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Original Paper

Study on diversity of cladocerans (Cladocera: Branchiopoda) in some selected wetlands of West Midnapore district, West Bengal, India

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Souraditya Chakraborty[1,2]*, Priyanka Halder Mallick[2]

[1]Department of Zoology, Parimal Mitra Smriti Mahavidyalaya, Malbazar, Jalpaiguri, West Bengal, Pin 735221, India
[2]Department of Zoology, Vidyasagar University, Midnapore, West Bengal, Pin 721102, India

*Corresponding author, E-mail: sourachak@gmail.com

Abstract

Cladocerans, also referred to as "water fleas", are a special group of crustacean zooplankton, noteworthy for their highly nutritive value as "natural live feed" in aquaculture practices and also for maintaining ecosystem stability. Geographically, in eastern India, the district West Midnapore in West Bengal is a part of unique red lateritic soil region known as the "Rarh belt" or "Rarh Bengal". Due to this characteristic edaphic and topographical feature the biodiversity status of the wetlands herein are of special significance. An attempt was made to record the cladoceran species diversity in three ecologically contrasting freshwater bodies (a fishpond, a village pond, and a forest pond) in Garhbeta I block, in the northern fringe of West Midnapore district, West Bengal, India. The study revealed the presence of a total of 16 cladoceran species among the three study sites. Chydoridae (56%) was found to be the dominant family followed by Moinidae (19%). The fish pond (13 species) contained the highest species diversity followed by the forest pond (10 species) and village pond (eight species) respectively. The study showed that cladoceran species diversity seemed to be positively correlated with presence of nutrients. The species diversity was associated with the eutrophication status, ecosystem stability and productivity levels of the wetlands. The maximum species diversity was found in the pre-monsoon and least in the monsoon period. Thus, increase in temperature indicated a positive correlation with species diversity. The Shannon-Weiner index (*H'*) value ranged between 1.81 and 2.50 among the three sites, indicating overall moderately stable ecosystems. The one-way ANOVA results indicated that the variation in *H'* value across different seasons was not statistically significant, but statistically significantly differed among different sites. Similar trends were seen for species evenness index and other diversity indices as well. Bray-Curtis cluster analysis based on species distribution indicated Site I and Site III were more similar as compared to Site II. However, as the recorded species count was less than the overall species diversity (63 species) recorded in the region, further studies are recommended for greater exploration of the group in the area.

Key words: Cladocera, eutrophication, laterite, Rarh belt, species diversity, wetlands.
Abbreviations: *H'*, Shannon-Weiner index; PrM, pre-monsoon; M, monsoon; PoM, post-monsoon.

Introduction

Zooplankton is an integral biotic component of aquatic ecosystems and has impact on most functional features of water bodies including food chains, food webs, energy flow, material cycling etc. (Murugan et al. 1998; Dadhich, Saxena 1999; Sinha, Islam 2002; Mallick, Chakraborty 2015). Zooplankton groups in tropical water bodies are mainly comprised of Protozoa, Rotifera and Crustacea. Crustacean plankton includes the orders Cladocera, Copepoda, and Ostracoda (Forró et al. 2008). The composition, abundance and diversity of these groups show marked variation with geographic, physical, chemical, climatic, edaphic and seasonal factors. Resource availability and competition also affect availability of different species. Among different groups, cladocerans are of special significance in aquatic biology as natural "live feed" for juvenile and adult fish forms (Pennak 1978a).

Cladocerans, also referred to as "water fleas" (Smirnov 1971), are micro-crustacean zooplankton, belonging to class Branchiopoda under superclass Crustacea (Fryer 1987). Due to their 'hops and jumps', they are easily devoured and favoured by different fish species, thus, helping in trophic dynamics (Smirnov 1971). Apart from their importance as live feed, they also have roles in ornamental fish culture, prawn and shrimp culture, as bioindicators, and also as an important test model for biological experiments.

Globally around 620 species of cladocera are known, but the cladoceran species richness is estimated to be probably up to four times higher than what is currently recorded (Forró et al. 2008). In India, about 109 species have been recorded from different freshwater habitats (Sharma 1991; Murugan et al. 1998). Recently, the Zoological Survey of India published a comprehensive annotated checklist of 131 cladoceran species, compiled from inland freshwater habitats in India (Sharma, Sharma 2017). The recorded

diversity is relatively more explored from north-eastern states of India as compared to other parts of the country (Sinha 2018; Chakraborty, Mallick 2020).

