Spatial Analysis of Composition and Species Interactions with Temporal Variation of Zooplankton Community of Shallow Tropical Lake: Thol Bird Sanctuary, India

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Abstract:
Spatial and temporal patterns in the distribution of the zooplankton in a tropical Man-made reservoir- Thol Bird Sanctuary were investigated for two consecutive years from September 2007 to August 2009. The zooplankton was sampled at two different zones of Thol wetland located 23°15'N and 72°30'E near Ahmedabad city of Gujarat state, India. Sixteen species of Rotifers rich in number of individuals, density were dominant throughout the seasons in two sampling sites among the other groups. The main species were Polyarthra vulgaris, Keratella tropica, K. cochlearis and Brachionus forficula. Eleven species of Cladocera were more abundant in spring with the occurrence of Daphnia sp. and Macrothrix rosea at site 1 (feeder canal of the lake). Whereas, Diaphanosoma birgei, the most abundant Cladoceran, mainly occurred at site 2 (littoral zone of the lake). Peaks of tinted Protozoan were observed at site 1 during winter and spring. Variation in spatial distribution was noticeable, the abundance of zooplankton was significantly higher (P< 0.05) at the site 2 than the site 1 as a result of preponderance of the small Rotifers and Cladocerans particularly Bosmina longirostris. The analysis of one way ANOVA between the sites for the first year showed the F (5.84) value is greater than critical F value (4.30), whereas in the second year P’ value (0.0005) is lesser than alpha (α) value 0.05.

Keywords: Density, Spatial-temporal distribution, Thol bird sanctuary, Zooplankton community

1.0 Introduction
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 (Cadjo et al., 2007). Protozoan, Cladocera, Copepoda, Rotifer are the indicators of water quality. 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). The shallow lakes are much influenced by the intensive exchange of nutrients between their water columns and sediments (Vicente et al., 2006). Due to the excessive nutrient condition the loss of structural diversity and decrease in biodiversity at upper trophic levels generated. The variation of spatial and temporal of zooplankton biomass do not considered with the well-developed generated accepted body of knowledge (Clark et al., 2001). Phytoplankton, zooplankton, macrophytes, macrobenthos and tertiary consumers are considerably undertaken for the biomonitoring of lakes ecosystem.

According to Ferrar et al., (2002) 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 (2003) attributed this to food availability and avoidance of predators. Zooplanktons are globally recognized as pollution indicator organisms in the aquatic environment (Sunkad et al., 2004). The review of limnological literature indicates limited information available on the ecology, diversity and role in aquatic productivity of inland aquatic
environ 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 (Rajasheker, 2009).

In Gujarat, although some information are available on the zooplankton community of marine ecosystem, studies are sparse and restricted to mere short term taxonomic observation reports of lentic ecosystem without any real quantitative analysis. Several studies have been done on different aspects of lentic ecosystems. The floral and faunal diversity of aquatic ecosystem and the major industrial development pressures posed by the mangrove and coastal ecosystem of Gujarat observed by Oswin (2004). Kumar et al., (2005, 2008) explored physico-chemical characteristics of water and sediments, diversity of macrophytes. Temporal and spatial variations, with reference to community composition of zooplankton had been studied by Soni (2007) for two community reservoirs (Pariyej and Kanewal), Central Gujarat for a yearlong study period. Influence of water quality on composition and seasonal abundance of phytoplankton community in Thol Wetland of Gujarat studied by Kumar and Verma (2011). Kamini (2011) investigated the quality of surface water deteriorating due to rapid industrialization, population growth and urbanization of Ahmedabad city by weighted arithmetic index method.

The ecology of composition and spatial-temporal variations among plankton community of shallow lakes, in spite of its significant role in food web of aquatic ecosystem, is poorly understood. Hence, the present study undertaken in western India carries special significance. The study aims to provide a baseline data on the zooplankton of Thol Lake Bird Sanctuary and analyzed the spatial composition, species interaction with temporal variations of shallow tropical lake.

2.0 Materials and Methods
2.1 Study Area
The Thol Wildlife Sanctuary is situated 40 km away from Ahmedabad on the north side of Gujarat, in Kadi taluka, Mehsana district. It lies in between (23°15’ to 23°30’ and 72°30’ to 72°45’ E). Sampling was carried out in the manmade Thol Lake Bird Sanctuary (Fig. a). The wetland was declared as “Bird Sanctuary” in November 1988 by Department of forest, Government of India which is a habitat of 150 of bird species, of which, 100 bird species are water bird and 30 bird species are migratory. The site is important for pre-breeding congregation and nesting of Indian Sarus Crane (Grus Antigone antegone). Gopi Sunder et al., (2000) have seen 35 cranes in May 1998. Wetland Thol is characterized by alkaline water, good oxygenation of surface water, for decades the wetland has been used for irrigation purposes. Rural settlement is found towards the North East and North West direction of the wetland.

As the wetland come under the Natural Conservation Area for birds of Gujarat the anthropogenic activities such as washing, poaching, cattle wading, bathing and illegal entry are strictly restricted. Birds such as Common coots, Shelduck, Common pochards, Flamingoes, Painted stork, Spoonbills, Ibis are dominated species throughout the investigated period and Spot Billed Duck, Eurasian Wigeon, Asian openbill are found mostly seasonal and appeared only during in winter season. In the present study, samples were collected from two sites of the wetland area: one shoreline site and one deep area. Site 1 is the major inlet of the wetland as stream of river Narmada canal drains into the wetland. Site 2 is one of the deepest outlets of the wetland. The water is then used for irrigation and drinking purpose by the villagers. The shoreline vegetation comprises predominantly of the following macrophytes Ipomea aquatica, Polygonum sp., Typha angustata, T. domengensis, Eichhornia crassipes and Salvinia natans. T. angustata, Ipomea aquatica were observed as the dominant vegetation at the site 1.

2.2 Sampling and Analysis
Zooplankton was sampled monthly during two different annual cycles (September 2007- August 2009) and at the two sites of the Wetland (Fig.a). Surface samplings were carried out with a 25 cm diameter and 75 cm length net of 20 µm mesh size. The volume of water filtered has been determined indirectly assuming that the net filters the whole volume of the column of water traversed by the net (De Bernardi, 1984). All samples were immediately fixed with 4% formalin and examined in the laboratory with light invertscopes (Olympus, CKX31) with magnification varying from 100 to 400×. The most abundant organisms and rotifers were identified and counted on sedimentation chambers and 1ml subsample from the final sample were chosen so that organisms did not pile up on one another (APHA, 2000). The less frequent or larger organisms (e.g., predatory
Cladocera) were counted with a long working distance objective at 40x after sedimentation of larger subsamples (10 ml) on petri dishes. Identification of species was made according to Edmondson (1959) for Copepoda, Wetzel (2001); Biswas (1949) for Rotifera, and other published literature.

