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Zooplankton community of Keibul Lamjao National Park (KLNP) Manipur, India in relation to the physico-chemical variables of the water*

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Abstract Keibul Lamjao National Park (KLNP), a floating park in Loktak Lake, Manipur (India) was studied from Winter (WIN) to Post Monsoon (POM) for its zooplankton composition and some selected water parameters. The resultant data were subjected to multivariate techniques—Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA). Analyses of water parameters with PCA revealed that the first PC axis (PC1) accounts for maximum variance in the seasonal data, explaining a variability of 91%. The PCA revealed that the seasonal variability in water parameters was due to the wet and dry cycle of seasons and the stations were distinguished on the basis of transparency and turbidity. Zooplankton abundance was dominated by copepods followed by cladocerans. Temporally, abundance of copepods reached a maximum during Post-monsoon (POM) (3 880 ind./L). Spatially, S6 was found to be most abundant of the other stations in zooplankton. Copepodites and nauplii larvae were the major components of zooplankton. The Rotifera were the least abundant among the three zooplankton groups. *Brachionus* formed the major component of Rotifera zooplankton at all the stations during the study period. In the Cladocera, *Macrothrix* was present during all the four seasons, while *Pleuroxus*, *Oxyurella*, *Kurzia* and, *Diaphanosoma* were rare. The CCA shows that maximal temporal variability in zooplankton abundance was explained by temperature and rainfall. ANOVA revealed no significant difference in mean zooplankton abundance among the seasons, but there was a statistically significant difference among the sites.

Keyword: zooplankton; Principal Component Analysis (PCA); Canonical Correspondence Analysis (CCA); abundance; Loktak Lake

1 INTRODUCTION

Zooplankton are the main structural link between the primary producers and higher trophic levels in aquatic ecosystems. Their community structure-like composition and densities are affected by biotic factors, as well as abiotic factors like temperature (Edmondson, 1965), salinity (Egborge, 1994), pH (Sprules, 1975) and electrical conductivity (Pinto-Coelho et al., 1998). Investigations of zooplankton communities in different ecosystem types have been carried out by different workers in India (Gopal and Zutshi, 1998; Jana, 1998). The Keibul Lamjao National Park (KLNP) is a part of Loktak Lake (Ramsar site)—the largest fresh water lake in Northeast India. This lake has seen a slow deterioration in its water quality (Kosygin and Dhamendra, 2009) and change in its hydrological regimes—from a natural wetland with annually fluctuating water levels into a reservoir with less fluctuation of water level due to the construction of the Loktak Multipurpose project for hydro power generation and irrigation (Singh and Singh, 1994). As reported by the authors (Sharma et al., 2013) water quality in this park is relatively good. The zooplankton community of this

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lake has been studied by different workers (Singh, 1991; Sharma, 2007; Sharma and Sharma, 2009, 2011). Recently, Reddy (2013) reported and described *Tropodiaptomous signatus* Keifer, 1982 from two samples archived at the Zoological Survey of India (ZSI), which were collected from KLNP. Work on the community structure of zooplankton of the aquatic eco-system of KLNP is, however, lacking. So, the present communication will help to fill the lacunae in scientific understanding of community structure of this unique ecosystem. This work is also different from the previous works on zooplankton from Loktak Lake, in that the multivariate data analysis techniques, including Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA) have been employed to understand the underlying gradients and hidden factors which are responsible for spatial and temporal changes in the zooplankton assemblage.

2 MATERIAL AND METHOD

2.1 Study area

Keibul Lamjao National Park (KLNP) (Fig.1) is located in the southern part of Loktak Lake covering an area of about 40 square kilometers. This park consists of floating *phumdis* (masses of heterogeneous mixture of vegetation and decomposing organic matter), hillocks and elevated strips of land. *Phumdis* float on lake water with about one-fifth of their thickness above and four-fifths under the water surface appearing in three distinct vertical zones, lying one above the other (Fig.2a). The uppermost root zone is generally 10–15 cm thick followed by the next mat zone of 25–65 cm and the lowermost peat zone 10–25 cm. Free-floating plants, such as water hyacinth and partly decomposed roots and rhizomes contribute greatly to its development (Devi and Sharma, 2008). Besides its uniqueness as the only floating park, this is the only natural home to endangered *Sangai* (*Rucervus eldii eldii*). A detailed habitat feature of this park is given by Trisal and Manihar (2004).

Six sampling stations were chosen inside KLNP (Fig.1) taking into consideration the feasibility of approaching, presence of open water and maximum representation of the park. Here is a brief description of the sampling stations. Sagram (S1) is located in the northern side, close to Chingjao Hill. It is a small opening on the *phumdis* forming a small open water body. Thangbarel (S2) is again a small open water body close to Sagram. Chingmei (S3) is a small water way, made by clearing *phumdis*, leading to the Toya