The south-western part of West Bengal, India, including the districts of Murshidabad, Birbhum, Bankura, Puruliya, East Bardhaman and West Bardhaman, East Midnapore and West Midnapore, is frequently referred to as the "Rarh belt" or "Rarh Bengal", due to the presence of iron oxide rich lateritic red soil (Bagchi, Mukherjee 1983). Owing to this unique edaphic factor, the freshwater wetlands here are of special ecological relevance and the biodiversity herein is significantly unique. Despite these facts, studies on the diversity, abundance and distribution of Cladocera as a group in the water bodies of this area has been is much unorganized, fragmentary and meagre (Chakraborty, Mallick 2020).

The aim of the present study was to assess the diversity of cladocerans from three selected contrasting wetlands (with respect to: water source, nutrient status, usage and management level), of West Midnapore district, West Bengal, India. The survey was necessary to update and enrich the records of cladoceran diversity in this part of the world. Since cladocerans are an integral part of the trophic dynamics, this survey will aid in conservation of wetlands in the area and also augment fish production, and therefore, generate livelihood opportunities and boost economy of the region in the future.

Materials and methods

Study sites

The West Midnapore district is located in the south-western part of the state of West Bengal, India, between 22°57'10" and 21°36'35" N and between 88°12'40" and 86°33'50" E. In terms of impounded water area, the district Midnapore (combining East Midnapore and West Midnapore) comprises 37199.13 ha in total, of which 41.16% is derelict or semi-derelict in nature. Most of these unproductive wetlands are in the western, north-western or northern belt and are hardly managed or commercially utilised throughout the year (DMCDS Paschim Medinipur 2019). Garhbeta I block has a total area of 36117 ha, of which 18452 ha (51.1%) area is net cultivable. The soil comprises of 85% laterite and 15% alluvium, reflecting its low water holding capacity and thus, relative infertility (DMCDS Paschim Medinipur 2019). To determine the cladoceran diversity, three isolated freshwater wetlands (fish pond, Site I; village pond, Site II; and a forest pond, Site III) were chosen in the northern fringe of district West Midnapore, in Garhbeta I block. The selection of the sites was based on contrasting ecological characteristics of the wetlands, such as connectivity (to surface flow lines), water source, nutrient status, usage and management level (Steele 2014). The description and features of the sites are given in Table 1, Fig. 1. The study area maps mentioned in the study were prepared using QGIS software (ver. 2.18.2, Las Palmas).

Collection and qualitative analysis of samples

Samples for the present study were collected monthly during a period of one year from April 2019 to March 2020. Four distantly located stations were selected within each site (Site I, Site II and Site III) and water samples were randomly collected in early hours of the day between 6:00 to 8:00. Water samples were collected by towing of a Henson's standard nylon bolt plankton net (No. 25, 64 µm mesh size) in a zigzag fashion horizontally at a depth of 50 to 100 cm for about 10 min with uniform speed. The plankton biomass was transferred to polyethylene specimen bottles (100 mL) prefilled with 5% formalin (10 mL). Individual species of zooplankton were mounted on microscopic slides with a drop of 20% glycerine after staining with eosin. The identification of cladocera was made on the basis of overall morphological features referring to standard manuals, text books and monographs (Needham, Needham 1962; Pennak 1978b; Battish 1992; Michael, Sharma 1988; Carling et al. 2004; Michael, Sharma 2008), using a compound microscope (Magnus Trinocular Microscope, MLX-Tr Plus, PA-LED) and specimens were photomicrographed using a CMOS camera (IS 300) attached to a compound light microscope.

Quantitative analysis of samples

Ten litres of water sample from each site was sieved through the plankton net and concentrated into a 50 mL vial attached to the terminal end of the net. The samples procured in this way were preserved in 5% formaldehyde. The concentrated samples (1 mL) were placed on a "Sedgewick Rafter Counting Cell" (Adoni et al. 1985) of 1 mL capacity, allowed