Basic statistical methods on variance of spatial distribution patterns of the zooplankton were studied through analysis of variance (ANOVA). The zooplankton counts were analyzed for differences between habitats (littoral and deep area). Whereas significant values ($P< 0.005$) were obtained by dominant species with the other members of the groups.

### 3.0 Results and Discussion

#### 3.1 Zooplankton species abundance and Diversity:

A diverse planktonic assemblage in both the samples with a total of thirty identifiable species being recorded across the study area (16 Rotifera, 11 Cladocera and three Protozoa). Relative species distribution of abundance (ind. $\times 10^5 \mu l^{-1}$) of both the sites for each year is shown in Table 1. Rotifera are the most abundant and the most constant accounting 16 species, this settlement has rather great specific richness and high diversity. The most abundant and dominant group during the study period, ranging from $16.4 \times 10^5 \mu l^{-1}$ and 19.2
x 10^5 µl^{-1} at both the sites in first year and 34.6 x10^5 µl^{-1} at site 2 in both the years. A spatial variability is less noticed in the settlement of this group among the two sites. The main species of rotifers were Polyarthra vulgaris, Keratella tropica, K. cochlearis, and Brachionus forficula. The most numerically dominant species Keratella cochlearis accounting 7.6 x 10^6 µl^{-1} at site 2 were recorded in first year followed by Keratella tropica 4.64 x 10^5 µl^{-1}.

Rotifer probably sensitive to some limiting factors (pollution and predation) on the other hand presents a relative decrease in abundance in the rainy season. Rotifers react less to different trophic levels given that some species, e.g. Keratella cochlearis, which is typically predominant in eutrophic lakes (Gliwicz, 1969), were observed both in eutrophic and oligo-mesotrophic lakes (Maier and Buchholz, 1996). Brachionus calyciflorus and Keratella tropica Aspein were able to maintain high population during the wet season suggesting that they are resistant to suppression by the cladocerans. Cladocera are more clearly distributed according to the season and are more abundant in the rainy season and present a dynamics clearly related to the sites of the wetland. Eleven species of Cladocera were more abundant in spring with the occurrence of Daphnia sp. Macrothrix rosea at site 1. Whereas, Diaphanosoma birgei, the most abundant Cladoceran, mainly occurred at site 2. The species richness and density of Cladoceran were low at both the sites in two years. Average minimum density (8.64 x 10^5 µl^{-1}) of Cladocera recorded at site 1 in first year and maximum density (18.56 x 10^5 µl^{-1}) at site 2 in second year.

However, in the present study we noticed the maximum density of cladoceran at site 2 shows the spatial variation among the two sites. Similar observation is made by Dejen et al. (2004), who reported that in Lake Tana, the Cladocerans were most abundant in the sub-littoral zone and least abundant in the littoral zone, because the littoral zones sampled were devoid of aquatic macrophytes. Site 2 of the lake is the outlet, and found to the deepest point of the wetland. In the rainy season, water arriving in the reservoir drives a great quantity of organic and inorganic matters (Kabre, 2001) dissolved or in suspension, which brings about an expansion of phytoplankton and bacteria. These matters together with the phytoplankton and the bacteria constitute the essence of the food of the zooplankton which accounts for the significant development of the Cladocera (Wetzel, 2001). The other possible factor explaining the high density of zooplankton in the deeper part of the lake could be the less predation pressure in this zone.

### Table 1: Zooplankton Species Average Density for Each Site of Both the Years from Thol Bird Sanctuary (Measured in individual (ind.) x 10^5 µl^{-1})

<table>
<thead>
<tr>
<th>Species Name</th>
<th>First Year Site 1</th>
<th>First Year Site 2</th>
<th>Second Year Site 1</th>
<th>Second Year Site 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chilomonas paramecium</td>
<td>1.04</td>
<td>1.36</td>
<td>1.28</td>
<td>1.84</td>
</tr>
<tr>
<td>Cladocera Hilli</td>
<td>3.12</td>
<td>4.16</td>
<td>3.68</td>
<td>5.60</td>
</tr>
<tr>
<td><strong>Rotifera</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asplancha sp.</td>
<td>0.00</td>
<td>0.96</td>
<td>0.00</td>
<td>0.56</td>
</tr>
<tr>
<td>Brachionus sp.</td>
<td>1.12</td>
<td>1.12</td>
<td>1.36</td>
<td>1.28</td>
</tr>
<tr>
<td>B. calyciflorus</td>
<td>0.96</td>
<td>1.36</td>
<td>1.12</td>
<td>1.44</td>
</tr>
<tr>
<td>B. forficula</td>
<td>1.04</td>
<td>1.52</td>
<td>1.44</td>
<td>1.68</td>
</tr>
<tr>
<td>B. quadridentata</td>
<td>1.12</td>
<td>0.96</td>
<td>1.36</td>
<td>1.04</td>
</tr>
<tr>
<td>B. mirabilis</td>
<td>0.64</td>
<td>1.52</td>
<td>0.56</td>
<td>1.84</td>
</tr>
<tr>
<td>Filinia longiseta</td>
<td>1.44</td>
<td>3.28</td>
<td>1.68</td>
<td>4.88</td>
</tr>
<tr>
<td>F. apolitenses</td>
<td>1.12</td>
<td>1.68</td>
<td>1.2</td>
<td>1.84</td>
</tr>
<tr>
<td>F. terminalis</td>
<td>0.64</td>
<td>2.32</td>
<td>0.72</td>
<td>2</td>
</tr>
<tr>
<td>Monostyla decipiens</td>
<td>0.96</td>
<td>0.96</td>
<td>1.12</td>
<td>0.8</td>
</tr>
<tr>
<td>Keratella tropica</td>
<td>2.32</td>
<td>4.64</td>
<td>2.24</td>
<td>4.8</td>
</tr>
<tr>
<td>K. cochlearis</td>
<td>1.68</td>
<td>7.6</td>
<td>2</td>
<td>4.16</td>
</tr>
<tr>
<td>K. procurva</td>
<td>0.8</td>
<td>1.36</td>
<td>1.04</td>
<td>2.32</td>
</tr>
<tr>
<td>Keratella valga</td>
<td>0.64</td>
<td>0.48</td>
<td>0.96</td>
<td>0.08</td>
</tr>
<tr>
<td>K. tropica (Apstein)</td>
<td>0.4</td>
<td>1.2</td>
<td>0.4</td>
<td>1.36</td>
</tr>
<tr>
<td>Polyarthra vulgaris</td>
<td>1.52</td>
<td>3.2</td>
<td>1.92</td>
<td>4.08</td>
</tr>
<tr>
<td>Total ind x10^5 µl^{-1}</td>
<td>16.40</td>
<td>34.16</td>
<td>19.12</td>
<td>34.16</td>
</tr>
</tbody>
</table>