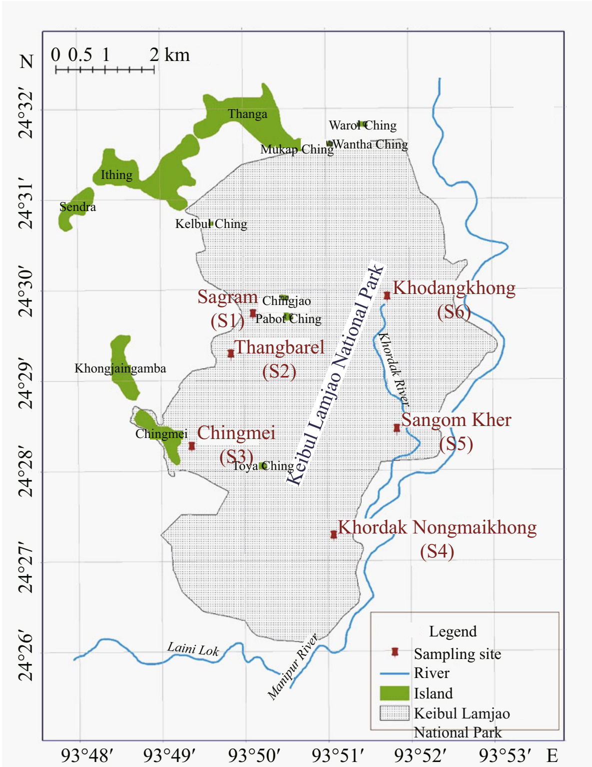

Fig.1 Map of Keibul Lamjao National Park (KLNP) showing the location of sampling stations

Sagram (S1), Thangbarel (S2), Chingmei (S3), Khordak-Nongmaikhong (S4), Sangomkher (S5), Khodangkhong (S6).

hillock located deep inside the park. The width of the waterway is nearly one meter. Khordak-Nongmaikhong (S4) is located in the south-eastern part of the park. Here also water was collected from small waterways, made by clearing of *phumdis*. Water courses pass through these waterways with weak currents resembling a small river. Depending on the opening and closing of Ithai Barrage the direction of water current changes. Sangomkher (S5) is a small opening made by the local fishermen by clearing *phumdis* for making embankments of their fish farms later. Water stands still in this station. Khodangkhong (S6) is located in the eastern part of the park near the mouth of Khordak River. This sampling point is extensive open water where fishing takes place. Zooplankton and water samples were collected seasonally from each station in three replicates during Winter (December 2009, January and February 2010) to Post Monsoon (September, October and November 2010). A total of 72 samples (3 replicates × 6 stations × 4 seasons) were collected.

2.2 Physico-chemical analysis

Water samples were collected from the subsurface

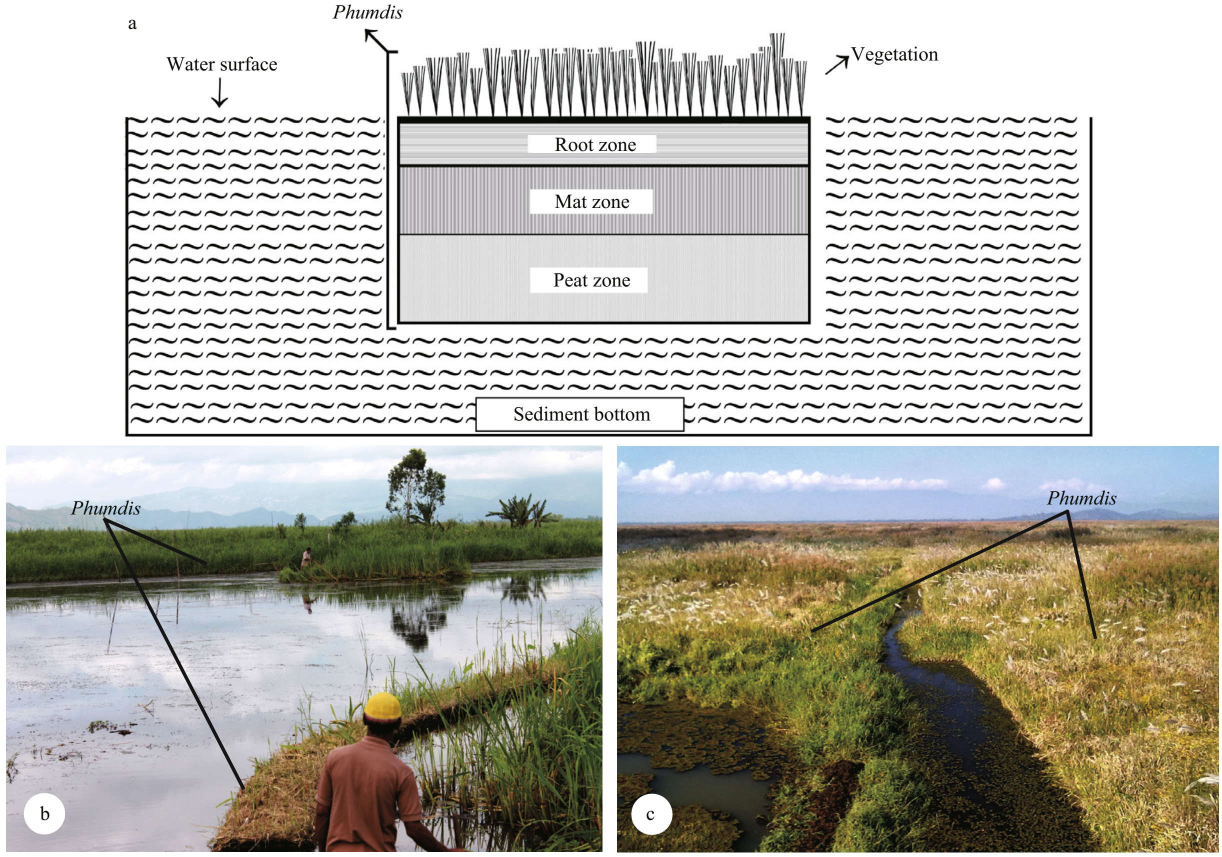

Fig.2 Schematic diagram of *phumdis* showing its different layers (representation purpose only, not to scale) (a) and photos of the study site showing *phumdis* (b, c)

