

Full Length Research Paper

Spatio-temporal variation of the zooplankton community in a tropical wetland (Bhoj Wetland), Bhopal, India

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Bhopal, the capital city of the state of Madhya Pradesh, India is famous for its numerous lakes. The Bhoj Wetland is a wetland of international importance (Ramsar Site). In the two years of study period, a total of 82 zooplankton species were recorded from February 2008-January 2010. Out of which 66 species were recorded in the 1st year (2008-2009), and 70 species documented during the 2nd year (2009-2010). The zooplankton population belongs to five major groups namely: Rotifera (46%), followed by Cladocera (34%), Protozoa (10%) and Copepoda and Ostracoda contributing 6 and 4%, respectively. With regards to Rotifera, in the major peak of June 2009 (38 species), was dominated by the various species of *Brachionus* and *Keratella*. The population density data revealed that cumulative site mean density ranged from 84 to 1579 Ind. l⁻¹, with an overall mean of 399 Ind. l⁻¹. The 24 months of mean site density indicated a major peak of 1579 Ind. l⁻¹, in June 2009, with 47 and 43% contribution from Copepoda and Rotifera. However, among Copepoda, *Cyclops* and Nauplius larvae were major contributors to this peak and among Rotifera, *Brachionus caudatus* and *Keratella tropica* were dominant contributors. The comparative cumulative mean data on zooplankton in Bhoj Wetland indicate that during the 1st year, the diversity was 31 species and 30 species in the 2nd year. The mean density, during the 1st year was 276 Ind.l⁻¹ that increased to 468 Ind.l⁻¹ in the 2nd year. This variation in density during two years may be attributed low water volume caused by drought conditions in the second year. Bhoj wetland is under eutrophic state as a result of human stress in the catchment area. Further, increase of plant nutrients in the wetland waters is deteriorating its ecological condition. Hence, it is imperative to focus on preservation of these endangered habitats to achieve ecological sustainability.

Key words: Zooplankton, diversity, density, indicator species, BhojWetland.

INTRODUCTION

Water is one of the basic needs of mankind and is vital to all forms of life, it exist in lentic and lotic habitats. Tropical wetlands have played an important role for humankind

(Junk, 2002; Bhat et al., 2014). These are characterized by a large number of ecological niches and harbour a significant percentage of world's biological diversity. Wetlands

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are among the most productive ecosystems in the world (Thomas and Deviprasad, 2007). Wetlands are highly productive systems which support diverse plant and animal communities. They are shallow and can warm up quickly, and aquatic vegetation can thrive, because light frequently penetrates to the bottom of the water column. The aquatic vegetation creates ideal habitat for invertebrates, fish and waterfowl. Wetlands are highly variable systems, differing in water flow, depth, extent and type of vegetation and available nutrients (Lougheed and Chow-Fraser, 1998). Zooplankters are the microscopic, free-swimming animalcule components of an aquatic ecosystem, which are primary consumers on phytoplankton. Zooplankton community is cosmopolitan in nature and they inhabit all freshwater habitats of the world. Zooplankton diversity and density refers to variety within the community (Jalilzadeh et al., 2008). Verma and Munshi (1987) have suggested that zooplankton provide the main food item of fishes and can be used as indicators of the trophic status of a water body.

Rotifers, cladocerans, copepods, protozoa and ostracods constitute the major groups of zooplankton. Zooplankton plays an important role in energy transfer and occupies a central position in the trophic link between primary producers and higher trophic levels (Tunde, 2009). The influence of environmental factors, chemical conditions of hydro-geology of aquatic ecosystem cause changes in the composition of zooplankton and influence their densities, and so, they are also termed as bioindicators of the physical and chemical conditions of aquatic environments. The members of zooplankton are important for their role in the aquatic food chain (Cadjoet et al., 2007). The factors on the basis of bioindicators are evaluated through the qualitative and quantitative condition, relative success, community structure (composition) trophic structure or environmental heterogeneity and species interactions (Holyoak et al., 2005). According to Ferrar (1972), the primary productivity fluctuates with changes in environmental factors and grazing by zooplankton. Trivedi et al. (2003) disclosed that places of low zooplankton population usually have rapidly multiplied phytoplankton population. Zooplankton distribution is non homogenous. Some are mainly found in the littoral waters while others are in selected limnetic waters. Hakanson et al., (2003) attributed this to food availability and avoidance of predators. The review of limnological literature indicates limited information available on the ecology, diversity and role in aquatic productivity of inland aquatic environs of India (Sharma and Sharma, 2008). The dominant species and their seasonality are highly variable in different ecosystem according to their nutrient status, age, morphometry and other location factors (Rajashankar et al., 2009).

The objectives of this study are i) to study the fluctuations of zooplankton abundance of the Bhoj Wetland, ii) to understand the impact of pollution on zooplankton community in the Bhoj Wetland. In this investigation, the data of zooplankton density and diversity in a tropical wetland system (Bhoj Wetland) was studied for two years.

Study area

Bhopal, the capital city of the state of Madhya Pradesh, India is famous for its numerous lakes. Of these, the most important are the Upper and Lower Lakes, which have commonly been designated as Bhoj Wetland (Figure 1). The Bhoj Wetland is a wetland of international importance. The Upper Lake basin comprises of a submergence area of about 31.0 sq. km and a catchment area of 361 sq. km., whereas the Lower Lake basin comprises of a submergence area of 0.9 sq. km and catchment area of 9.6 sq. km. While Lower Lake is surrounded on all sides by dense urban settlements, only about 40% of the fringe area of Upper Lake has dense human settlement and the rest is sparsely populated having cropping as the major land use. The Upper Lake spread over longitude 77°18'00" to 77°24'00" E and latitude 23°13'00" to 23°16'00" N, whereas the considerably smaller Lower Lake is spread over 77°24'00" to 77°26'00" E and latitude 23°14'30" to 23°15'30" N. The Upper Lake was created in the 11th century by constructing an earthen dam across Kolans River, the main feeding channel of the lake with the objective of supplying potable water for the city dwellers. The wetland also supports a wide variety of flora and fauna. Several species of phyto and zooplankton, macrophytes, aquatic insects, amphibians, fishes and birds (resident as well as migratory) are found in the Bhoj Wetlands. Considering its ecological importance, Ramsar site was declared by the Government of India in 2002. Increasing anthropogenic activities in the catchment during the second half of the last century has resulted in environmental degradation of the wetland.

Investigations on the ecology of Bhoj wetland of Madhya Pradesh indicate that this man-made wetland is under severe degradation pressure. Siltation, solid waste disposal and weed infestation, dumping of agricultural waste, hospital waste disposal and idol immersion in the wetland during the festival season pollutes the wetland ecosystem beyond the tolerable limits of any aquatic system.

MATERIALS AND METHODS

Water samples were collected on monthly basis for a period of two year. For the present study, nine sampling points in the Bhoj Wetland were selected and each point, taking into account the human activities such as washing, bathing, fishing and boating, etc. the outlets, inlets, morphometric features and growth of aquatic vegetation etc., and other important factors considered during the selection of the sampling sites (Table 1).