**Cladocera**

<table>
<thead>
<tr>
<th>Species Name</th>
<th>First Year Site 1</th>
<th>First Year Site 2</th>
<th>Second Year Site 1</th>
<th>Second Year Site 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alona monocantha</td>
<td>0.72</td>
<td>0.96</td>
<td>0.96</td>
<td>1.6</td>
</tr>
<tr>
<td>Bosmina longirostris</td>
<td>1.12</td>
<td>3.44</td>
<td>2.4</td>
<td>3.76</td>
</tr>
<tr>
<td>Macrothrix rosea (By Birge)</td>
<td>1.12</td>
<td>0.72</td>
<td>0.72</td>
<td>2.16</td>
</tr>
<tr>
<td>Ciliophora</td>
<td>1.12</td>
<td>1.12</td>
<td>1.36</td>
<td>2.32</td>
</tr>
<tr>
<td>Daphnia sp.</td>
<td>1.76</td>
<td>0.32</td>
<td>1.6</td>
<td>0</td>
</tr>
<tr>
<td>Diaphanosoma birgei</td>
<td>1.12</td>
<td>1.2</td>
<td>1.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Plagiocampa mutabilis</td>
<td>1.04</td>
<td>0.48</td>
<td>1.28</td>
<td>1.68</td>
</tr>
<tr>
<td>Phylloptomas blanici</td>
<td>0.08</td>
<td>0.56</td>
<td>0.32</td>
<td>2.08</td>
</tr>
<tr>
<td>Nemata sp.</td>
<td>0</td>
<td>0.72</td>
<td>0.08</td>
<td>1.6</td>
</tr>
<tr>
<td>Halophyta simplex</td>
<td>0.16</td>
<td>0.88</td>
<td>0.16</td>
<td>1.76</td>
</tr>
<tr>
<td>Coleps hirutus</td>
<td>0.4</td>
<td>0.99</td>
<td>0.48</td>
<td>0.88</td>
</tr>
<tr>
<td>Total ind.x105 µl^{-1}</td>
<td>8.64</td>
<td>11.39</td>
<td>10.56</td>
<td>19.44</td>
</tr>
</tbody>
</table>

However, the density of individual species of Cladocera were low when compared with Rotifera occurrence, Bosmina longirostris were the most occurred species with the maximum density 3.76 x 10^5 µl^{-1} and 3.4 x 10^5 µl^{-1} at site 2 in both the years and 2.4 x 10^5 µl^{-1} at site 1 in second year. The distinct variability in the settlement and abundance of Cladocera and Protozoa were noticed that represents a seasonal dynamics.
Protozoa were the least occurred species in both the years at two sites contributing mainly *Diffuglia* species. Maximum density recorded among the species of protozoa at site 2 with $2.4 \times 10^5 \mu l^{-1}$ of *Diffuglia* oblong in second year. The species abundance of Protozoa ranged between 0.25 to $7.36 \times 10^5 \mu l^{-1}$ at site 1 and 2 in both the years.

### 3.3 Zooplankton Temporal Distribution

The analyse of Box Whisker Chart (Fig. b) clearly shows the significant difference among the average values, medians and standard deviation among the zooplankton density according to the factor season. This population presents an increased variation in October, November and April, May, June of first year and then decreases to relatively low levels in July and August of the first annual cycle, whereas, total plankton population shows two increased trends during September to January and March to May of the second year.

Fig. c shows the spatial and temporal trends of Rotifera, Cladocera of both the sites. Regarding the two groups of organism, Cladocera and Rotifera, we note that the distribution of Rotifera is independent with the sites but dependent on the seasons, showing decrease in abundance in rainy seasons, whereas two peaks were equally noticed in both the years in summer seasons. As for Cladocera distributions, it is not independent in any of the two cases. These results show that the Cladocera zooplankton have very important seasonal variability in contrast with Rotifers. This population presents a drastic increase in July (1.2), September (1.36) and January (2.08) $\times 10^5 \mu l^{-1}$ at site 2, (0.72, 0.64 $\times 10^5 \mu l^{-1}$) in October and June at site 1.

In the present study it was found that in Lake Thol, rotifers have contributed the maximum densities of zooplankton composition in two years. Rotifers are the nutrient tolerant species and good competitor of survival, and are found with maximum densities in summer seasons. Whereas, Cladocera and Protozoa densities are quite low in this season but contribute good density in October and November. The relative density and compositions of the various groups of zooplankton show that the small sized zooplankton dominated the community. These high values were mostly due to small-bodied nauplii stages, high densities of small rotifers and cladocerans which are characteristic of lakes with planktivorous fishes. Densities of large bodied Cladocera were low during the study period probably as a result of predation pressure. Rotifers are regarded as bio indicators of water quality (Sladecek, 1983; Saksena, 1987) and high rotifer density has been reported to be a characteristic of planktivore fish eutrophic lakes (Sendacz, 1984). The impact of predation on zooplankton abundance is also indicated by Whittaker et al. (2001), where significantly lower plankton density was associated with the presence of the planktivore fish.

### 3.4 Predictions among the Group

The analysis of one way ANOVA in Table 2.1 among the sites for the first year showed the $F(5.84)$ value is greater than critical $F$ value (4.30) with the means of population aims to believe there is no such significant spatial difference in between the two sites density of zooplankton for the first year, whereas in the Table 2.2 second year $P'$ value (0.0005) is lesser than ($\alpha$) value 0.05, supports a significant difference in between the two samples, believed there is difference between the two samples and density/occurrence of zooplankton due to hydro-geochemical properties and depend on the geomorphology of the wetland.

According to the total density of zooplankton (Fig. c) occurred high at site 2 could represent a bias analysis if, as commonly reported, species number depends on lake geomorphology (Walseng, 2006). However, to resist this bias relationship with the application of One-way ANOVA (Table 2.1 and Table 2.2), our study does not reveal any correlation between lake geo-morphology and density of zooplankton $P'=5.84$, greater than critical $F$ value (4.30) of the first year, but, the results of the second year considering $P'=0.0005$, least value than $P'=0.05$, representing correlation between site location and density of zooplankton. The significantly higher density of zooplankton at site 2 (one of the outlet of the lake-littoral zone) supports the findings of Dodson (2000). There is also a shift in the species composition of rotifers, which was represented by 16 species of different genera. Taxonomic dominance of rotifers was reported in several water bodies (Nogueira, 2001; Cavalli et al., 2001; Sampaio et al., 2002; Neves et al., 2003). This pattern is common in tropical and subtropical freshwaters, whether in lakes, ponds, reservoirs, rivers or streams (Neves et al., 2003).
Figure b. Box and whisker plot of total species numbers from both the sites of two years. Vertical line is median of all observations, dark boxes within boxes is median of the category, extension of boxes represents 25th and 75th percentiles and extension of lines is 10th and 90th percentiles.