Table 1. Description of the study sites

Site	Location	Type/ water supply	Description
Baroshivalay pukur (Site I)	22.86°N, 87.36° E	Fish pond; perennial	Man-made depression, concrete boundary, well managed, regularly manured, aquaculture practised throughout the year
Mangala pukur (Site II)	22.85° N, 87.355° E	Village pond; perennial	Man-made depression, natural boundary, unmanaged, domestic sewage fed
Bhatmara pukur (Site III)	22.93° N, 87.38° E	Forest pond; perennial	Natural depression, natural boundary, unmanaged, rain water fed

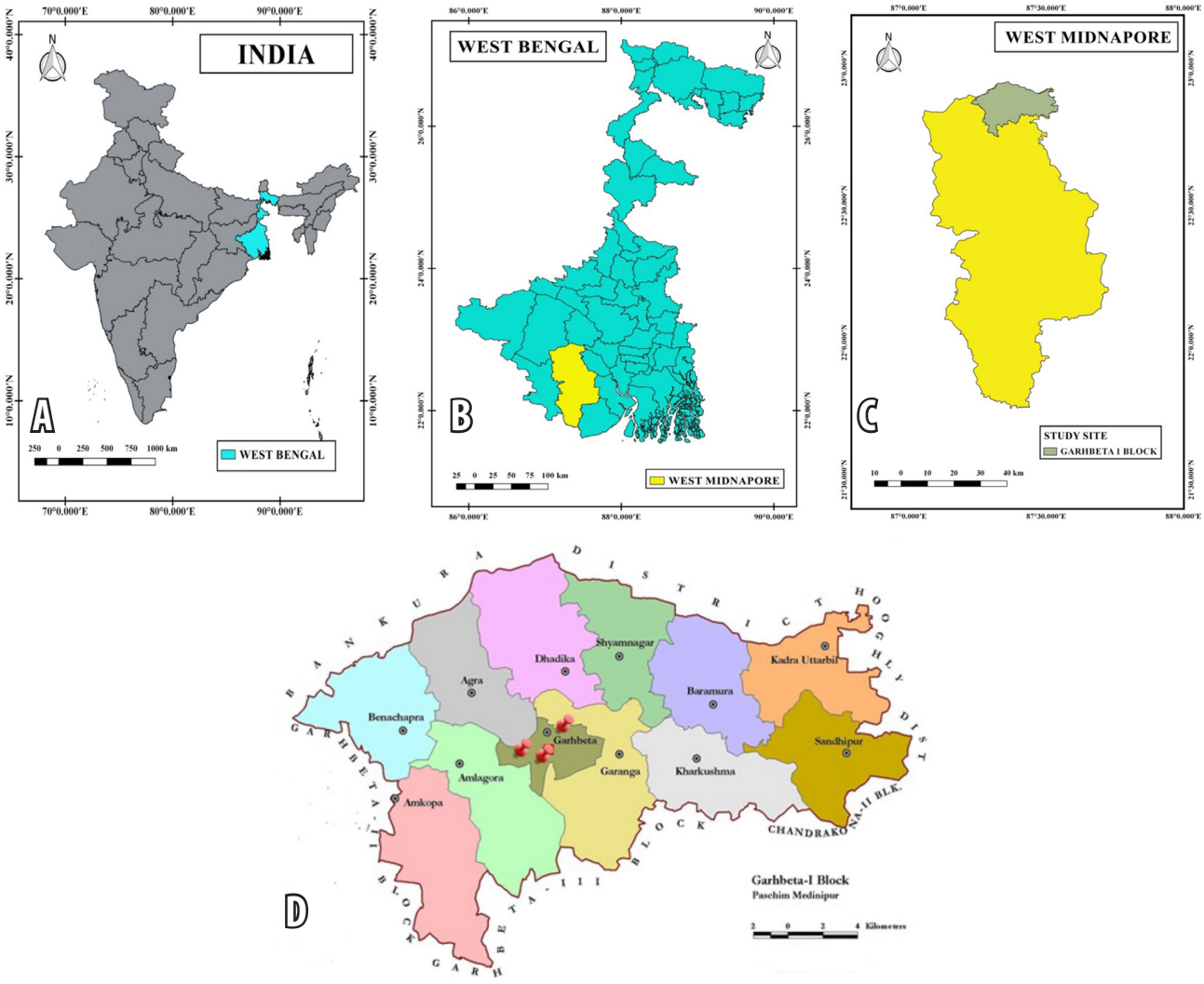

Fig. 1. Location map of study sites. A, West Bengal state in India; B, West Midnapore district in West Bengal; C, Garhbeta I block is West Midnapore; D, study sites at Garhbeta I block.

to settle and then observed under compound microscope for quantitative estimation. Counting was done in triplicate and the average was taken to ensure accuracy of species counts. Number of cladoceran individuals per litre of water was calculated using the following formula (Welch 1948; Santhanam et al. 1989):

$$N = (n \times v) / V;$$

where N is the number of individuals per litre of water, n is the average number of individuals in 1 mL of the concentrated sample, v is the volume of the concentrated sample (50 mL), and V is the volume of the original water sample sieved (10 L).