The water samples were collected in one liter polyethylene canes of the surface waters by the boat between 8 am to 12 pm from the selected sites during first week of every month of the Bhoj Wetland. For the quantitative analysis of zooplankton, water was collected from the surface with minimal disturbance and filtered through a No. 25 bolting silk cloth, net of mesh size 63 µm. Ten liters of water were filtered and concentrated to 100 ml and were preserved by adding 2ml of 4% formalin simultaneously. The quantitative analysis of zooplankton was done by using Sedgwick-Rafter cell with dimensions of 50mm x 20mm x 1mm, following the method given in

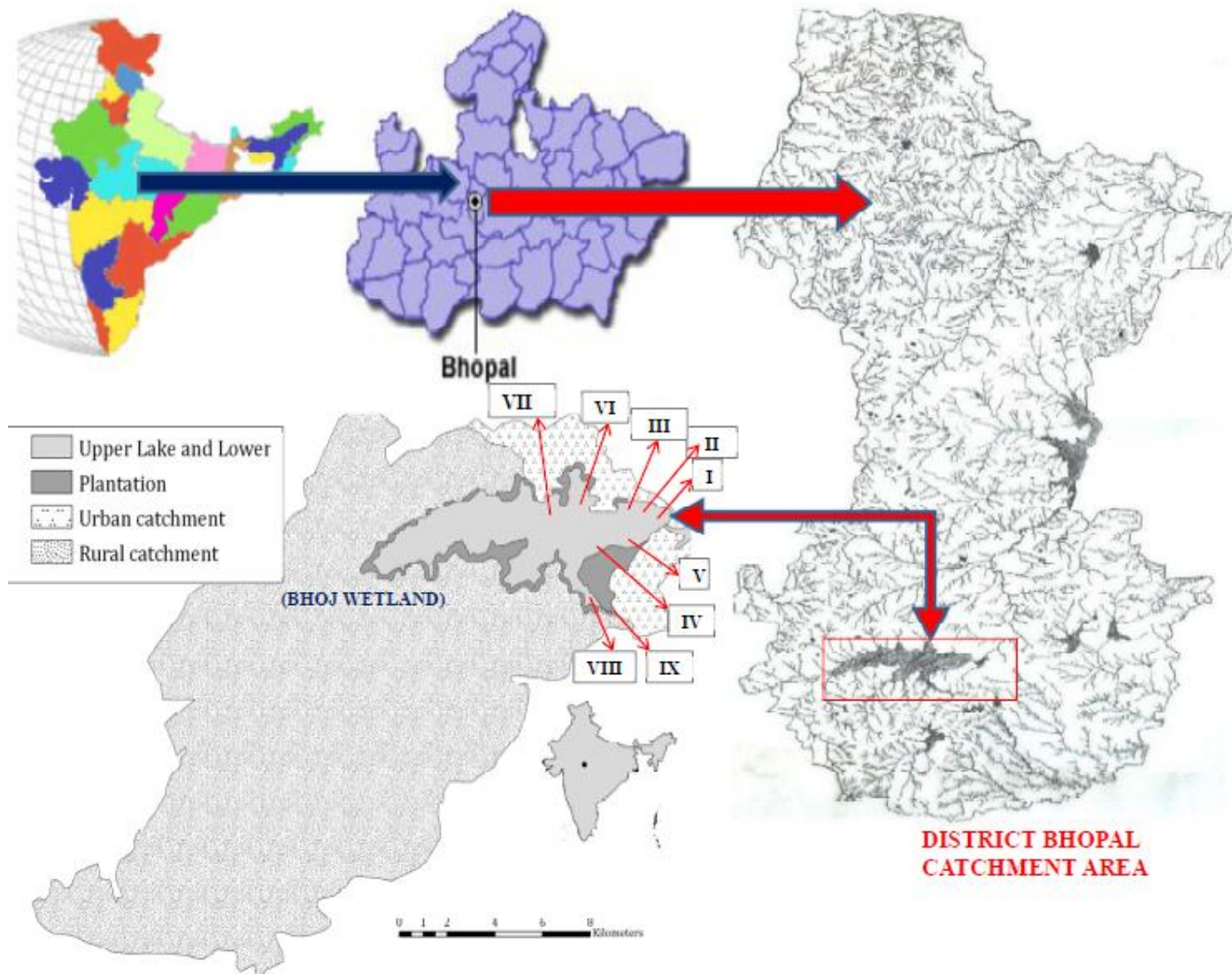


Figure 1. Map of India indicating location of Madhya Pradesh State and also indicating location of study area (Bhoj wetland), Bhopal.

Table 1. Some of the features of the sampling sites.

| Station no./name | Description of the stations |
|--|--|
| Station 1 (Kamla Park) | This station is situated on eastern end of the wetland. It is subjected to maximum anthropogenic pressure. The Idol immersion activity at this site has been reduced after developing Prempura Ghat particularly for immersion activity. |
| Station 2 (G. Medical College) | It is situated close to the inlet of Shaheed Nagar Nallah adjacent to Gandhi Medical College. |
| Station 3 (Koh e Fiza) | There is an intake point for water supply in this area. This station is also the site of Tazia immersion. |
| Station 4 (Van Vihar) | This station represents the area that comes under protected forest (Van Vihar). The station is comparatively free from human intervention and other anthropogenic activities. |
| Station 5 (Yatch Club) | This is the boating station, where maximum human interaction takes place. Tourists start their motor and paddle boats from this station, and a crowd of tourists can be observed from morning till evening at this station. |

Table 1.Contd

| | |
|------------------------------------|--|
| Station 6 (Bairagarh) | This station of Bhoj Wetland is situated near Bairagarh where substantial inflow of domestic sewage can be seen. The area has become shallow due to high density of free floating, emergent, and submerged macrophytes. |
| Station 7 (Sehore side) | A lot of agricultural land surrounds this station in Bhoj Wetland. Most of the catchment area consists of agricultural land. Because of this all the fertilizers, pesticides and agricultural residues used in the fields find their way as run off into the wetland waters. |
| Station 8 (PrempuraGhat) | This is the Idol immersion station. During the Hindu religious festivals, lots of idols are immersed in water. |
| Station 9 (Nehru Nagar) | This station is highly influenced by anthropogenic and cattle activities. The run-off from the catchment area adds nutrients to the wetland. The region is covered with high density of emergent/submerged macrophytes. The run-off from the catchment area also adds considerable quantities of nutrients to the wetland. |

APHA (2000). 1 ml of concentrated sample was taken in a Sedgwick-Rafter counting cell and the entire contents were counted. The identification of aquatic biota (zooplankton) was done following the standard works and methods of Edmondson (1959), Needham and Needham (1962), Pennak (1978), Victor and Fernando (1979), Michael and Sharma (1988), Battish (1992) and Sharma (1999). The results are expressed as individuals/l (Wanganeo and Wanganeo, 2006).

$$\text{Number of zooplankton "n"} = \frac{C \times 1000 \text{ mm}^2}{A \times D \times E}$$

C = Number of organisms recorded; A= area of field of microscope; D= depth of field (SRC depth) in mm; E = number of fields counted.

$$\text{Number of zooplankton/l} = \frac{n \times \text{Vol. of concentrate (ml)}}{\text{Vol. (litres) of water filtered}}$$

Shannon diversity index

This index is an index applied to biological systems derived from a mathematical formula used in communication area by Shannon-Weaver, 1947.

$$H' = -\sum [(n_i / N) \times (\ln n_i / N)]$$

H': Shannon Diversity Index; n_i: number of individuals belonging to i species; N: total number of individuals.

Simpson diversity index

It is a diversity index derived by Simpson in 1949 (Mandaville, 2002). Simpson index values (Δ) are between 0-1. But while calculating, final result is subtracted from 1 to correct the inverse proportion.

$$1 - \Delta = [\sum n_i (n_i - 1)] / N (N-1)$$

Δ : Simpson diversity index; n_i: number of individuals belonging to i species; N: total number of individuals.

Margalef diversity index

It has no limit value and it shows a variation depending upon the number of species. Thus, it is used for comparison of the sites (Kocataş, 1992).

$$d = (S-1) / \ln N$$

d: Margalef diversity index; S: total number of species; N: total number of individuals.

Pielou evenness index

It was derived from Shannon index by Pielou in 1966. The ratio of the observed value of Shannon index to the maximum value gives the Pielou Evenness index result. The values are between 0–1. When the value is getting closer to 1, it means that the individuals are distributed equally (Pielou, 1966).

$$J' = H' / H'_{\max}$$

J': Pielou evenness index; H': the observed value of Shannon index; H'_{max}: ln S; S: total number of species.