Figure c. (i, ii) Temporal Abundance Patterns for Rotifera, Cladocera of Two Sites for Both the Years
Table 2.1: P-Values of Single Factor ANOVA of the Two Sites, According to Group of Organisms Density and Season Factor of the First Year September 2007-August 2008

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>F-value</th>
<th>P-value</th>
<th>F critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1</td>
<td>5.84</td>
<td>0.024</td>
<td>4.30</td>
</tr>
<tr>
<td>Within Groups</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.2: P-Values of Single Factor ANOVA of the Two Sites, According to Group of Organisms Density and Season Factor of the Second Year September-2008 to August 2009

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>F-value</th>
<th>P-value</th>
<th>F critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1</td>
<td>16.93</td>
<td>0.0005</td>
<td>4.35</td>
</tr>
<tr>
<td>Within Groups</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This may be due to their special characteristics, i.e., less specialized feeding, high fecundity and frequent parthenogenesis reproduction, constellation of life traits that make them opportunist and typical r-strategist, favoured in unstable and eutrophic environments (Rocha et al., 1995). This may be also due to a wide spectrum of food particles exploited by this group, which display the ability to consume bacteria, algae and detritus of different sizes, which allows quite distinct diets for the many species simultaneously present in the water body (Starkweather, 1980). *Brachionus* and *Keratella* was the prominent genus represented by five species each. The genus *Brachionus* and *Keratella* is the index of eutrophic water (Sladecek, 1983) and its abundance is considered as a biological indicator for eutrophication (Nogueira, 2001). The species *B. calyciflorus* is considered to be a good indicator of eutrophication (Sampaio et al., 2002). Qualitative dominance of zooplankton in net plankton communities of Loktak Lake concurs with the findings of Sharma and Sharma (2010) but differs from the higher phytoplankton richness observed by Sharma and Hussain (2001).

In the present study 11 Cladoceran species are recorded and the most frequent Cladocerans were *Diaphanosoma birgei* and *Bosmina longirostris*. These two members represented major part of Cladocerans; these organisms usually associate with macrophytes, periphyton and sediment (Wnisiewski et al., 2002). According to Uttangi (2001) Cladocerans prefer to live in clear waters. It was observed that more number of Cladocerans species were in monsoon season in both the years at site 2. In the absence of low organic pollution during monsoon seasons may have contributed the maximum abundance of Cladocerans. In conclusion, our study demonstrates that the zooplankton community structure of the wetland Thol has features typical of shallow lakes with high productivity. The seasonal variations among the abundance, spatial difference between the densities of zooplankton and prevailing Rotifers over other groups both in total number and diversity are seen to be typical for high productivity and eutrophic wetland.

4.0 Conclusion:
Three main zooplankton groups were identified in the study (Rotifera, Cladocera and Protozoa) with 30 identified forma. The maximum zooplankton density peaked in October, November and April, May, June of first year and in months of September to January and March to May of the second year, then decrease relatively low during rainy season. Spatially, the highest levels occurred at the outlet (Site 2). Seasons are the important factor influencing zooplankton assemblages. A noticeable decrease in density and species richness of zooplankton was noticed at site 1. With the one way ANOVA application, the community composition do not show any relationship with site specific and found highly changed with time series. Several species of Rotifers were present throughout the study period.

5.0 Acknowledgement:
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Influence of Water Quality on Composition and Seasonal Abundance of Phytoplankton Community in Thol Wetland, Gujarat, India

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ABSTRACT

The study deals with water quality parameters affecting the composition, seasonal abundance and dominance of phytoplankton in a wetland, Thol Bird Sanctuary, Central Gujarat, India. Hydrochemical parameters of water samples were analysed during September 2007 to August 2009. Monthly variation of water quality parameters like temperature, pH, dissolved oxygen, total dissolved solids, total alkalinity, total hardness, chloride, phosphate, sulphate and nitrate were investigated during the study period. Nutrients like chloride, phosphate, sulphate and nitrate were found higher during summer and lower during monsoon months in both the years. 102 phytoplankton taxa were identified of which Cyanophyta represented by 44 species, constituted the largest group, followed by Bacillariophyta by 25 species, Chlorophyta by 23 species and Euglenophyta by 10 species. Remarkable seasonal variation in mean density of Chlorophyta and Bacillariophyta was observed during the study period. Chlorophyta members were present in reasonable numbers throughout the study period, being most abundant in post monsoon and winters. Cyanophyta and Euglenophyta populations showed less seasonal variations except a noticeable increased in density of Euglenophyta in summer 2009. The interrelationship between the hydrochemical properties and phytoplankton assemblages and influence of water quality parameters were investigated by adopting statistical correlation coefficient analysis and linear curves. The hierarchical cluster analysis was used to define biologically distinct regions within the wetland based on the composition of phytoplankton.

INTRODUCTION

Phytoplankton are the main primary producers and they condition the structure and density of consumers as well as hydrochemical properties of water (Harold et al. 2007). The community varies widely in respect to taxonomic composition and cell size and their density increase with increasing nutrient status or trophic state (Senerpont 2007).

Phytoplankton are very suitable organisms for the determination of the impact of toxic substances on the aquatic environment because any effect on the lower level of the food chain will also have consequence on the higher level (Akbulut et al. 2001). Phytoplankton encountered in the water body reflect the average ecological condition and therefore, they may be used as indicator of water quality (Hakason et al. 2003). Several studies in India, have correlated phytoplankton composition in response to water parameters in wetlands and reservoirs under distinct trophic states. Chattopadhyay & Benerjee (2007) observed phytoplankton response immediately to the surrounding changes and hence, their standing crop alters due to indicated water quality. Knowledge of phytoplankton population dynamics is relevant because temporal and spatial fluctuations in composition and biomass may be efficient indicators of natural or anthropogenic alterations in the aquatic ecosystems (Prescot 2004, Olele 2008).

Studies on phytoplankton diversity and abundance in Gujarat are sparse and restricted to mere short term taxonomic observation reports. However, certain limnological studies were done by Nirmal Kumar et al. (2005) on assessment of eutrophication and weed growth of certain wetlands. Nirmal Kumar et al. (2006, 2007, 2008) examined the patterns of site-specific variation of waterfowl community, abundance and diversity in relation to seasons in Nal Wetland Bird Sanctuary. Nirmal Kumar (2008, 2009) assessed the variations in hydrochemical characters of wetlands of Gujarat. The present work assessed the composition and seasonal variation of phytoplankton in relation to hydrochemistry to understand the status of the wetland Thol Bird Sanctuary.