(20 cm) layer using PVC bottles. Six parameters were measured in situ. Water temperature (WT) was measured using a standard mercury in glass thermometer. The pH, Electrical Conductivity (EC) and Turbidity (Turd) were measured using a Eutech pH meter (Model. pH 5/6 & Ion 5/6), a hand-held conductivity meter (Model. CON 6/TDS 6), a portable turbidimeter (Model. TN10/T10) respectively (Eutech Instruments, Singapore). Transparency (Tran) was measured by a Secchi disc. Dissolved Oxygen (DO), Chloride (Cl^{-}), Total Hardness (TH), Calcium (Ca^{+2}) and Magnesium (Mg^{+2}) were estimated by standard methods of APHA (2005). Rainfall (RF) data was obtained from the Environment and Ecology Office, Government of Manipur, India.

2.3 Zooplankton analysis

Zooplankton samples were collected by filtering through a plankton net (mesh size: 40 µm) 25 L of water-collected from the sub-surface layer (20 cm) with least disturbance, using a 5-L bucket. The samples were fixed in 4% formalin, transferred to specimen tubes and further concentrated to 25 mL. Enumeration of zooplankton populations was done by taking a 1-mL aliquot of the above thoroughly mixed homogeneous sample into a Sedgwick Rafter counting cell under a microscope (Dewinter Binocular Biological Microscope). Three replicates from each sample were counted and the average taken. The results were expressed as ind./L. The zooplankton samples were identified using standard literature (Edmondson, 1963; Michael and Sharma, 1988; Battish, 1992; Haney et al., 2013).

2.4 Data analysis

The physico-chemical variables of the water were synthesized using Principal Component Analysis (PCA). PCA is an ordination technique used to reduce the dimensionality of multivariate data sets and enable graphical representation of relationship between variables (Waite, 2000; Arora and Mehra, 2009). To characterize the source of variability in seasonal data and station-wise data, two PCAs were computed, one for the temporal variation and another for the spatial variation. The variables were $\log_{10}(x+1)$ transformed except for pH, to make the data normally distributed.

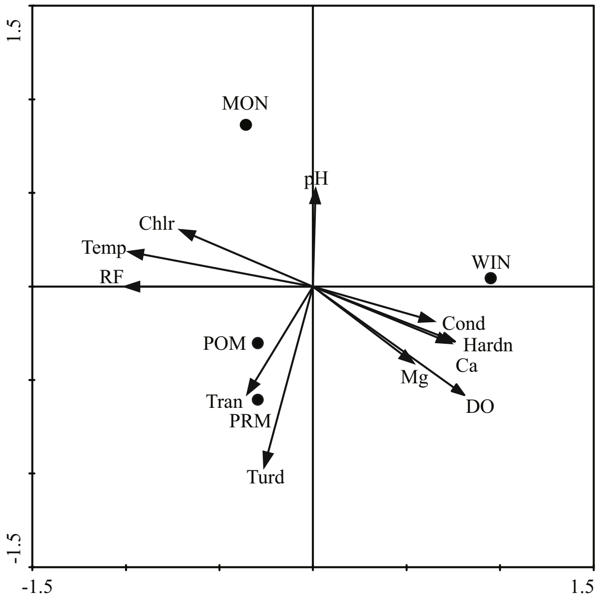

Fig.3 PCA ordination diagram of water of KLNP with environmental variables (arrows) and seasons (solid circles)

The first axis is horizontal and the second axis is vertical. WIN: winter; PRM: pre-monsoon; MON: monsoon; POM: post-monsoon.

Canonical Correspondence Analysis (CCA) was done to examine the relationship between the zooplankton assemblage and the measured physico-chemical variables. CCA is a multivariate direct gradient analysis technique used to elucidate the relationship between biological assemblages of species and their environment. The method is designed to extract synthetic environmental gradients from ecological data sets (ter Braak and Verdonschot, 1995). Two separate sets of CCA were done, seasonal zooplankton abundance data with corresponding environmental variables and station-wise zooplankton abundance data with corresponding environmental variables.

All the physical, chemical and biological variables except pH, were $\log_{10}(x+1)$ transformed prior to analysis. A forward-selection method was used to test the independent effect of each environmental variable (Marginal Effect) on the zooplankton composition with best k equal to number of variables and then each variable was ranked on the basis of importance for which it was responsible for species composition. In the next step, the best variable was selected and the rest were ranked according to the effect that each variable brought in addition to all the variables already selected (Conditional Effect). The statistical significance of effect of each variable was tested by a Monte-Carlo Permutation Test (with 499 unrestricted permutations) (ter Braak and Verdonschot, 1995; Lepš and Šmilauer, 2003).

One way Analysis of Variance (ANOVA) was used to test the statistical significance of difference in physico-chemical parameters of the water and also zooplankton assemblages among the seasons as well as among the stations by using the statistical package SPSS version 20.

Table 1 Physico-chemical parameters of water with their mean, standard deviation (SD) observed at KLNP during the study period

Parameters	Symbols*	Mean	SD	Range
Water temperature (°C)	Temp	22.7	±5.1	10.4–28
Transparency (cm)	Tran.	108.9	±44	44.5–200
Dissolved oxygen (mg/L)	DO	7.84	±0.81	6.55–10
Electrical conductivity (μs/cm)	Cond.	139.09	±24.4	105.5–201
Turbidity (NTU)	Turd	4.14	±7.07	0.35–33.2
pH	pH	6.6	±0.24	6.26–7.26
Chloride (mg/L)	Chlr	14.09	±5.51	7.1–22.95
Total hardness (mg/L)	Hardn.	53.6	±10.29	41–78
Calcium (mg/L)	Ca	10.9	±2.11	8–16.03
Magnesium (mg/L)	Mg	6.20	±1.52	3.4–9.2

*: corresponding symbols used in PCA and CCA.