RESULTS AND DISCUSSION

Zooplankton dynamics

In the two years of study, a total of 82 zooplankton species were recorded from February 2008-January 2010. Out of which 66 species were recorded in the 1st year (2008-09), and 70 species documented during the 2nd year (2009-2010) (Table 2). The above zooplankton population (82 species) belongs to five major groups viz: Rotifera (46%), followed by Cladocera (34%), Protozoa (10%), and Copepoda and Ostracoda contributing 6 and 4%, respectively (Table 3 and Figure 2).

Annual mean trends

Diversity: Studies on Zooplankton dynamics carried out for 24 months (from February 2008 to January 2010), revealed a total of 82 species in Upper basin of Bhoj Wetland. The present study indicated significantly higher zooplankton diversity as compared to earlier reports, Verma et al. (2009) recorded 36 species, Pani et al. (2000) reported 29 species. However, Agarker et al. (1994) reported higher diversity of 78 species from the same waterbody. The

Table 2. List of Zooplankton species of Bhoj Wetland (2008-2010).

| Zooplankton species | 2008-2009 | 2009-2010 |
|--------------------------------|-----------|-----------|
| Cladocera | 19 | 26 |
| <i>Alona</i> sp. | + | + |
| <i>Alonelladentifera</i> | + | + |
| <i>Alonellasp.</i> | + | + |
| <i>Bosminalongirostris</i> | + | + |
| <i>Bosminasp.</i> | + | + |
| <i>Bosminopsisdeitersi</i> | | + |
| <i>Ceriodaphniasp.</i> | + | + |
| <i>Chydorusphaericus</i> | | + |
| <i>Chydorusventricosue</i> | + | |
| <i>Chydorus</i> sp. | + | + |
| <i>Conochiloidessp.</i> | + | |
| <i>Daphnia</i> sp. | + | + |
| <i>Diaphanosomabrachyurum</i> | | + |
| <i>Diaphanosomaexcisum</i> | | + |
| <i>Diaphanosomasarsi</i> | | + |
| <i>Diaphanosomasp.</i> | + | + |
| <i>Leydgiasp.</i> | + | + |
| <i>Macrothrix</i> sp. | + | + |
| <i>Moinamacrocopa</i> | + | + |
| <i>Moinamicrura</i> | | + |
| <i>Moinasp.</i> | + | + |
| <i>Moinadaphniasp.</i> | + | + |
| <i>Pleuroxusaduncus</i> | | + |
| <i>Scapholebrissp.</i> | | + |
| <i>Sidacrystallina</i> | | + |
| <i>Sidasp.</i> | + | + |
| <i>Simocephalus</i> sp. | + | + |
| <i>Streblocerussp.</i> | + | + |
| Rotifera | 35 | 33 |
| <i>Ascomorphasp.</i> | + | + |
| <i>Asplanchnasp.</i> | + | + |
| <i>Asplanchnopsis</i> | + | + |
| <i>Brachionusangularis</i> | + | + |
| <i>Brachionusangulosum</i> | | + |
| <i>Brachionuscalyciflorus</i> | + | + |
| <i>Brachionuscaudatus</i> | + | + |
| <i>Brachionusfalcatus</i> | + | + |
| <i>Brachionusforficula</i> | + | + |
| <i>Brachionusquadridentata</i> | + | + |
| <i>Brachionusurceus</i> | + | |
| <i>Cephalodellasp.</i> | + | + |
| <i>Colurellasp.</i> | + | + |
| <i>Conochilus</i> sp. | + | + |
| <i>Filiniasp.</i> | + | + |
| <i>Gastropussp.</i> | + | + |
| <i>Harringiasp.</i> | + | + |
| <i>Hexarthrasp.</i> | + | + |
| <i>Keratellacochelearis</i> | + | + |
| <i>Keratellatropica</i> | + | + |

Table 2. Contd

| | | |
|------------------------------|-----------|-----------|
| <i>Keratellasp.</i> | + | |
| <i>Lecanasp.</i> | + | + |
| <i>Lepodellasp.</i> | + | + |
| <i>Monostylasp.</i> | + | + |
| <i>Mytilinasp.</i> | + | + |
| <i>Philodinasp.</i> | + | + |
| <i>Platyiasp.</i> | + | + |
| <i>Ploesomasp.</i> | + | |
| <i>Polyarthrasp.</i> | + | + |
| <i>Rotariasp.</i> | + | + |
| <i>Scaridium</i> sp. | + | + |
| <i>Synchaetasp.</i> | + | |
| <i>Tetramastixapoliensis</i> | | + |
| <i>Trichocercalongiseta</i> | + | + |
| <i>Trichocercasp.</i> | + | + |
| <i>Trichotria</i> sp. | + | + |
| <i>Triploceroslimnias</i> | + | |
| <i>Trochosphaerasp.</i> | | + |
| Protozoa | 4 | 6 |
| <i>Actinophyrussp.</i> | + | |
| <i>Arcellasp.</i> | | + |
| <i>Centropyxis</i> sp. | + | + |
| <i>Climacostomum</i> sp. | | + |
| <i>Colpidium</i> sp. | + | |
| <i>Oxytrichasp.</i> | + | + |
| <i>Colepssp.</i> | | + |
| <i>Verticellasp.</i> | | + |
| Copepoda | 5 | 4 |
| <i>Cyclops</i> sp. | + | + |
| <i>Diaptomus</i> sp. | + | + |
| <i>Mesocyclopssp.</i> | + | + |
| Nauplius larvae | + | + |
| Unidentified copepod | + | |
| Ostracoda | 3 | 1 |
| <i>Cyprinotussp.</i> | + | + |
| <i>Cyprissp.</i> | + | |
| <i>Stenocyprissp.</i> | + | |
| Overall Total | 66 | 70 |

Table 3. Percentage of different groups of Zooplankton.

| S/No. | Zooplankton group | Percentage (%) |
|---------------|-------------------|----------------|
| 1 | Rotifera | 46 |
| 2 | Cladocera | 34 |
| 3 | Protozoa | 10 |
| 4 | Copepoda | 6 |
| 5 | Ostracoda | 4 |
| Total percent | | 100% |

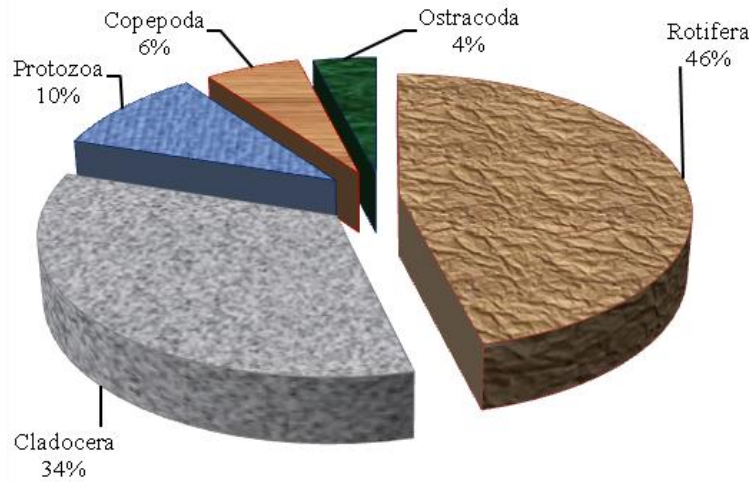


Figure 2. Percent contribution of different groups of zooplankton.