MATERIALS AND METHODS

Site description: Thol is a shallow wetland with maximum depth of 3 m, having an area of 6.99 sq. km and located 24 km from Ahmedabad city, district Mehsana (23°15’ to 23°30’ N and 72°30’ to 72°45’ E) of Gujarat. The wetland was declared as a bird sanctuary in November 1988, which inhabitant hundreds of bird species of which 30 bird species are migratory. Wetland Thol is characterised by alkaline
nature of water and good oxygenation of surface water. For decades the wetland has been used for irrigation purposes and fishing (Fig. 1). Rural settlement is found towards the north east and north west direction of the wetland. As the wetland comes under the natural conservation area for birds of Gujarat, the anthropogenic activities such as washing, poaching, bathing, cattle wading and illegal entry are strictly restricted. Birds like Common coots, Shelduck, Common pochards, Flamingoes, Painted stork, Spoonbills, Ibis are dominant species throughout the investigated period and Spot Billed Duck, Eurasian Wigeon, Asian openbill are found mostly seasonal and appeared only during in winter season. Ipomea aquatica, Polygonum glabrum, Typha angustata, T. domingensis, Eichhornia crassipes and Salvinia natans are some marshy and floating aquatic macrophytic species providing food and shelter to these aquatic fowls.

**Water sampling and analysis:** Monthly surface water samples were collected for two years (September, 2007 to August, 2009) for physical and chemical analysis at two stations (Stations 1 and 2). Collection was made between 7:00 and 9:00 hours IST (Indian Standard Time). Samples for dissolved oxygen were collected just a few centimetres below the surface and fixed with Winkler’s reagents. The collected samples were brought to the laboratory within 1h and stored in a refrigerator for further analysis. The physico-chemical analysis was made following the methods given by APHA (2000) and Trivedy & Goel (1987). The average of two samples was considered as one reading.

**Phytoplankton sampling and identification:** The phytoplankton samples were simultaneously collected by using 20 µm mesh size planktonic net along with the water samples, and fixed by addition of 1 mL of 4 % formalin solution. The camera lucida diagrams were drawn under light microscope and identification of phytoplankton was made by using various monographs, books and published literature (Desikachary 1959, Prescott 2004, Hadi et al. 1984).

**RESULTS**

The average hydrochemical properties of water are given in Table 1 for the two years, and Fig. 2 shows their annual variation. Water temperature varied from 14.8 to 29.6°C and the maximum water temperature was achieved in the summer season of second year, and the minimum in the winter season of the same year. Values of pH remained alkaline, and lowest value of 8.2 was observed in the monsoon season of the first year. The dissolved oxygen fluctuated between 4.5 and 7.9 mg/L, with minimum values in May, and maximum values (7.9 mg/L) in winters of the second year. Decomposition processes and sediment oxygen demand were sufficient to cause lower dissolved oxygen values. In the dry period Thol wetland had low dissolved oxygen, and high pH and temperature, when compared to rainy and winter seasons.

Total alkalinity values varied in a narrow range from 173 to 244 mg/L. In first year alkalinity was characterized by higher values than the second year. Chlorides attained their maximum in post monsoon season (154 mg/L) and found minimum in monsoon season (71 mg/L) of first year, whereas in the second year the values of chlorides ranged from 69 to 146 mg/L.

Nutrient analysis revealed the remarkable differences, observed in the concentration of nitrate and phosphate after monsoon season. Sulphate values ranged between 16 and 80 mg/L, and phosphate between 0.5 and 3.3 mg/L. The recorded high phosphate values are probably due to release of great amounts of runoff from the agriculture fields, and the lower values of phosphate could be attributed to vigorous uptake by plankton. The maximum value of nitrate was found in summer (1.2 mg/L), and minimum in winter (0.2 mg/L). The highest values of nitrate reflect the direct effect of the agriculture run off, while the lowest values are the indicator of phytoplankton uptake. On the other hand, phosphate content was recorded maximum in summer season (3.3 mg/L), and minimum in monsoon season (0.4 mg/L). Mean concentration of sodium (247 mg/L) and potassium (212 mg/L) were recorded maximum in second year.

The correlation analysis of the important parameters with the phytoplankton density showed a positive correlation of temperature with Cyanophyta (0.17), Bacillariophyta (0.05) and Euglenophyta (0.02), and DO with Cyanophyta (0.65). Further, sulphate and nitrate also showed a positive correlation with Cyanophyta (0.47) and Euglenophyta (0.49). Following a similar trend at site 2 also, DO correlated positively with Cyanophyta (0.39), Chlorophyta (0.61) and...
Table 1: Hydrochemical characteristics of water in Thol Bird Sanctuary.

<table>
<thead>
<tr>
<th></th>
<th>First Year 2007-2008</th>
<th>Second Year 2008-2009</th>
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</thead>
<tbody>
<tr>
<td></td>
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<tr>
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<tr>
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<tr>
<td>K</td>
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<td>26.70</td>
</tr>
</tbody>
</table>

All values are in mg/L except temperature (°C) and pH; Standard Deviation (SD); Standard Variance (SV)

Bacillariophyta (0.58). Nitrate also showed a positive correlation with Cyanophyta (0.76), Chlorophyta (0.58) and Bacillariophyta (0.58).

Phytoplankton: The phytoplankton consisted of total 102 taxa belonging to Cyanophyta (44), Bacillariophyta (25), Chlorophyta (23) and Euglenophyta (10) (Table 3). According to the percentage distribution of species diversity, the highest rich algal group was Cyanophyta (42.8%). In terms of the counting results, the total density of Bacillariophyta, Chlorophyta and Euglenophyta was 31.0%, 19.7% and 5.6% respectively (Table 3).

The diagram obtained from cluster analysis showed that the five different groups comprised in the water samples at 14% hierarchical level (Fig 4). The first important group within these was characterized by the dominance of Coelastrum cambricum and other group species Cosmarium monomatum and Aphanocapsa elachista. The second important group was characterised by the increase of the green algae. In this month Scenedesmus and Pediastrum from Chlorophyta were dominant species. The second group was characterized by the increase of the green algae together with beginning of spring and end of winter. The third group comprised with the decline of blue green algae, green algae and the increase of diatoms. Cyclotella and Nitzschia from the diatoms and also Anabaena, Aphanocapsa, Gloeocapsa, Merismopedia and Microcystis from Cyanophyta were prevalent species in the same group.

When the relative abundance of species in the samples of the two years was compared, the highest similarity was seen between the first and second year. According to the diagram obtained from cluster analysis, similar clusters were seen between different months of both the years (Fig. 4).