Table 2 Eigen values and cumulative percent variation of environmental data for the first four PCA axes for the four seasons of KLNP

PCA axis	Eigen value (λ)	Cumulative percentage variation of environmental data
1	0.911	91.1
2	0.058	96.9
3	0.031	100
4	0	0

3 RESULT

3.1 Physico-chemical parameters

The means of the water parameters studied during the study period are summarized in Table 1. In this section we will concentrate on multivariate analysis of the physico-chemical parameters only.

The Principal Component Analysis (PCA) bi-plot (Fig.3) of the seasonal data of physico-chemical variables reflects the variability seen among the four seasons. The first three PCA axes account for 100% of the variability, of which the First PC axis (PC1) i.e. the horizontal axis, accounts for maximum variance in the seasonal data, explaining 91% of the variability (Table 2). The relative importance of each variable

Table 3 Eigen values and cumulative percent variation of environmental data for the first four PCA axes for the six stations inside KLNP

PCA axis	Eigen value (λ)	Cumulative percentage variation of environmental data
1	0.897	89.7
2	0.075	97.2
3	0.015	98.7
4	0.010	99.7

(arrows) in explaining the variability and correlation among them is clearly depicted by the ordination diagram (Fig.3). The bi-plot shows that the vectors (arrow) of rainfall and WT are strongly correlated with the PC1 and form a group on the left side of PC1. The vectors of DO, EC, TH, Ca^{+2} form a group on the right side of PC1 in the bi-plot. The above mentioned two groups have an inverse relationship to one another as seen from the bi plot. The PC2 was closely associated with pH.

Relative positions of the seasons (dark circle) in the bi-plot (Fig.3) with respect to the environmental variables depict the status of each variable in that particular season. Winter season (WIN) occupy a position opposite to that of monsoon (MON). Pre-monsoon (PRM) and post-monsoon (POM) where WT and RF tend to be higher are placed close to each other and associated with transparency and turbidity. During WIN variables like DO, EC and TH increased. So, it seems that PC1 is the gradient for a wet-and-dry cycle which determines the season in this part of the region.

PC1 which accounts for the maximum variability (Table 3) has major contributions from transparency, turbidity, Ca^{+2} and Mg^{+2}. The position of the stations in the biplot and the vectors of each variable gave a profile of variables in each station (Fig.4). In S6, turbidity, ions and the associated parameters, TH, and EC, increased because of this station's position near the Khordak River. DO was high in S1, S2 and S5 and they clumped in a group. PC1 seems to be a gradient for loading of sediments and ions. Transparency and turbidity seemed to be strongly distinguishing factors among the stations studied.

There was no statistically significant difference among the stations in terms of physico-chemical parameters of the water as determined by one way ANOVA (F (5, 786)=0.139, P=0.983 (P>0.05)) but season-wise the physico-chemical parameter of the water was found to be significantly different (F (3,788)=3.068, P=0.027 (P<0.05)). A post-hoc Tukey

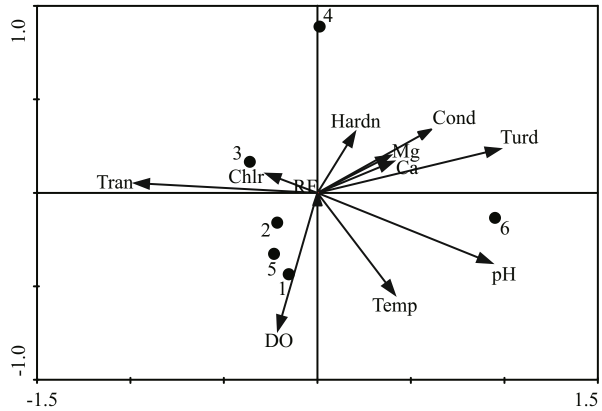

Fig.4 PCA ordination diagram of water of KLNP with environmental variables (arrows) and stations (solid circles)

The first axis is horizontal and the second axis is vertical. 1: S1; 2: S2; 3: S3; 4: S4; 5: S5; 6: S6.

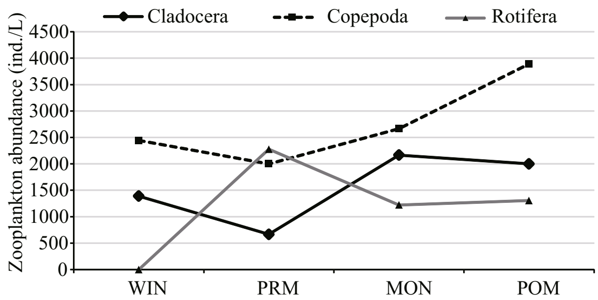

Fig.5 Temporal variations in the abundance of the three main zooplankton groups found in the water of KLNP during the study period

test revealed that among the seasons WIN and POM seasons were significantly different.

3.2 Spatio-temporal analysis of zooplankton

A total of 30 zooplankton taxa -14 Cladocera genera, 7 Cyclopoid Copepoda genera, 9 Rotifera genera and the family Diaptomidae-were recorded during the study period (Table 4).

