles (Wetzel, 2001). In the present study copepods also showed positive correlation with the rotifer population during the study period, indicating their differential food preference in the reservoir. These groups also showed positive correlation with some algal groups (Annexture Va, Vb and Vc).

Watanabele *et al.* (1993) has reported that the copepods are excellent food for zooplanktivorous fish and their nutritional value is also very high. Hence, it is suggested that abundant population density of copepods in Yashwant lake may be favorable for pisciculture practices too.

With reference to abiotic factors a limited influence was noted on the copepod abundance. According to Das *et al.* (1996) copepods favour more stable environments and generally are regarded as pollution sensitive taxa as they disappear from polluted waters. This indicates that Yashwant Lake is not a polluted aquatic habitat. However, pollution tolerant taxa are also found in this Lake. Das *et al.* (1996) have established a positive correlation between zooplankton densities, pH and alkalinity which holds true in present study too (Table 4B.5). As far as species richness is considered total six species of copepod were noted at YSL of which five were cyclopoid and one calanoid. Among these two groups the copepod *Cyclops* dominated the lake both in quality and quantity. It is well established that eutrophication leads to decrease in the percentage of calanoid copepods, while promotes the development of cyclopoid copepods among the crustacean community (Maier, 1996; Kasprzak and Koschel, 2000). Further, this again gives indication of beginning of pollution which may lead to eutrophication. However, Geoff and Daniell (2007) have discussed human related issues with reference to copepod, as the role of copepod as intermediate host for variety of parasites. Species of *mesocyclops* are intermediate host for guinea worm (*Dracanculus medinensis*), a debilitating nematode parasite. Guinea worm though less prevalent in recent times remains a major health problem, particularly in W. Africa and India. The role of these Copepods with reference to human related issues needs to be evaluated. Further, free living copepods can be voracious predators. This functional role has been explained in the use of *Mesocyclop sp.* as biological control agents against mosquitoes, which spread disease such as malaria and dengue. Considering the importance (economic and ecological) of this group continuous monitoring of the water body is essential along with monitoring the occurence of parasitic disease in the area.

2c. OSTRACODA

Ostracods are mainly benthic macroinvertebrates (Chakrapani *et al.*, 1996). Compared to other zooplanktonic groups the maximum density of Ostracods in monsoon may be attributed to the inflow of rain water creating water current and turbulance because of which the benthic ostracods are disturbed and come to the surface. Being benthic in nature, plenty of dead organic matter brought to the water body with rain runoff may help in the growth of ostracods and hence increase their density. The dependency of ostracods on organic matter is reflected by their low density in summer when water level is stable and no mixing of water is noted and water temperature is moderate. Kaushik and Sharma (1994) reported that ostracods occur in greater number when the temperature of the reservoir is 20 °C. At YSL average water temperature was around 20 °C in monsoon while 22 °C in summer which is favourable for plankton in general but in winter when the water level and water current are well stabilized the temperature at YSL is around 18 °C temperature which does not favour the benthic ostracods (Padmanabhan and Belagali, 2008). Further, Talsande and Attigre reservoir in South Indian tropical climate where temperature fluctuations are negligible Hujare (2005) could not show any seasonal trend in ostracod occurrence.

The Ostracods are known to grow well in hard water (Harshey *et al.,* 1987). The total hardness of YSL water ranged between 49.3 ± 2.1 and 67.6 ± 1.4 which is considered as soft water which may be attributed to lower density of ostracods. At YSL the Ostracods and the total hardness were not significantly correlated (Annexture Va, Vb and Vc). The concentration and composition of dissolved ions within a freshwater body are influenced by precipitation-evaporation ratio as well as rock water interactions, both at surface and ground levels (Gibbs, 1970; Hem *et al.,* 1990). All these reactions are responsible for increase in $CaCO_3$ which increases Mg/Ca ratio. This type of environment provides Ostracods with sufficient $CaCO_3$ to make their shells (Joan and Gajewski, 2005). Such conditions are available at YSL in monsoon only and hence probably to high density of Ostracods were observed in monsoon only.

There are nearly 1700 species of Ostracods recorded in the world out of which nearly one third occur in freshwaters (Edmondson, 1959). The knowledge on Ostracod fauna of Maharashtra is rather poor as ZSI records of freshwater ostracods of Maharashtra include only 38 species belonging to 15 genera spread over 4 families (Patil and Talmale, 2005). In present study also only three species of Ostracods were recorded. These are *Cypris subglobosa, Hemicypris species* and *Strandesia labiata.*

As noted for rotifers, ostracod density is also positively correlated at the level of 0.01 with various physicochemical parameters except DO, NO_3^-, TH and it is negatively correlated at the same level with transparency and water cover (Annexture Va, Vb and Vc) and were variously correlated with biotic components at the three stations with respect to their microhabitats.

The present study was the first attempt to investigate the status of this reservoir at higher altitude. The reservoir plays a very important role in maintaining the biodiversity of the area. More information concerning zooplankton and their biological characteristics and their interaction with physico-chemical parameters of the reservoir is necessary for proper understanding and management of the ecosystem so that the aquatic fauna get more suitable environment for living.