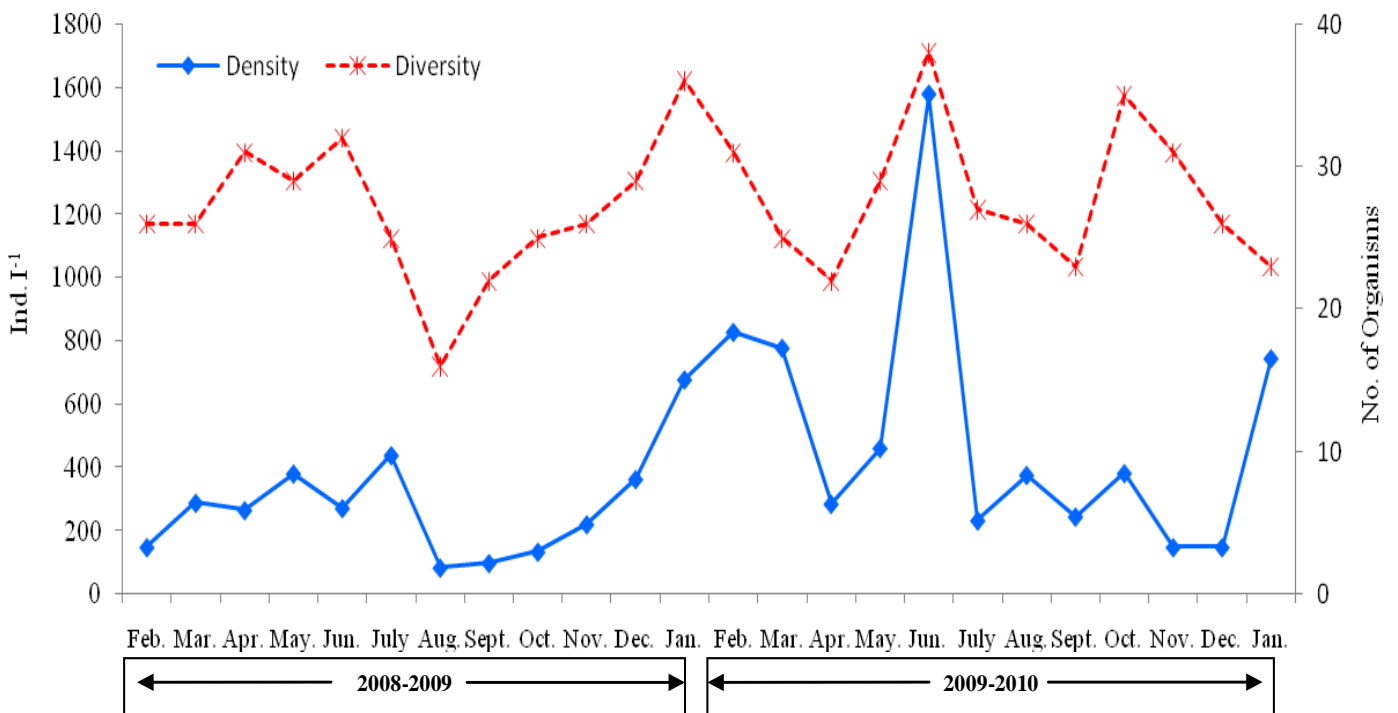


Figure 3. Comparison between diversity (no. of species) and density (Ind. l⁻¹) of Zooplankton.

current study varying exhaustive, was able to record much higher zooplankton diversity during the period of 2008-2010. The cumulative site mean diversity ranged from 16 to 38 species with a mean value of 28. A major peak of 38 species was recorded in the June 2009 with two minor peaks of 36 species (January 2009) and 35 species (October 2009). Rotifera contributed to this diversity to the tune of 47, 58 and 51% in three peaks recorded in June, January and October, respectively. The data further indicated that

among Rotifera, the major peak of June 2009 (38 species) was dominated by the various species of *Brachionus* and *Keratella*, these species also dominated minor peaks recorded during January and October 2009 (Figure 3).

The monthly variability of Zooplankton groups in terms of species number showed significant changes. The Rotifera recorded ≥ 60 species in March 2009 and September 2009 and in remaining months, it was mostly within 40-60 species, while minimum of < 40 species was

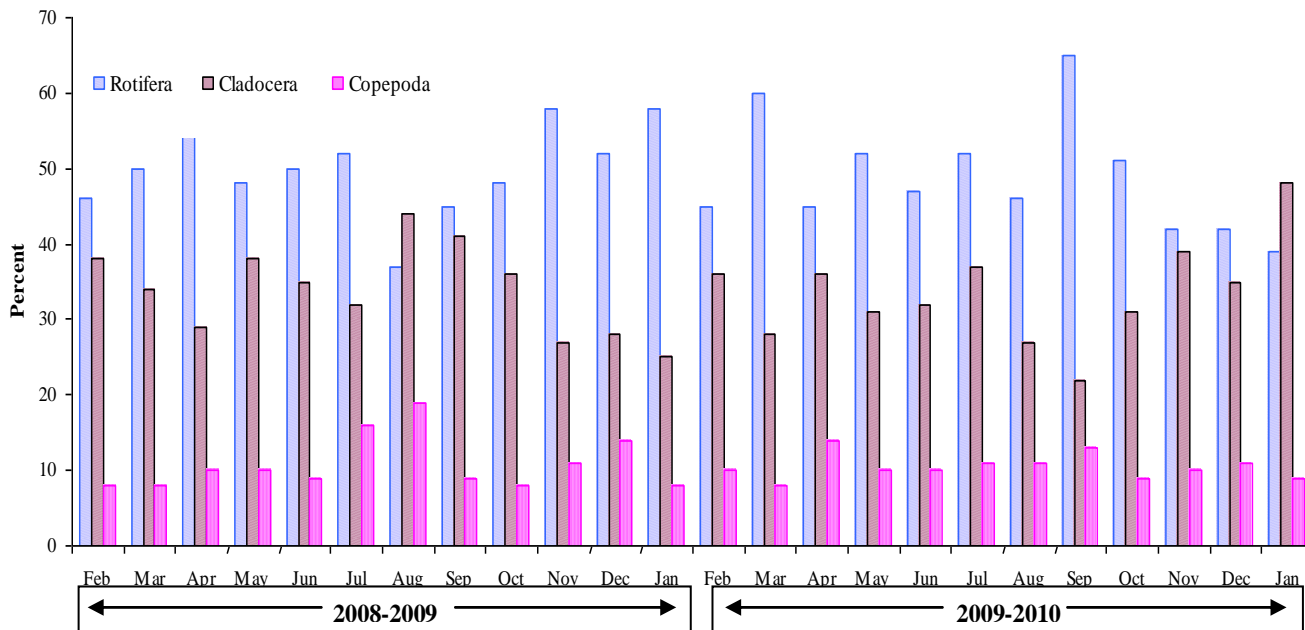


Figure 4. Group wise percent contribution of Zooplankton diversity.

recorded in August 2008 and January 2010. The Cladocera, encountered >40 species on three occasions viz, August, September 2008 and January 2010, while in remaining months the species number ranged between 30-40, and <30 was noted in April, November, December and January 2008 and March, August and September 2009. The Copepoda was significantly different and the overall species were restricted to <20 in the study period (Figure 4).

Zooplankton group Dynamics: On the basis of mean percentage contribution of different zooplankton groups, during the present study, among the total of 82 species, Rotifera formed the highest number of species (46%) followed by Cladocera (34%), Protozoa (10%), Copepoda (6%) and Ostracoda (4%) (Figure 2).

In general, Rotifera registered highest number of species in terms of percentage during the period of study except in the month of August 2008 and January 2010. Cladocerans recorded second highest and followed by copepods. The maximum diversity and population density of rotifers recorded in the present study was mainly due to organic load and eutrophic condition. High rotifer population in the lake waters indicates enrichment due to direct inflow of untreated domestic sewage from adjacent area into the lake (Arora, 1966). Chandrashekhar (1998) recorded diversity of rotifers to be influenced by the different water quality and other chemical factors.