Temporally, abundance of copepods was high in the major part of the study period, reaching a maximum during POM (3 880 ind./L) (Fig.5). Copepods accounted for 36.23% of total zooplankton during WIN, 40.45%, 44.03%, 54.05% during PRM, MON and POM respectively (Fig.6). Copepods formed the major component of zooplankton abundance at almost all the stations with highest abundance observed at S6, where it formed 55.3% of the total zooplankton (Fig.8). Copepodite stages were the most abundant form of Copepoda found almost at all the stations, closely followed by nauplius stages (Fig.7). These two pre-adult stages were encountered the whole year round, suggesting a continuous growing population.

Table 4 List of zooplankton taxa recorded from KLNP during the study period and the symbols used in CCA biplot for the same

Rotifera	
Brachionus Pallas, 1776	Branchio
Keratella Bory de St. Vincent, 1822	Kerat
Lepadella Bory de St. Vincent, 1826	Lepa
Lecane Nitzsch, 1827	Lecan
Monostyla Ehrenberg, 1830	Monosty
Asplanchna Gosse, 1850	Aspla
Filinia Bory de St. Vincent, 1824	Fili
Platyias Harring, 1914	Platy
Euchlanis Ehrenberg, 1832	Euchla
Cladocera	
Simocephalus Schoedler, 1858	Simo
Ceriodaphnia Dana, 1853	Cero
Moina Baird, 1850	Moina
Moinodaphnia Herrick, 1887	Moi.dap
Bosmina Baird, 1845	Bosm
Macrothrix Baird, 1843	MacThrix
Ilyocryptus Sars, 1862	Iiycryp
Pleuroxus Baird, 1843	Pleura
Alona Baird, 1843	Alona
Oxyurella Dybowski & Grochowski, 1894	Oxyu
Kurzia Dybowski & Grochowski, 1894	Kurz
Chydorus Leach, 1816	Chydo
Bosminopsis Richard, 1895	Bosminop
Diaphanosoma Fischer, 1850	Daipsom
Copepoda	
Eucyclops Claus, 1893	Eucyc
Mesocyclops Claus, 1893	Meso
Macrocyclops Claus, 1893	Maccyc
Microcyclops Claus, 1893	Micrcy
Diacyclops Keifer, 1927	Diacyclop
Acanthocyclops Keifer, 1927	Acancyp
Cyclops	Cycl
Nauplii larvae	Naup
Immature stages (copepodites)	Immat
Family: Diaptomidae Baird, 1850	Diap

The genus *Mesocyclops* was encountered during all four seasons and was found to be high at S6. The Rotifera population crashed during the WIN season (Fig.5) at the study site and in the PRM it reached a maximum (2 270 ind./L) and formed 46.06% of the total zooplankton abundance and in the next two

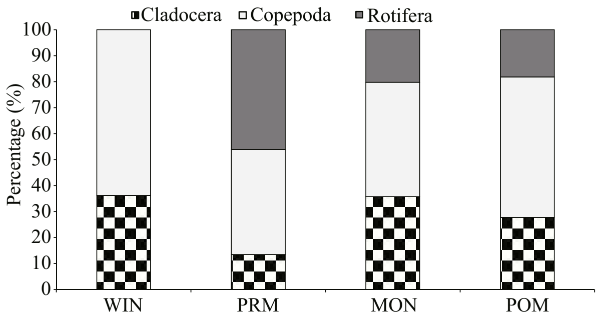

Fig.6 Relative abundance of the three main zooplankton groups in the water of KLNP during different seasons of the study period

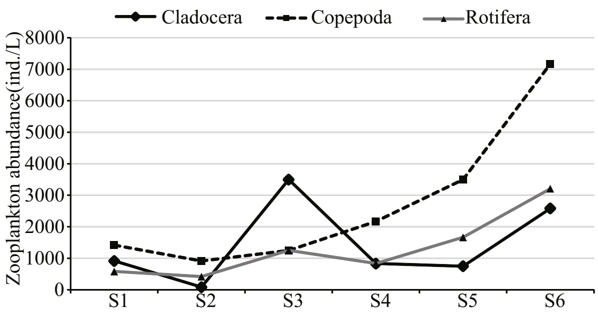

Fig.7 Spatial variations in the abundance of the three main zooplankton groups found in the water of KLNP during the study period

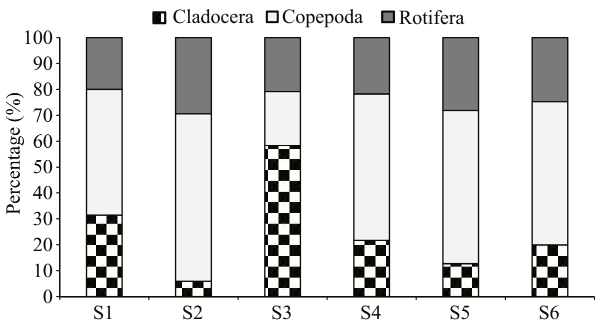

Fig.8 Relative abundance of the three main zooplankton groups in the water of KLNP at different stations during the study period

seasons its abundance dwindled and became the least abundant zooplankton group making up 20.18% (MON), 18.14% (POM) of the relative abundance (Fig.6). Rotifera abundance at S6 was the highest in comparison to the other stations (Fig.7). *Brachionus* and *Lecane* formed the major component of the Rotifera population in the three seasons (PRM, MON and POM). *Brachionus* formed the major component of Rotifera at all the stations during the study period. Cladocera constituted the second most abundant group of zooplankton in all the seasons except in PRM where the abundance was minimum (660 ind./L) (Fig.5) and relative abundance was 13.48% (Fig.6). Maximum abundance was recorded during MON season (2 160 ind./L) where it constituted 35.78% relative abundance. *Macrothrix* was present in all four seasons. *Pleuroxus*, *Oxyurella*, *Kurzia*, *Diaphanosoma* were rare, occurring only once in a particular season. There was no statistically significant difference among the seasons in terms of abundance of zooplankton as determined by one-way ANOVA (F (3, 128)=0.636, P=0.593 (P>0.05)) but station-wise the abundance of zooplankton was found to be significantly different (F (5, 761) =5.875, P=0.00 (P<0.05)). A post-hoc Tukey test revealed that among the stations S6 was significantly different from all other stations.