Statistical analysis and biodiversity indices calculation

The monthly data recorded were grouped by season: pre-monsoon (PrM) (March to June), monsoon (M) (July to October), and post-monsoon (PoM) (November to February). The data on cladoceran counts were represented as means ± SD and analysed using descriptive statistics. The results obtained were statistically analysed using Microsoft Excel (ver. 2010) and PAST software (Paleontologia Electronica, ver. 4.03, Oyvind Hammer, June 2020). Means, standard deviations and ANOVA (one-tailed, at 0.05% level of significance) were calculated using Excel. All diversity indices were calculated using the basic programme of PAST and all graphs were prepared using Excel. Cluster analysis (Bray Curtis similarity index, UPGMA) of the study sites was conducted using PAST software. The diversity indices used were calculated as follows.

Index of dominance (D) (Harper 1999):

$$D = \sum_{i=1}^{s} (n_i / N)^2,$$

where n_i is the number of individuals of taxon i, N is the total number of individuals in each species, S is the number of species. The value of D ranges between 0 and 1. Here, 0 denotes evenness of all the species while 1 denotes complete dominance of one species.

Simpson's diversity index ($S.D$):

$$S.D = (1 - D).$$

This index measures 'evenness' of the community from 0 to 1. It is opposite to the index of dominance.

Shannon-Wiener diversity index (*H'*) (Krebs 1999):

$$H' = \sum_{i=1}^{s} (n_i / n) \times \ln (n_i / N),$$

where n_i is the number of individual of taxon *i*, *N* is the total number of individuals in each species, *S* is the number of species. It is a comprehensive index of species richness and a measure of the uniformity of the distribution of individuals, which reflects the degree of complexity and the stability of community structure.

Buza's and Gibson's evenness index (*E*):

$$E = \frac{e^{H'}}{S}$$

where *H'* is the Shannon-Weiner index, *S* is the number of species.

Brillouin index (*HB*) (Pielou 1975):

$$HB = \frac{\log n! - \sum_{i=1}^{s} \log n_i!}{n},$$

where $n_i!$ is $1 \times 2 \times 3 \times \ldots \times n_i$ and n_i is the number of individuals in species *i* and $n = \sum_{i=1}^{s} n_i$ is the total number of individuals in the community. *HB* is similar to *H'* and takes into account the rare species in the community when calculating diversity. However, *HB* measures the diversity of a collection rather than a sample (as done in *H'*). Nevertheless, *HB* values give similar comparative results as *H'*.

Menhinick's richness index (D_{mn}) (Whittaker 1977):

$$D_{mn} = S / (\sqrt{N}),$$

where *N* is the total number of individuals in each species, *S* is the number of species. This species richness index is used to compare samples of different sizes.

Margalef's richness index (*R*) (Brower, Zar 1977):

$$R = (S - 1) / \ln N,$$

where *N* is the total number of individuals in each species, *S* is the number of species. It reflects the richness of species number and individuals. It is one of the most favoured biodiversity indices.

Pielou's evenness index (*J*) (Harper 1999):

$$J = H' / \ln S,$$

where *H'* is the Shannon-Weiner index, *S* is the number of species. It represents the evenness of the individual's distribution among species. It also indicates the pattern of distribution of individuals within a species.

Berger-Parker dominance (*d*) (May 1975):

$$d = N_{max} / N,$$

where N_{max} is the number of individuals in the most abundant species, and *N* is the total number of individuals in the sample. It is a simple dominance index emphasising the most dominant species.