**DISCUSSION**

Wetlands exhibit different water quality status depending on the geological formation in the catchment and inflow includes wastewater (Bendell-Young et al. 2000). It is evident that the maintenance of healthy conditions in aquatic systems is dependent on the hydrochemical properties of water and biological diversity. The temperature of the water body is an important parameter influencing the water quality. In both the years temperature varied according to the seasonal fluctuations of atmospheric temperature with maximum during summers and minimum during winters (Nirmal Kumar et al. 2005). Dissolved oxygen is an important parameter of aquatic system, which is essential to the aerobic metabolism of all aquatic organisms (Wetzel 1975). In summer with the increase in water temperature, there was reduction in DO, whereas in winter months due to decrease in temperature, the level of DO increased. These results were in conformity with Ahmed Masood & Krishna Murthy (1990) and Srivastava et al. (2003). Comparatively low values of DO in the first year indicate an oxygen deficient condition, which could be due to the high respiratory activity of the biota present there (Alom & Zaman 2006). Low quantity of water level during spring, summer and pre monsoon may be the reason for the increase of the chloride concentration which corroborated with the study of Sukhija (2007). Higher values of hardness were observed during summer, which may be due to low water level and high rate of decomposition and evaporation thus concentrating the salts (Chatterjee & Raziuddin 2007).

High concentration of nutrients like phosphate, sulphate, chloride, nitrate and others was recorded in second year. High phosphate concentration indicates fertilizer runoff, domestic waste discharge and detergents. Similar observations were also made by Khare et al. (2007). The monthly variation of hydrochemical properties also indicated that concentration of nutrients was greater during warmer months in the wetland, which could be attributed to high atmospheric temperature, evaporation and high amount of entry of waste discharge from surrounding villages corroborating with the findings of Ranjan et al. (2007).

In tropical regions, different algal groups were seen as if they followed typical succession model (Reynold 2004). It is thought that these successions cause the variations related to the use of the light and temperatures. According to the number of species, Chlorophyta and Bacillariophyta type of
Phytoplankton existed in Wetland Thol. The wetland had a typical phytoplankton population of eutrophic wetlands, which represent members of Chlorophyta, Bacillariophyta and Cyanophyta along with harmful water blooms (Paerl et al. 2001). The seasonal succession of algae in Wetland Thol was Chlorophyta and diatoms in the spring, Chlorophyta in early summer, Cyanophyta in late summer and Diatoms in autumn and winter. Generally, it was a complicated succession, as it happens in many shallow tropical wetlands (Hutchinson 2007).

In the dendrograms obtained from cluster analysis, species making blooms encountered as densely composed groups. *Monoraphidium* sp., *Oocystis borgei*, *Pediastrum boryanum* and *Secenedesmus* sp. showed blooming sometimes. Round (2002) reported that some Chlorococcales members are quite abundant in tropical wetlands showing transition from oligotrophic condition to eutrophic one. In terms of Hutchinson (2007), these species are dominant organisms in eutrophic waters. Wetland Thol is located in sensum environment; green algae are dominant and are responsible for making blooms in some months. Also, *Chroococcus* sp. from blue green algae and *Euglena gracilis* from euglenoids were prevalent species in the wetland having eutrophic properties in particular. Prescott (2004) reported that Cyanophyta members make blooms in the stagnant water of certain tropical wetlands. In the eutrophication of wetland ecosystems, the blooming of blue greens is a frequent event (Moss et al. 2006). Blue green algae are the most prevalent and harmful for people and limit the convenient use of water (Pitois et al. 2001).

When the phytoplankton dynamics expressed to seasons, blue green algae were found to make blooms in summer and early autumn. *Cryptomonas* genus is an indicator of eutrophic wetlands (Akbulut & Yildiz 2001). In these months, blue greens and green algae made blooming in phytoplankton. *Anabaena catenula*, *Microcystis aeruginosa*, *Nodularia spumigena* and *Pseudoanabaena limnetica* species were noticed important increases in summer and late autumn.

Because of organic pollution, Euglenoid members were often found in Wetland Thol. *Phacus* and *Trachelomonas* from Euglenophyta were dominant organisms in spring months. It is reported that Euglenophyta members generally develop very well in waters which is rich in organic substances (Round 2003).
The results obtained from cluster analysis and the counting methods supported to each other regarding phytoplankton abundance. There was no difference between the phytoplankton composition and the seasonal dynamics except for some months. When the diagram was examined, the dominant species comprised groups in cluster analysis of both the years. It was reported that these taxa composed of groups in wetland with eutrophic characteristic (Hutchinson 2007).

Diversity of plankton population is fairly dependent on quality of water and climatic factors. Phytoplankton diversity and productivity are strongly related to water quality (Moss 2006) as well as to biotic factors (Kruk et al. 2002). The non-monsoon months recorded higher phytoplankton density when compared to the monsoon months as observed from the density values. The fall down of the phytoplankton community in monsoon months can be attributed to dilution of the phytoplankton biomass caused by runoff. The average values of the chemical parameters and the algal group densities for the first year and the second year depicted that sulphate and nitrate seem to be stimulating growth of the different algal groups as evident from the positive correlation coefficient values. Phosphate seems to limit the growth as depicted from the negative correlation coefficient values for both the years with Chlorophyta and Bacillariophyta density. Ersanli et al. (2003) stated that temperature, pH, alkalinity and phosphate have been emphasized to be limiting factors for controlling distribution of Cyanophyceae which also corroborated with the present study. Tripathy & Panday (1990) and Rana & Nirmal Kumar (1993, 2005) reported that high water temperature, phosphate, nitrate and low DO support the growth of Chlorophyceae. pH was found to be in the alkaline range (8.9 to 9.3) supporting a good population of the diatoms. Moreover, DO content was found to be considerably high in colder months. The plankton community, on which the whole aquatic population depends, is largely influenced by interaction of a number of limiting factors and number of hydrochemical and biological factors acting simultaneously must be taken into consideration in understanding the diversity of plankton population. The data obtained from this study indicated that the wetland is progressing to eutrophication stage.

**REFERENCES**


SPATIAL AND TEMPORAL PATTERNS OF WATERBIRD ABUNDANCE AND SPECIES RICHNESS IN A SEWAGE FED WETLAND, KHODIYAR, GUJARAT, INDIA

J.I. Nirmal Kumar, Manishita Das, Rita N. Kumar, Yamini Verma

Abstract. The structure, composition and abundance pattern of species of waterbird assemblages in sewage fed wetlands has been poorly documented. The study explored censuses of twelve month from January to December, 2008. Overall, 71 waterbird species belonging to 48 genera and 15 families were registered, including 38 species year-round residents and 33 migratory species. Among these, 9 species were considered to be abundant, 38 species common and 24 species rare. The number of species varied among sites and showed seasonal pattern. Abundances were good in number during the winter period due to increased abundance of Anseriformes, Gruiformes and Ciconiiformes. Overall waterbird density was highest where resident species such as Greater Flamingo, Little Egret, Glossy Ibis and Black-winged Stilt were present; some migratory species such as Garganey, Northern Shoveler, Common Coot, Black-tailed Godwit and Ruff contributed to areas with high density during cooler days. The monthly data were pooled to compare various indices of species diversity, i.e. Shannon–Weaver (H'), Evenness (Hill’s) Index and Simpson’s Index. The Shannon–Weaver (H') varied from 1.813 to 1.531, Evenness (Hill’s) Index from 34 to 65 and Simpson’s Index from 0.038 to 0.069. The local abundance and composition of waterbird assemblages seemed to be affected by the interplay of several environmental factors.