The CCA result of seasonal species-environmental data shows the first three axis of CCA, which explain all the variability in the data set. The eigenvalue for CCA axis 1 (0.464) and axis 2 (0.208) together explain 79.8% of the variability, with axis 1 contributing 55.1% of the total variability (Table 5). Marginal effects and conditional effects of the environmental variables on the species composition were obtained using the forward selection with Monte Carlo test (Table 6). From the table with marginal effects, WT with eigenvalue (λ) 0.46 was the most important for determining species composition, followed by RF (λ: 0.43), TH (λ: 0.41) and Ca^{+2} (λ: 0.4). Conditional effects showed that WT, RF and Turbidity were the variables that showed the maximum variability in the data. These three variables are closely related with axis 1 of CCA. The CCA ordination diagram (Fig.9)

Table 5 Eigenvalues and cumulative percent variation of species and environmental data for the first four axes of CCA performed between zooplankton and physico chemical parameters for the four seasons of KLNP

CCA axis	Eigenvalue (λ)	Cumulative percentage variation of species-environmental data
1	0.464	55.1
2	0.208	79.8
3	0.170	100
4	0.00	
Total inertia	0.842	

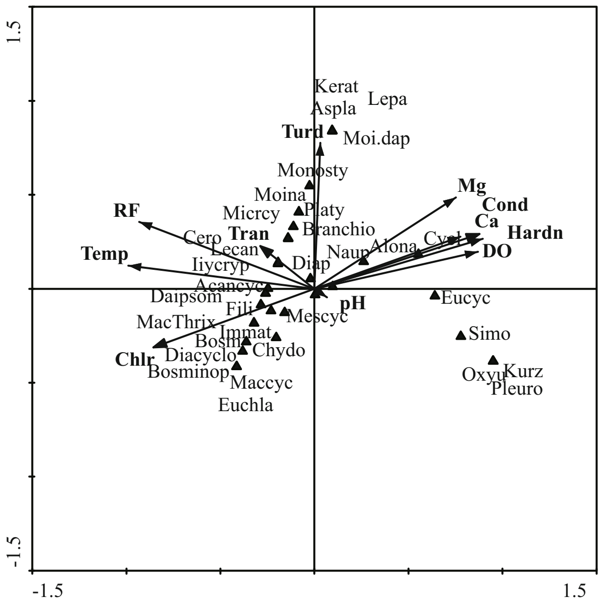

Fig.9 CCA ordination bi-plot of temporal zooplankton taxa (triangles) assemblage and environmental variables (arrow)

The first axis is horizontal and the second axis is vertical. Abbreviations used for different zooplankton taxa are listed in Table 4.

Table 6 Marginal and conditional effects obtained from the summary of forward selection for seasons

Marginal effects			Conditional effects				
Variable	Var. N	Lambda1	Variable	Var.N	LambdaA	P	F
Temp	1	0.46	Temp	1	0.46	0.052	2.4
RF	11	0.43	RF	11	0.21	0.46	1.24
Hardn	7	0.41	Tran	2	0.17	1	0
Ca	8	0.4					
DO	3	0.39					
Chlr	6	0.39					
Cond	4	0.35					
Mg	9	0.35					
Tran	2	0.2					
Turd	5	0.19					
pH	10	0.17					

shows that *Alona*, *Cyclops*, *Eucyclops* were closely related to high values of Mg^{+2}, Ca^{+2} and TH. *Ceriodaphnia*, *Macrothrix*, *Bosmina* and other zooplankton genera on the left side of the biplot are mostly found during high rainfall and increasing temperature. S*imocephalus*, *Oxyurella*, *Kurzia* were at the extreme opposite of RF and WT variables. The ordination biplot between zooplankton and seasons (Fig.10) clearly depicts the segregation of zooplankton based on seasons. As mentioned above, the genera associated most closely with high RF were the ones which were more abundant during the MON and the POM seasons, as seen in the biplot. Winter-occurring zooplankton were those at the opposite side of WT variable.

The CCA for stations showed that the four CCA axes together explain 93.5% of the variance of which CCA axis 1 and CCA axis2 together account for 68.8% of the cumulative percentage variance (Table 7). The conditional table (Table 8) shows that WT, EC, TH, turbidity and transparency have significant contributions to the variations observed in zooplankton abundance among the stations. The CCA biplot (Fig.11) shows that genera such as *Mesocyclops*, *Ceriodaphnia*, *Bosmina*, *Brachionus* tend to be abundant at S5 and at S6, where environmental variables such as turbidity, Mg^{+2}, EC and WT tend to be high, whereas *Chydorus*, *Macrothrix*, *Lecane* concentrate at stations S3 and S1, where Ca^{+2}, TH and transparency (Fig.12) were high.