The most abundant zooplankton group during the study was rotifera, the group, across all stations was dominated by different species of *Brachionus* and *Keratella*, and

these are found extensively in eutrophic waters as reported (Arora, 1966; Berzins and Pejler, 1989). The diversity patterns greatly depend on the water temperature and availability of food in the waterbody. Phytoplankton populations constituting the essential component of the rotifera dietary spectrum, increase with higher water temperature in summer that impacts species diversity in the wetland. Maximum Rotifera members in the wetland may be due to optimal nutrient and temperature conditions and favourable DO content, as reported by Subla et al. (1992) and Padmanabha and Belagali (2006) in their investigations. The *Brachionus* has cosmopolitan distribution in India and during the present study, it was represented by (8) species namely: *Brachionu sanguularis*, *Brachionus angulosum*, *Brachionus calyciflorus*, *Brachionus caudatus*, *Brachionus falcatius*, *Brachionus forficula*, *Brachionus quadridentata* and *Brachionus urceus*. Pejler (1977) and Fernando (1980) have also stressed that *Brachionus* was an important genera among tropical zooplankton community. Among the 8 species, *B. caudatus* was the most dominant, which is supported by the observations of Patil (1978), Isairasu and Mohandoss (1998) and Malathi (1999). Hutchinson (1967) observed that *Brachionus* species are very common in temperate and tropical waters, having alkaline pH. The dominance of *Brachionus* has been related to eutrophic nature and the presence of high organic matter in the water (Dadhich and Saxena, 1999; Sampaio et al., 2002). In other investigations Mageed (2008) and Uzma (2009) stated that presence of more than (5) species of *Brachionus* reflects eutrophication of water bodies. The Bhoj Wetland being a tropical water body is highly eutrophic and receives sewage

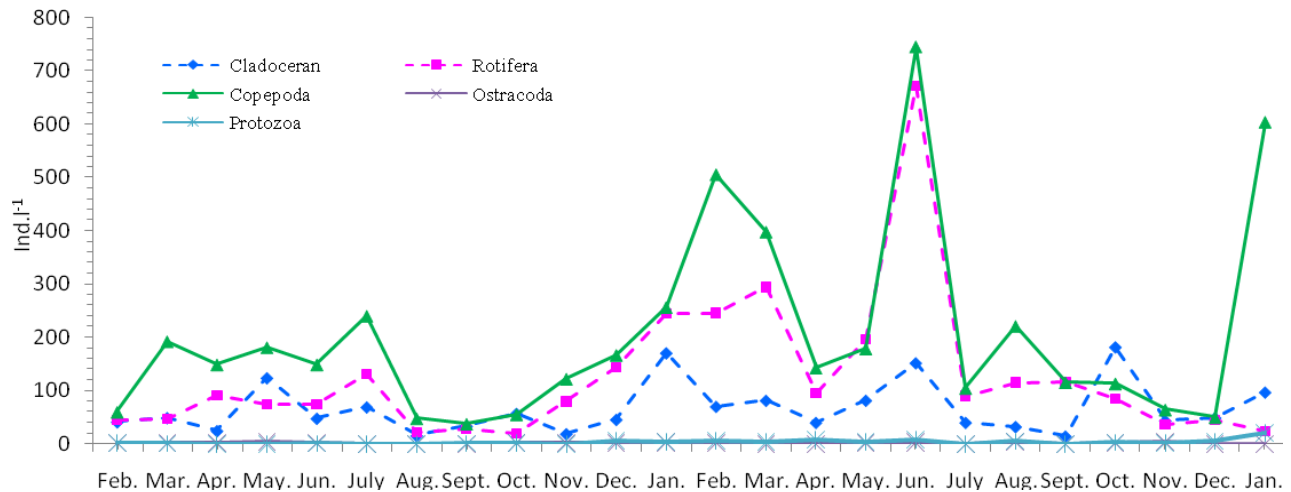


Figure 5. Variation in total density (Ind.l⁻¹) of Zooplankton during the period of study.

and other agricultural effluents from the catchment records dominance of *Brachionus*.

Density: The population density data revealed that cumulative site mean density ranged from 84 to 1579 Ind. l⁻¹, with an overall mean of 399 Ind. l⁻¹. The 24 months of mean site density indicated a major peak of 1579 Ind. l⁻¹, in June 2009, with 47 and 43% contribution from Copepoda and Rotifera (Figure 5). However, among Copepoda, *Cyclops* and Nauplius larvae were major contributors to this peak and among Rotifera, *B. caudatus* and *Keratella tropica* were dominant contributors. The two minor peaks of 828 and 744 Ind. l⁻¹ were recorded in February 2009 and January 2010, respectively. Among Copepoda, *Cyclops* contributed significantly to the February 2009 and January 2010 peaks, to the tune of 61 and 81%.

It is reported that Copepoda are best adapted to eutrophic lakes (Gannon and Stremberger, 1978). In the present study, the high density of rotifers (43%) and of Copepoda (47%) provides a positive evidence of the progression of eutrophication. The significant density of copepod nauplii larvae in Bhoj Wetland was recorded during the warm period, indicating the role of high temperature in promoting the egg production and development. This is in agreement with Makino and Ban (2000) who reported that higher water temperature causes more rapid development and higher egg production while increased food density results in larger body size and higher egg production. Singh et al. (2002) reported that higher rotifer population occurs during summer and winter which might be due to higher trophic level of the lake, high summer temperature and low level of water in winter. In our investigation, *Keratella* and *Brachionus* are common rotifers with a wide range of tolerance to different physico-chemical conditions. *Cyclops* is regarded as a strictly pollution sensitive copepod (Bhatti and Rana, 1987). However, in our study, they were

common genera at all stations. The occurrence of nauplii throughout the study period in wetland indicated extended reproductive phase of the cyclopoid, which is in agreement with the reports of Sharma (2011) and Sharma and Sharma (2011). The Bhoj is typically tropical wetland, with rotifers recording highest density and dominated mainly by *Brachionus* and *Keratella*. The members of rotifera are reported as good indicators of eutrophication and pollution (Saksena, 1987) and eutrophic lakes have been noted to harbor high density of *Brachionus* and *Keratella* (Arora, 1966).

The comparative cumulative mean data on zooplankton in Bhoj Wetland indicate that during the 1st year, the diversity was 31 species and 30 species in the 2nd year. The mean density during the 1st year was 276 Ind.l⁻¹ that increased to 468 Ind.l⁻¹ in the 2nd year. This variation in density during two years may be attributed to low water volume caused by drought conditions in the second year (Plate 1, 2, 3, 4). The maximum population density recorded in the 2nd year also reflected a positive relationship with temperature, nitrate and phosphate concentrations. Similar observations were recorded by Paliwal (2005). The maximum population density of zooplankton in the 2nd year may also be attributed to greater availability of food namely: phytoplankton and suspended detritus. The factors like temperature, D.O play an important role in controlling the diversity and density of zooplankton (Edmondson, 1965; Baker, 1979). According to Kurbatova (2005) and Tanner et al. (2005), the pH more than 8 means highly productive nature of a water body, in the present study, the average pH recorded was 8.3, indicating water highly productive for zooplankton population.

Comparison between diversity and density: Comparing diversity and density of zooplankton in the present study, the two seem to be positively related, the data revealed highest diversity of 38 species and density of

1579 Ind. l⁻¹ in June 2009, In August 2008, a minimum diversity of 16 species corresponded with a low density of 84 Ind.l⁻¹. Drawing a comparison between two years on the cumulative mean trends, the data revealed that in the 1st year, the mean diversity was 27 and 28 in the second year; similarly the mean density in the 1st year was 281 Ind. l⁻¹, which increased to 518 units l⁻¹ in the second year (Figure 3). The diversity/density pattern was similar in both years, but their relative abundances varied. The variability in density during two years may be attributed to hydrological change in the second year, mainly caused by acute drought conditions (Plate 1, 2, 3, 4). In summer season, low flow of water brings stability to the ecosystem and more availability of food due to production and decomposition of organic matter. The high diversity and density of zooplankton recorded in June 2009 may be related to high phytoplankton density during this period. It is documented that nutrient availability influence the abundance of rotifer and Copepoda (Kumar et al., 2004). Overall, the diversity and density of zooplankton depends upon the nutrient status of water body and enabling water quality. Sarkar and Chowdhury (1999) reported that variability in temperature, total alkalinity, phosphate, nitrate and pH does influence the growth of zooplankton. Low zooplankton diversity and density during the rainy season has been attributed by Okogwu et al. (2010) to turbulence generated by the excess water flows.