Key words: fauna, community, number, wetland.

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INTRODUCTION

Wetlands represent highly complex environments, and constitute sites where numerous bird species concentrate and have some of the highest biodiversity and biological productivity levels in the world and several globally threatened avian species depend on them (Paracuellos, Telleria, 2004). Waterbirds comprise a large group of species including Anseriformes, Charadriiformes, Ciconiiformes, Gaviiformes, Gruiformes, Pelecaniformes, Podicipediformes and Procellariformes (Nirmal Kumar et al., 2007; Bolduc, Afton, 2008). Waterbird communities experience seasonal and annual fluctuations in abundance and species composition, on a local, as well as on a regional scale (Romano et al., 2005). Variations in bird abundance result from population processes (i.e. birth and death rates), as well as migration among habitats (Poulin et al., 1993). Bird abundance at a local scale depends on morphometric characteristics, availability, distribution and density of food, and the availability of suitable sites for roosting or resting (Wiens, 1989). Moreover, variations in habitat conditions may also produce changes in community species composition (Caziani et al., 2001). The community of waterbirds in sewage ponds has not been documented; where nutrients might be limiting sewage fed environments usually belong to either the eutrophic or hypertrophic categories (Hamilton et al., 2005). Waterbird abundance generally responds to processes of nutrient increases (or decreases) in inland waters (Noordhuis et
al., 2002), for example some wintering waterbird species respond positively to nutrient inputs during a period of lake eutrophication (Martínez et al., 2005). Therefore, this study highlights spatial and temporal changes in the abundance and distribution of waterbirds, in the sewage fed wetland, Khodiyar, Gujarat, India, from January to December 2008.

MATERIAL AND METHODS

Study Area

Khodiyar wetland is located between 22° 34’ 56.15´´ N latitude and 72° 56’ 56.90´´ E longitude and situated 5 km away from Anand, Central Gujarat (Fig. 1). The wetland is fully down pour of sewage water received from Municipal sewage lines of Vallabh Vidya nagar and Anand Town, so called ‘sewage fed wetland’. The sewage fed wetland gains its importance due to the presence of seventy species of waterfowls, especially during cooler months of the year. The acute pressures affecting the bird folk are a railway line which passes in between the wetland, cattle interferences, irrigation, soil excavation and poaching by local folk. Even municipal’s solid wastes are dumped here at some extent.

The macrophyte species mainly dominating is *Eichhornia crassipes*, besides, *Alternanthera philoxeoides*, *Ipomoea aquatica* and *Azolla pinnata* invade the open water areas admist *Eichhornia crassipes*. A small area on the margins is covered by *Typha angustata* and *Ipomoea convolvulus*. Terrestrial vegetation like *Prosopis juliflora*, *Acacia* spp. and *Zizyphus jojoba* are found on the banks of Khodiyar. The vegetation provide the nesting and hatching grounds to many avian species.

This wetland experiences semi arid climate. The summer season started from March and continued till the onset of the western monsoon, and arrived in the third-fourth week of the June. The monsoon season lasted till mid September followed the winter months from November till February. Three sites have been earmarked for the present study.

Study site 1 (K1). This site (Fig. 2) is located near to Khodiyar village with a depth of 7–8 feet, which is highest amongst three study sites. The macrophyte species mainly dominating is *Eichhornia crassipes*. The avian fauna includes Egrets, Jacanas, Ibises, Black-winged Stilts (*Himantopus himantopus*), Purple Swamphens (*Porphyrio porphyrio*) and Herons but density and diversity is poor as compared to other two sites.

Study site 2 (K2). The site (Fig. 3) is located on one side of the railway track. The water depth is lowest (1 to 4 feet). The dominant plant species at this site is *Eichhornia crassipes*, while a small area is covered by...
Typha angustata and Ipomoea aquatica, I. convolvulus on the margins. Typha angustata and I. convolvulus provide the nesting and hatching grounds to many aquatic avian species. The site is dominated by Flamingos, Egrets, Sarus Cranes (Grus antigone), Stilts, Ibises, Jacanas, Herons and many winter visitors like Spoonbills (Platalea leucorodia), Garganeys (Anas querquedula), Northern Shovelers (A. clypeata), Pintails (A. acuta), Common Coots (Fulica atra), Ruffs (Philomachus pugnax), Graylag Goose (Anser anser), etc.

Study site 3 (K3). The water depth of this site (Fig. 4) is shallow (1 to 6 feet). The floral species dominating the site is Eichhornia crassipes while Typha angustata and I. convolvulus provide the nesting and hatching grounds to many aquatic avian species. The site is dominated by Flamingos, Sarus Cranes, Egrets, Stilts, Ibises, Ruddy Shelduck (Tadorna ferruginea), Purple Swamphens, Herons and many winter visitors like Spoonbills, Garganeys, Shovelers, Coots, Ruddy Shelduck, Ruffs, Pintails, Common Teals (Anas crecca), etc.

Waterbird Survey

The enumeration of waterbird abundance and species composition was carried out on monthly basis from January to December 2008. Waterbirds’ abundance was calculated during the morning feeding between sunrise and 9th by point count method (Rogers, Breen, 1990). In each census, all birds present at three sites were counted separately and identified to species level using binoculars, (Romano et al., 2005) and species compositions observed were identified with the help of standard literature by Ali (1996), Kazmierczak and Perlo (2000) and Grimett et al. (1999).

Indices

The 12-months of data were pooled to compare various indices of species diversity, Rarefaction and Abundance plot, Species
Diversity/Species Richness Indices: Shannon–Weaver (H') (1963), and Evenness Index (Hill 1973) index and Dominance (Simpson’s Index) (1949), as per the BD pro software. Total bird count recorded with less than 100 individuals during survey were categorized rare; between 100 to 500 individuals as common and that recorded more than 500 individuals were assigned abundant status (GEER, 1998).

RESULTS

24,032 individuals of 71 waterbird species, belonging to 48 genera and 15 families, were recorded in 12 census, carried out on monthly basis. Out of these, 38 (53.5%) species accounted for year-round residents and 33 species (46.5%) are migratory. Species occurrence varied month after month and site by site with K1, being the site with the lowest species richness. Whereas, K2 and K3, species richness was higher especially during the winter, with the inflow of migratory birds.