Table7 Eigenvalues and cumulative percent variation of species and environmental data for the first four axes of CCA performed between zooplankton and physico-chemical parameters for the six stations inside KLNP

CCA axis	Eigenvalue (λ)	Cumulative percentage variation of species-environmental data
1	0.345	35.3
2	0.327	68.8
3	0.143	83.4
4	0.099	93.5
Total inertia	0.977	

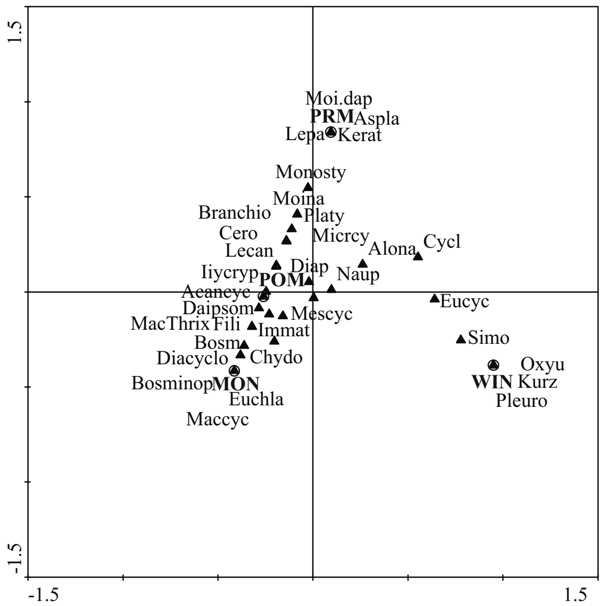

Fig.10 CCA ordination bi-plot of temporal zooplankton taxa (triangles) assemblage and the seasons (circle)

The first axis is horizontal and the second axis is vertical. Abbreviations used for different zooplankton taxa are listed in Table 4.

Table 8 Marginal and conditional effects obtained from the summary of forward selection for stations

Marginal effects			Conditional effects				
Variable	Var.N	Lambda1	Variable	Var.N	LambdaA	*P*	*F*
Temp	1	0.27	Temp	1	0.27	0.04	1.54
Cond	4	0.25	Cond	4	0.26	0.134	1.78
pH	10	0.24	Hardn	7	0.21	0.182	1.69
Mg	9	0.23	Turd	5	0.15	0.274	1.91
Turd	5	0.2	Tran	2	0.09	1	0
Chlr	6	0.2					
Tran	2	0.19					
DO	3	0.16					
Ca	8	0.15					
Hardn	7	0.13					

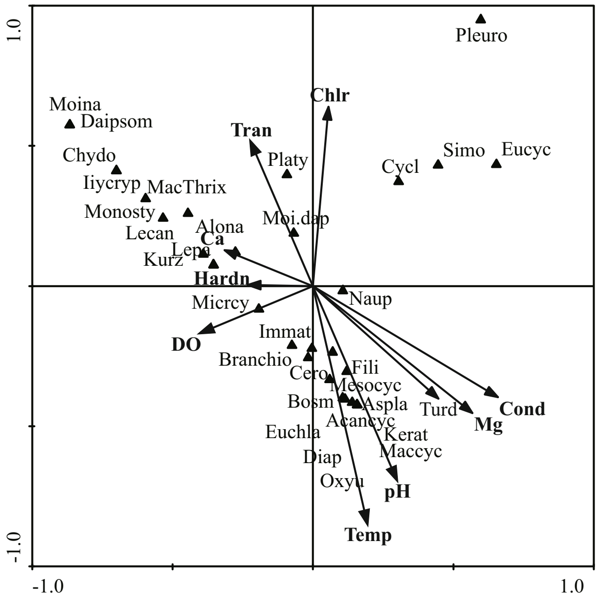

Fig.11 CCA ordination bi-plot of spatial zooplankton taxa (triangles) assemblage and environmental variables (arrows)

The first axis is horizontal and the second axis vertical. Abbreviation used for different zooplankton taxa are listed in Table 4.

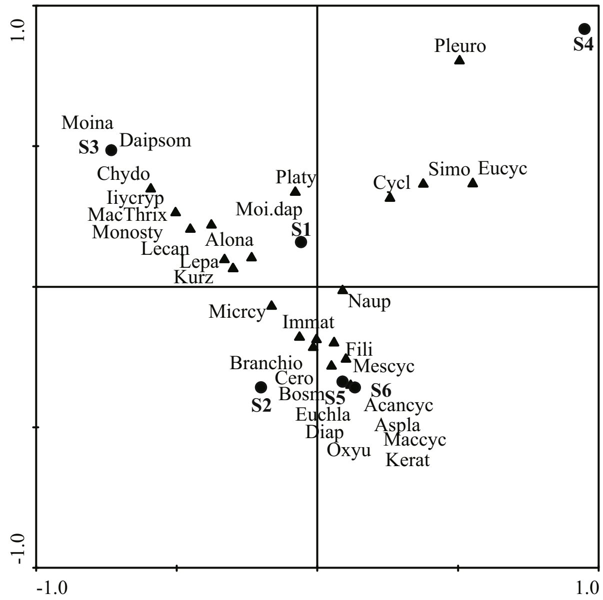

Fig.12 CCA ordination bi-plot of spatial zooplankton taxa (triangles) assemblage and stations (circles)

The first axis is horizontal and the second axis vertical.