Site variability

Diversity: In the first year (2008-2009), the species number from different stations, ranged from 20 to 40, a maximum of (40 species) encountered at station VIII (Prempura Ghat), and minimum of 20 species at station VII (Sehore Side). In the second year (2009-2010), a minimum of 16 species were recorded at station VII and maximum of 52 species at station VIII (Figure 6). The peak diversity recorded at station VIII in both years, was due to dominance of rotifers and cladocerans species. The higher nutrient status at station VIII resulting from decomposition of macrophytes enabling higher diversity as well as density of zooplankton. Maximum zooplankton peak obtained at station VIII (Prempura Ghat) in the wetland may be due to high nutrients like (nitrate \bar{X} =0.62mg/l and phosphate \bar{X} =0.27mg/l) and favourable temperature and DO conditions, similar trend has been reported by Padmanabha and Belagali (2006). The progressive decrease in the zooplankton diversity at station VII during the 1st year may be attributed to drought from January 2009 to June 2009 (Plate 3).

Density: The zooplankton density at nine stations recorded a minimum of 67 Ind.l⁻¹ and a maximum of 520 Ind.l⁻¹ with overall mean density of 276 Ind.l⁻¹ in the 1st year, while in the 2nd year, a minimum of 56 Ind.l⁻¹ and a

maximum of 1059 Ind.l⁻¹ was recorded with mean density of 468 Ind.l⁻¹. The mean cumulative monthly density of different stations indicated major peaks of 520 and 1059 Ind. l⁻¹ at station VIII in the 1st and 2nd year, respectively. Maximum contribution of 46 and 47% by Copepoda in the above peaks in both years was recorded. Among Copepoda, two major contributors were *Cyclops* (65 and 73%) and its Nauplius larvae (29 and 25%) in the 1st and 2nd year, respectively (Figure 6). Joshi (1987) reported dominant population of Copepoda (*Cyclops*) throughout the year from Sagar Lake. Gupta (1989) reported Copepoda population throughout the year in Gulabsagar and Gangloan water bodies of Jodhpur, this was attributed to enriched nature of waters. Syuhei-Ben (1994) stated that individual growth rate of Copepoda may also depend on temperature conditions. Gannon and Stemberger (1978) found that cladocerans and cyclopoid copepods are more abundant in nutrient enriched waters of the Great Lakes.

Two year comparison: Two years diversity/density data showed a positive relation, the station VIII recorded the maximum diversity/density (40 and 52 species and 520 and 1059 Ind. l⁻¹) in the 1st and 2nd year (Figure 6). The *Cyclops* and its nauplius larvae, dominated the zooplankton density peak. In diversity peaks, *Brachionus* (7 and 6 species) recorded maximum during the 1st and 2nd year and *Diaphanosoma* (3 species) only in the 2nd year. Among rotifers, the numerical superiority was found to be high in the case of *Brachionus* (7 species), which is considered typical and most frequent in tropical environment (Nogueira, 2001; Mulani et al., 2009). In the present investigation, *Brachionus* species was frequently observed at all stations. This species is considered the indicator of eutrophication (Sampaio et al., 2002). Nogueira (2001) reported that *Brachionus* species as indicator of sewage and industrial pollution. Jana and Pal (1984) reported the abundance of *Diaphanosoma excisum* in water bodies having high organic content. Therefore, presence of *Diaphanosoma* at all the stations in the present study can also be considered as an indication of increased organic content in the water, from sewage and other agricultural effluents.

Among the different groups, Rotifera varied from 25 to 62% with lowest at station VII (Sehore side) and highest at station IV (Van Vihar) in the first and second year, it varied from 38 to 58% with minimum at station VII (Sehore side), and maximum at station VI (Bairagarh) respectively, (Figure 7). Across the overall station trend in zooplankton diversity was Rotifera > Cladocera > Copepoda. The highest rotifera species diversity was observed at stations IV and VI, characterized by dense well developed macrophyte stands, which provides shelter, varied niches and comparatively good quality water as evinced by the physico-chemical properties of water (Robinson, 2004). The sufficient nutrient availability and other favourable conditions result in dominance of



Station I (Kamla Park) during full tank level



Station I (Kamla Park) receded water level during summer



Station II (Gandhi Medical College) during full tank level



Station II (Gandhi Medical College) during dry phase



Station III (Kohe Fiza) during full tank



Station III (Kohe Fiza) during dry phase

Plate 1. Some evidence about drought conditions in the second year



Station IV (Van Vihar) during wet period



Station IV (Van Vihar) during dry phase



Station IV (Van Vihar) during dry phase



Station IV (Van Vihar) during dry phase



Station V (Boat Club) during full tank



Station V (Boat Club) during dry phase

Plate 2. Some evidence about drought conditions in the second year



Station VI (Bairagarh) during full tank level



Station VI (Bairagarh) during dry phase



Station VII (Sehore Side) during full tank level



Station VII (Sehore Side) during dry phase



Station VIII (Prempura Ghat) during full tank



Station VIII (Prempura Ghat) during dry phase

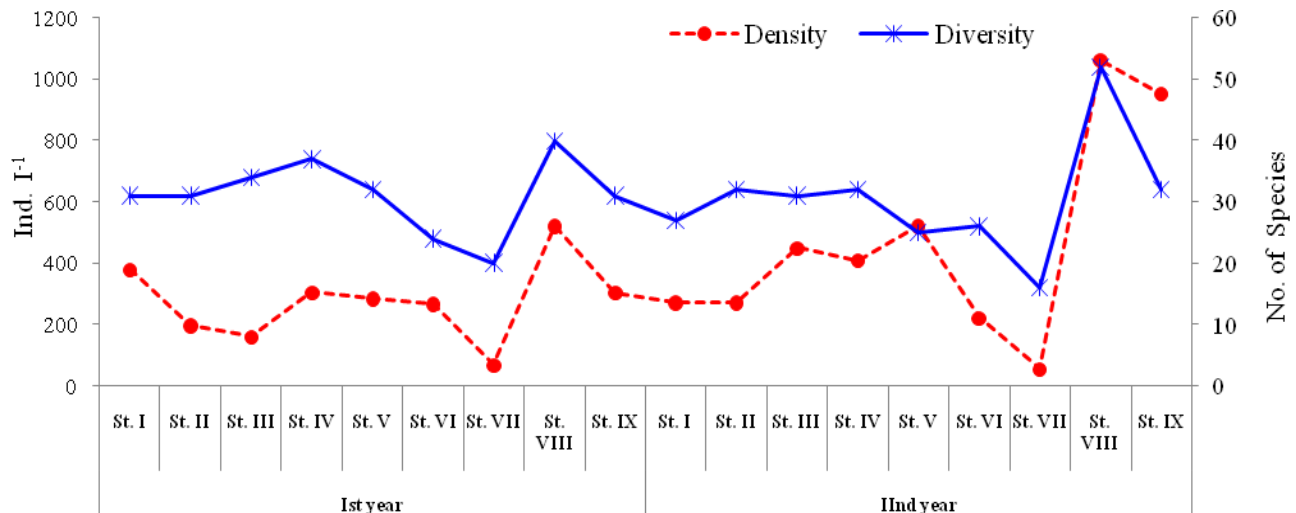
Plate 3. Some evidence about drought conditions in the second year