The most representative families noted were Anatidae with 14 species, Scolopacidae (10 species), Ardeidae (9), Charadriidae (7), Laridae (5), Threskiornithidae and Rallidae (4 species each). Nine abundant species encountered and contributed 12.7% which includes resident waterbirds such as Greater Flamingo (*Phoenicopterus ruber*), Little Egret (*Egretta garzetta*), Glossy Ibis (*Plegadis falcinellus*) and Black-winged Stilt and migratory birds such as Garganey, Northern Shoveler, Common Coot (*Fulica atra*), Black-tailed Godwit (*Limosa limosa*) and Ruff. 38 species (53.5%) of common birds were observed, while 24 species (33.8%) were found to be rare (Table).

Community composition varied in response to change in season and climatic variations. Abundances were higher in wintering period due to increased species of Gruiformes, Anseriformes and Ciconiiformes. The maximum number (100%) of families was recorded during summer and winter, followed by 73.3% during the monsoon period. On the basis of genus, the maximum number (100%) occurred during winter, followed by summer (85.4%) and monsoon (54.2%). Numbers of water birds species was greater in winter (94.5%), followed by summer (72.%) and monsoon (53.2%). Migratory species made their greatest contribution during winter. All species considered to be abundant were documented during winter and summer (100% each), followed by 44.4% during monsoon, while peak values of species of common occurrence occurred during winter (98.0%), and followed by summer (96.1%) and monsoon (78.4%). Among rare species, 90.0% were documented during winter, followed by summer (44.0%) and monsoon (22.0%). Overall, water birds were most abundant during winter (58.5%), followed by summer (32.8%) and monsoon (8.3%). The abundance of water birds recorded at Khodiyar wetland during different seasons largely corresponded to their density. The density of water birds was maximum during

Fig. 4. Study site K3 with waterbirds and a passing train.
Рис. 4. Участок К3 с гидрофильными птицами, виден проходящий поезд.
Waterbirds found during study period at Khodiyar wetland
Гидрофильные птицы, зарегистрированные в Ходияре

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### Birds Encountered at the Three Study Sites

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Winter (69.7%), followed by summer (52.0%) and monsoon (15.6%). Similar observations were made by Romano et al. (2005) in Melincue Lake, Argentina, while studying the seasonal and interannual variation in waterbird abundance and species richness.

The species richness was greater at K3 followed by K2 and K1, as shown by the rarefaction plot (Fig. 5). At site K1, 34 species were identified belonging to 10 families where as site K2 sheltered 62 species and a total of 65 species, belonging to 15 families were documented at study site K3. However the maximum abundance was observed at
study site K3, followed by K1 and K2, (Fig. 6). The water bird populations of Khodiyar wetland fluctuated among sites in different seasons due to local, environmentally dependent factors (Nirmal Kumar et al., 2007). The concentrations of wintering waterfowls were more pronounced at K2 and K3, as compared to K1.

A total of 34 species belonging to 10 families were identified at K1. The most common was Ardeidae, with seven species. At K2, 61 species were identified, belonging to 15 families. The family rich represented was Anatidae, with 13 species. Northern Shoveler and Garganey were observed on the entire wetland surface as common species, whereas Ruddy Shelduck and Tufted Duck (*Aythya fuligula*) were sighted only in the central part of the wetland. The rest of the species were found on both the central vegetation and the wetland shores. The study site K3 sheltered sixty six species. Avocet (*Recurvirostra avosetta*) was exclusive to this site; which was sighted only twice as transient individual on its way back to north, (Severo et al., 2002). It is worth noting that one of the species Sarus Crane found at both K2 and K3 has a vulnerable status listed in IUCN Red List, 2007 besides White Ibis (*Threskiornis melanocephalus*) a near threatened species as per IUCN Red List, observed in aplenty at this wetland.

The spatial and temporal variations of some of the abundant, common, rare and very rare waterbirds have been shown in Figures 7–10.

The various diversity indices for waterfowls are shown in Figure 11. The higher value for Shannon’s index was observed at K2 (1.546) followed by K3 (1.524) and K1 (1.353), similar trend was observed for Hill’s index (Hill’s Number H1) which had a maximum value (244.93) at K2, followed by (227.61) K3, and minimum value (128.97) at K1. It was noticed for Hill’s index (Hill's...
Fig. 7. Spatial and temporal variations of numbers of abundant waterbirds in Khodiyar wetland.
Рис. 7. Динамика численности многочисленных видов птиц на трех участках.

Fig. 8. Spatial and temporal variations of numbers of common waterbirds in Khodiyar wetland.
Рис. 8. Динамика численности обычных видов птиц на трех участках.
Fig. 9. Spatial and temporal variations of numbers of rare waterbirds in Khodiyar wetland. Рис. 9. Динамика численности редких видов птиц на трех участках.

Fig. 10. Spatial and temporal variations of numbers of very rare waterbirds in Khodiyar wetland. Рис. 10. Динамика численности очень редких видов птиц на трех участках.
system, this may be considered an important arrival and refuge area for avian fauna in spite of its small size.

Waterbirds respond locally to the main spatial and environmental gradients of nutrient discharges into the Khodiyar wetland. Site K2 evidently had the highest species richness due to inhabitant characteristic of larger variety of aquatic macrophytes, which provide greater habitat heterogeneity for the avian fauna. Severo et al. (2002) pointed out that birds can be shown to be influenced by many factors, the more relevant ones are the trophic status and the aquatic macrophytes, since they are correlated with an increase in the number of species which probably could exhibit the spatial and temporal patterns of waterfowl community. Similarly, Hoyer and Canfield (1994), examined trophic status, lake morphology, and macrophytes, and found a close correlation between greater trophic status and increase in species richness and abundance of birds. Nirmal Kumar et al. (2008) observed higher nutrient enrichment at K2 in the same wetland which could be the reason for the high waterbird abundance at this site.

Water depth is paramount in explaining waterbird density, and determining whether or not habitat is available; waterbird diversity generally is good at low water depth (shallowness) and correlated to hydrological diversity (Colwell, Taft, 2000; Holm, Clausen, 2006), therefore in our study at site K1 with higher water depth and lower degree of nutrient enrichment could be considered to be the prominent reasons for the low waterbird diversity, however reverse is the condition in site K2 followed by K3.

**CONCLUSIONS**

It is revealed that overall, 71 waterbird species belonging to 48 genera of 15 families were documented, which included 38 species...
year-round residents and 33 species migratory species. Among these, 9 species were considered to be abundant, 38 species common and 24 species rare. It is worth noting that one of the species Sarus Crane, found at both site K2 and site K3 has a vulnerable status listed in IUCN Red List, besides White Ibis a near threatened species as per IUCN Red List, observed in aplenty at this wetland. From the present study it was revealed that existence of various patterns of spatial and temporal segregation among the waterbird reflected the different requirements that are met by these limnologically variables. Higher values of Shannon’s and Hill’s indices indicated rich waterbird abundance and species richness at site K2 followed by K3 and K1, on the other hand Simpson’s indices denotes low waterbirds at site K1.

**REFERENCES**