4 DISCUSSION

Rainfall and temperature are the two main factors reflecting the climatic conditions of the seasons in this part of the country. So, the cycle of precipitation and dry conditions determines the temporal variations in physico-chemical parameters of the water of KLNP. A similar influence of these two factors on the temporal variation has been reported by Arora and Mehra (2009) in a shallow man-made hyposaline lake in Delhi, India. As reported earlier (Sharma et al., 2013), chloride is closely associated with the wet season i.e. MON, this is also seen in the PCA biplot of the present study. This can be attributed to runoff from the surrounding areas. EC, TH, Ca^{+2} and Mg^{+2} are ions which tend to concentrate due to evaporation during the dry seasons. Hence turbidity and transparency seem to be factors that differentiate the stations.

The relative abundance of zooplankton composition in the present investigation is in marked contrast to that reported by Sharma and Sharma (2011). They found a higher abundance of rotifers followed by cladocerans and copepods in an open part of Loktak Lake (India). Although, KLNP is also a part of Loktak lake, its ecosystem is different from that portion of the lake studied by Sharma and Sharma (2011) in that it is covered by a continuous mass of *phumdis*. At our study sites the abundance was dominated by copepods followed by cladocerans while rotifers were the least abundant zooplankton. Many workers have reported the dominance of rotifers (Chattopadhyay and Barik, 2009; Sarma et al., 2011). But our observation are consistent with the observations of Sharma and Pachuau (2013) in a reservoir in Mizoram (India), Sharma and Lyngskor (2003) at Nongmahir (India), Das et al. (1996) at Lake Tasek (India), Sharma and Hussain (2001) from a floodplain lake in Assam (India). Dominance of copepods has been reported in many Indian water bodies (Shyam, 1991; Varghese and Naik, 1992; Paulose and Maheshwari, 2008). A detailed study on the predation of rotifers by copepods was discussed by Brandl (2005), according to which cyclopoid and calanoid copepodites are efficient predators of rotifers, often causing a seasonal decline in the rotifer population. Based on their life-history strategies, the maximal rate of natural increase (r) occurs in Rotifera followed by Cladocera and Copepoda (Allan, 1976). This order of natural increase can be altered by the presence of different types of predators. Presence and abundance of vertebrate predators (fish) leads to an increase in rotifers and the elimination of larger cladocerans and copepods (Hrbáček et al., 1961; Brooks and Dodson, 1965). Whereas, in the case of invertebrate predation, it was the reverse, with the smaller species being selected (Anderson, 1970; Allan, 1973; Dodson, 1974). Special mention can be made of the *Mesocyclops* genus which was found in all the four seasons. *Mesocyclops* spp. are considered carnivorous or detrivorous (Fernando et al., 1990) which may have found this habitat (having high organic litter from the *Phumdis*) conducive for their survival and growth. *Eucyclops* was also one of the major components, attaining a peak during winter.

Rotifera were totally absent during winter in our samples. The Rotifera population might have been constrained by predatory zooplankton, other predatory animals associated with benthos and periphyton (Brandl, 2005) and also by lack of food (Nandini et al., 2008). Temperature might have also played a role here, as reported by Chen et al. (2012) who found that rotifer assemblages followed a temperature gradient which determined its seasonality. Peak Rotifera abundance was seen in PRM where it formed the main zooplankton component. *Brachionus* sp. contributed the bulk of the abundance. This sudden spurt and dominance could be explained by the life-history strategy of rotifers, less specialized feeding, high fecundity and frequent parthenogenetic reproduction which make the genus an opportunist and typical *r*-strategist (Allan, 1976; Sampaio et al., 2002). Sharma (2009) noted low richness of Brachionidae, *Brachionus* sp. in particular from Loktak Lake. In Deepor Beel (Assam, India) Brachionidae and Lecanidae formed the main group of the Rotifera population (Sharma, 2011), which is consistent with our observation. Cladocera formed the second major component of zooplankton, with *Simocephalus*, *Ceriodaphnia*, *Bosmina* and, *Chydorus* contributing to their abundance. The mean abundance of Cladocera was highest during MON, largely influenced by *Bosmina*, *Macrothrix*, and *Chydorus*. Cladocera were absent at S4 during the study period and sparse at all the other stations except for S6, where the greatest contribution in mean abundance of Cladocera occurred.

Many abiotic and biotic factors interact in an aquatic system and it is difficult to point out a particular factor responsible for determining the community structure. In such a case, multivariate data analysis helps in recognizing the significant sets of variables responsible for variance. The effect of abiotic environmental parameters is clearly identified by the CCA biplot. The maximal temporal variability in zooplankton abundance is explained by rainfall (Gaviria, 1993; Maia-Barbosa et al., 1998; Arora and Mehra, 2009) and temperature (Arora and Mehra, 2009) in our study. Since abundance tends to be highest during POM and MON the biplot diagram shows aggregation of most zooplankton on the left side of the biplot, which is a gradient of increase in both temperature and rainfall. Many rotifers tend to be in the highest temperature region. Temperature has a major influence on their reproductive rate, feeding, movement and longevity (Ruttner-Kolisko, 1974). The greatest abundance of zooplankton in comparison to other stations was found at S6, where the Khordak River discharges inside the KLNP. According to Gannon (1974) the greatest abundance of zooplankton is normally found in water masses comprised of river water diluted with lake water.

5 CONCLUSION

From the above discussion and analysis it can be inferred that the differences observed in physico-chemical parameters of water among the stations and seasons in KLNP was much influenced by the natural cycle of seasons and other physico-chemical parameters, particularly high turbidity, indicative of sediment load. The zooplankton population is also an indication of the health of the aquatic system of this park. Abundance of rotifers is mainly associated with eutrophic water, but in our system rotifers were the least abundant. The physical parameters associated with the seasons, sediment loading (transparency, turbidity) play an important role in determining the seasonal structure of zooplankton and the spatial difference observed.

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