Station IX (Nehru Nagar) during full tank level



Station IX (Nehru Nagar) during dry phase

Plate 4. Some evidence about drought conditions in the second year**Figure 6.** Comparison of diversity (no. of species) and density (Ind. l⁻¹) of Zooplankton at various stations.

rotifers while lower diversity at station VII may be due to the acute drought conditions (Plate 3) and significant use of pesticides in the agricultural activities. Kasai and Hanazato (1995) reported that application of herbicides induced the decline in zooplankton density; similar trend with regard to fungicide has been recorded by Willis et al. (2004). High species diversity of rotifera has been recorded with the peaks of phytoplankton, this suggests that the increase in zooplankton production may be attributed to greater availability of food in the form of phytoplankton coupled with enabling temperature (Wadajo, 1982; Wadajo and Belay, 1984; Webber and Roff, 1995; Christou, 1998; Uyeet al., 2000). The Cladocera ranged

from 25 to 55%, with a minimum at station V and maximum at station VII in the first year, while in second year, it ranged from 19 to 44% with minimum at station VI and maximum at station VII and VIII, respectively. The lower abundance and diversity of cladocerans found in the station VII may be explained as the grazing impact of planktivorous fishes (Wetzel, 1983; Arcifa et al., 1986; Basima et al., 2006; Jeppesen et al., 1998). However, Wetzel (2001) reported higher densities of cladocerans in littoral areas along with macrophytes.

Cladocerans feed on algae, small rotifers and copepod nauplii (Dodson et al., 2010). Rotifers and cladocerans strongly compete for the similar food resources (Kirk and

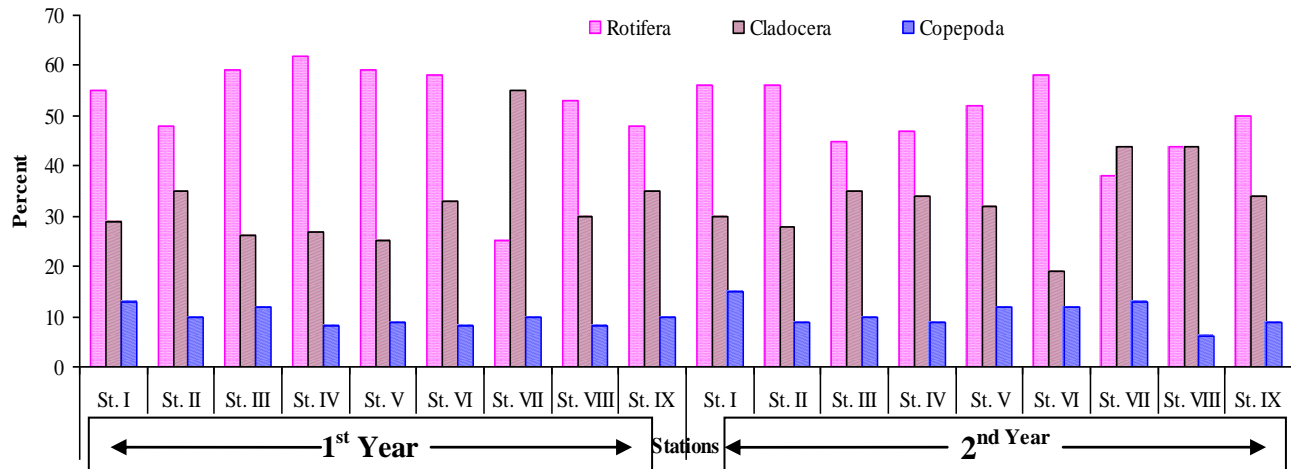


Figure 7. Percent contribution of Zooplankton groups at various stations.

Table 4. Zooplankton diversity indices of Bhoj Wetland (2008-10).

| Station | Shannon diversity index | | Simpson diversity index | | Margalef diversity index | | Pielou's evenness index | |
|----------|-------------------------|----------------------|-------------------------|----------------------|--------------------------|----------------------|-------------------------|----------------------|
| | 1 st Year | 2 nd Year | 1 st Year | 2 nd Year | 1 st Year | 2 nd Year | 1 st Year | 2 nd Year |
| St. I | 2.28 | 2.12 | 0.81 | 0.80 | 3.56 | 3.21 | 0.31 | 0.31 |
| St. II | 2.30 | 2.61 | 0.81 | 0.88 | 3.87 | 3.83 | 0.32 | 0.43 |
| St. III | 2.63 | 2.47 | 0.86 | 0.86 | 4.36 | 3.49 | 0.41 | 0.38 |
| St. IV | 2.39 | 2.58 | 0.82 | 0.88 | 4.37 | 3.65 | 0.29 | 0.41 |
| St. V | 2.27 | 2.20 | 0.84 | 0.81 | 3.81 | 2.75 | 0.3 | 0.36 |
| St. VI | 2.23 | 2.13 | 0.84 | 0.78 | 2.85 | 3.29 | 0.39 | 0.32 |
| St. VII | 2.21 | 2.39 | 0.81 | 0.87 | 2.88 | 2.52 | 0.46 | 0.68 |
| St. VIII | 2.68 | 2.58 | 0.87 | 0.85 | 4.46 | 5.39 | 0.36 | 0.25 |
| St. IX | 2.47 | 1.70 | 0.85 | 0.63 | 3.66 | 3.32 | 0.38 | 0.17 |

St.: station.

Gilbert, 1990). The large cladocerans limit the abundance of rotifera and thus, are usually the more competitively dominant taxa (Kirk and Gilbert, 1990). When different taxa compete for the same limited food resources, some populations may experience a decline due to the competition for food, feeding capabilities and reproduction capacity (Kirk and Gilbert, 1990). This situation may lead to a dormant or resting stage for the zooplankton rather than its complete decline (Wetzel, 1983).

Zooplankton diversity indices

In the present investigation, Shannon -Wiener diversity index ranged between the values of 2.215 to 2.682 in the 1st year (2008-09). The highest diversity index was found to be 2.682 at station VIII and a lowest 2.215 at station VII (Table 4). While in the second year, the values of Shannon-Wiener diversity index ranged from 1.703 to 2.614. The highest value was 2.614 at station II and a lowest 1.703 at station IX, respectively (Table 4). In

general, the index reveals that upper basin of Bhoj Wetland is more diverse. Wilhm and Dorris (1968) found that the value of index decline sharply in polluted zones of the lake.

Simpson diversity index varied between the values of 0.812 to 0.872. The minimum value of 0.812 was recorded at station II and a maximum of 0.872 at station VIII. While in the 2nd year of study, the diversity varied between 0.633 to 0.882 values. The minimum value was found to be 0.633 at station IX and a maximum of 0.882 at station IV, respectively (Table 4). Simpson's index of diversity showed that the index of diversity was significantly higher. The Simpson index (low value) indicates an increase in dominance of fewer species in Baigul water bodies (Mishra et al., 2010). The index value ranges from 0 and 1, the higher the index value, the higher the diversity.

The evenness components of diversity values were found to range 0.296 to 0.458. The lowest value of 0.296 was found at station IV and the highest value of 0.458 was found at station VII, respectively (Table 4). While in

Table 5. Percentage similarities (Sorenson's index) of Zooplankton (2008-09).

| | Similarity matrix | | | | | | | | |
|----------|-------------------|-------|---------|-------|-------|-------|--------|---------|-------|
| | St.I | St.II | St. III | St.IV | St.V | St.VI | St.VII | St.VIII | St.IX |
| St. I | * | 49.42 | 49.15 | 77.37 | 64.15 | 71.83 | 21.59 | 46.01 | 47.98 |
| St. II | * | * | 61.83 | 57.56 | 66.43 | 64.62 | 40.91 | 46.15 | 60.30 |
| St. III | * | * | * | 50.17 | 51.69 | 54.97 | 42.70 | 37.21 | 52.52 |
| St. IV | * | * | * | * | 65.65 | 72.47 | 25.93 | 49.15 | 54.57 |
| St. V | * | * | * | * | * | 78.06 | 27.95 | 51.19 | 60.80 |
| St. VI | * | * | * | * | * | * | 27.41 | 52.75 | 62.08 |
| St. VII | * | * | * | * | * | * | * | 17.77 | 27.00 |
| St. VIII | * | * | * | * | * | * | * | * | 59.57 |
| St. IX | * | * | * | * | * | * | * | * | * |

St.: station.

the second year of investigation, the value varied between 0.171 and 0.682. The highest at station VII and a lowest at station IX was recorded.

The Margalef diversity index varied from 2.85 to 4.46 in the first year of study. The highest Margalef index was recorded at station VIII (4.46) and a minimum at station VI (2.85) while in the second year of study, the Margalef diversity index varied from 2.52 to 5.39. The minimum value (2.52) was recorded at station VII and the maximum (5.39) at station VIII (Table 4). Mukherjee (1997) reported that the higher species richness is characterized by larger food chain (Dumont, 1994).

Overall, Zooplankton species richness in the present study is quite high. The present study supports the idea that overall species richness is positively affected by the number of diverse habitats in the Bhoj Wetland. All the diversity indices (Shannon-weaver, Simpson diversity and Margalef diversity index) showed high diversity at station VIII (first year) and during the second year, Shannon diversity index was high at station II. Simpson diversity index was also high at same station and also at station IV. However, on the basis of Margalef diversity index, it was station VIII which recorded highest diversity. Applying evenness index of Pielou, the present values depict that the species are not evenly distributed.

Cluster analysis

Cluster analysis of Zooplankton

The Bray-Curtis Cluster analysis are shown in Table 5 and Figure 8. In the present study, for the similarity matrix, the highest value is 78.06 for station numbers V and VI and thus linked together at level 1. The second highest similarity value of 77.37% is between the stations I and IV, hence station I is linked to IV. Extreme differences in the zooplankton structure were detected between the sampling station VII and VIII. The zooplankton communities indicate similarities (Sorenson's Index) ranging

from 17.77 to 78.06% during first year of the study period. Wetland exhibited higher zooplankton similarity, that is, >50% similarity in maximum instances (58.3%). This wetland, however, showed a relatively wide community similarity range (50-78.06%) during 2008 - 2009.

Bray-Curtis cluster analysis shows notable differences in annual cluster groupings in the sampled stations. In the second year of study, the Bray-Curtis cluster analysis indicated closer affinity in zooplankton between station III and IV and diverse composition of station VII and station VIII and IX communities during 2009 - 2010. During the second year, there was higher zooplankton similarity (4.75 - 68.42%). Majority of instances (25%) in the matrix however indicate similarities between 50-68.42% during 2009-2010 (Table 6 and Figure 9).

Wetlands are dynamic ecosystems, continually undergoing natural changes due to infilling with sediments and nutrients. They sustain all life and perform some useful functions in the maintenance of overall balance of nature (ecosystem). Rapid urbanisation, burgeoning human population and their various activities have contributed to the decline of quality and number of wetlands, also socio-economic value of the wetlands has decreased. Hence, it is imperative to focus on preservation of these endangered habitats to achieve ecological sustainability. Zooplankton community was represented by five groups namely: Cladocera, Rotifera, Copepoda, Ostracoda and Protozoa. The copepods and rotifera population were found maximum throughout the study period, whereas rotifer had maximum number of diversity during both years of the study. Thus, the wetland plays a very important role in maintaining the biodiversity. The presence of species indicative of eutrophic status condition in Bhoj wetland suggests that the ambient water has achieved a high trophic status on account of nutrient enrichment from its catchment area wherein varying types of anthropogenic activities were recorded as related to different socio-economic status of persons residing in its catchment area. It is concluded that the Bhoj wetland is under eutrophic state as a result of human stress in the

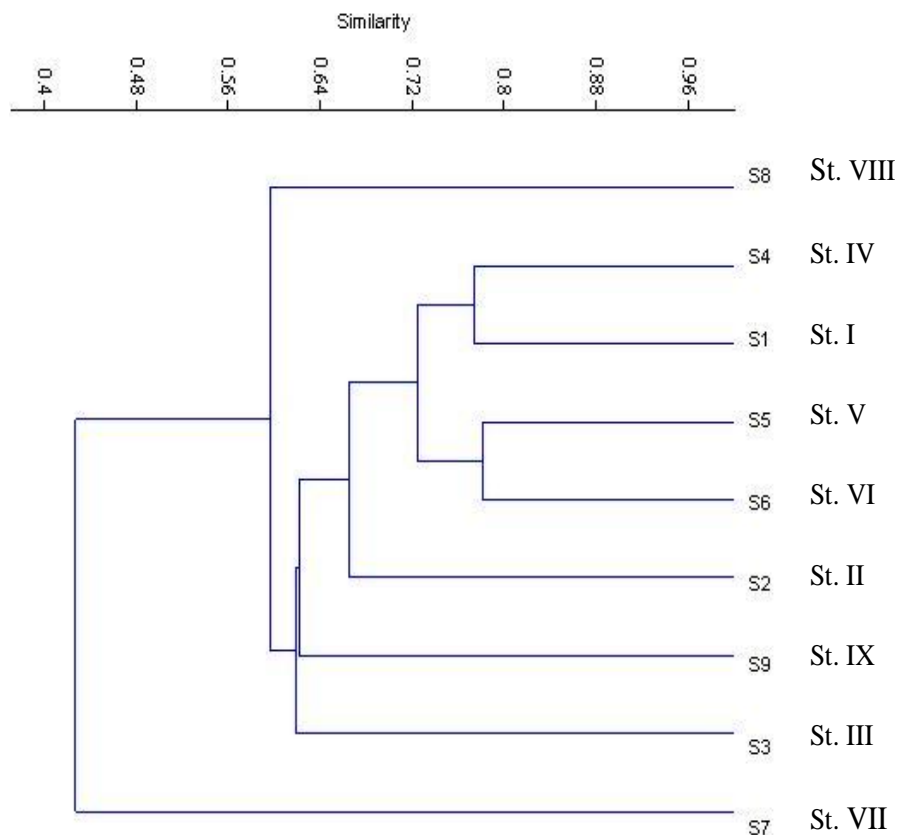


Figure 8. Bray-Curtis cluster analysis of Zooplankton of Bhoj Wetland (2008-09).

Table 6. Percentage similarities (Sorenson’s index) of Zooplankton (2009-10).

| | | Similarity matrix | | | | | | | |
|----------|------|-------------------|---------|-------|-------|-------|--------|---------|-------|
| | St.I | St.II | St. III | St.IV | St.V | St.VI | St.VII | St.VIII | St.IX |
| St. I | * | 56.15 | 55.50 | 64.55 | 55.14 | 38.74 | 10.29 | 32.02 | 39.84 |
| St. II | * | * | 56.95 | 55.98 | 49.90 | 41.78 | 13.48 | 33.37 | 41.21 |
| St. III | * | * | * | 67.62 | 68.42 | 29.65 | 8.75 | 33.62 | 32.90 |
| St. IV | * | * | * | * | 59.48 | 31.61 | 9.30 | 44.99 | 39.81 |
| St. V | * | * | * | * | * | 25.89 | 6.92 | 37.80 | 37.05 |
| St. VI | * | * | * | * | * | * | 28.92 | 16.94 | 25.00 |
| St. VII | * | * | * | * | * | * | * | 4.75 | 9.07 |
| St. VIII | * | * | * | * | * | * | * | * | 32.32 |
| St. IX | * | * | * | * | * | * | * | * | * |

St.: station.

catchment area. Further, increase of plant nutrients in the wetland waters is deteriorating its ecological condition.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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