Results

Qualitative analyses

Careful investigation of the water samples from the selected wetlands of the typical lateritic Rarh belt of West Bengal revealed the presence of 16 species of Cladocera belonging to four families and seven genera (Table 2). Among the three selected wetlands, Site I (fish pond) was found to contain the highest cladoceran diversity (13 species), followed by Site III (forest pond) (10 species) and Site II (village pond) (eight species) respectively. The amounts of nutrients in the form of organic manure in a maintained stress-free habitat had positive correlation to diversity of cladocerans. In terms of overall distribution of species within families, Chydoridae (56%) was the dominant family with nine species, followed by Moinidae (19%) with three species, Sididae (12.5%) with two species and Daphniidae (12.5%) with two species (Fig. 2). *Alona* sp (37.5%) was the most dominant genus with six species, followed by genus *Moina* sp. (18.75%) with three species. Thus, Chydoridae was the most abundant family overall, while *Alona* sp. was the most dominant genus in the study sites. In Chydoridae family, *Alona affinis* was the dominant species; in the Daphniidae family, *Schapholeberis kingi* was the dominant species; in the Moinidae family *Moina micrura* was the dominant species; and in Sididae family, *Diaphnosoma excisum* was the dominant species.

Quantitative analyses

In the present study, maximum species diversity as well as population density of most of the species of cladocerans was observed in the PrM period; while the lowest species diversity occurred in the M period at all of the three sites (Table 3, Fig. 3). Thus, increase in temperature appeared to have positive impact on zooplankton diversity in the area. This may be attributed to decaying vegetation, higher food availability or favourable environmental conditions. Low species diversity, as well as species density, during the M period may be due to high turbidity and low nutrient levels in the water bodies. However, the population of cladocerans gradually increased in PoM period, which may be due to restoration of favourable physicochemical and climatic conditions. *Alona affinis* at Site I and *Moina micrura* at Site II and Site III, showed the highest population density. Annual mean plankton density at the three sites was 36.79, 36.13, 31.08 individuals L^{-1} respectively.

Among the diversity indices, the Shannon-Weiner index (*H'*) values at the three sites (I, II and III) were 2.47, 1.84 and 2.0, respectively (Table 4). This suggests that Site II was the most polluted, followed by Site III and Site I. The high *H'* value at Site I indicates a comparatively healthy ecosystem status and less pollution level. Site II had the lowest *H'* value due to accumulation of organic debris from nearby areas, and thus had more stressed and man-caused eutrophic conditions. The *H'* values showed that Site III had a moderate level of natural eutrophication, compared to the other sites. However, as the *H'* value ranged between 1.81 and 2.50, the water bodies supported overall moderately stable ecosystems.

Margalef's species richness value (*R*) was maximum

Table 2. Species diversity with characters of cladoceran species recorded in the three study sites between April 2019 and March 2020

Species	Family	Carapace	Eye	Rostrum	Antennules	Head	Apical spine	Ocellus	Claw
Alona affinis (Leydig 1860)	Chydoridae	broad, compressed	small	long, pointed	small	indistinct	present	small	long
Alona pulchella (King 1853)	Chydoridae	ovoid	small	short	long	indistinct	present	small	long
Alona rectangula (Sars 1862)	Chydoridae	rectangular, striated	small	pointed	long	indistinct	present, large	large	pectinate
Alona verrucosa (Sars1901)	Chydoridae	broad, ovoid	small	pointed	small	indistinct	present, large	large	long
Alona sp.1	Chydoridae	elongated, rectangular	small	pointed	long	indistinct	present	large	pectinate
Alona sp.2	Chydoridae	ovoid	small	curved	long	indistinct	present	large	pectinate
Chydorus parvus (Daday 1898)	Chydoridae	round	large	pointed	short	not distinct	very minute	small	small
Chydorus sphaericus (Müller 1776)	Chydoridae	Oval	small	pointed	very short	not distinct	very minute	large	small
Coronatella rectangula (Sars 1862)	Chydoridae	ovoid	small	pointed	very short	not distinct	present	large	small
Daphnia lumholtzi (Sars 1885)	Daphniidae	round	large	small	well developed	pointed helmet	very large	small	pectinate
Schapholeberis kingi (Sars 1888)	Daphniidae	Oval-quadrangular	large	rounded	very small	rounded	minute	small	curved
Moina brachiata (Jurine 1820)	Moinidae	stout, heavy, square	large	small	very small	depressed	absent	absent	pectinate
Moina macrocopa (Straus, 1820)	Moinidae	Absent	moderate	absent	small	rounded	absent	absent	long, pectinate
Moina micrura (Kurz1874)	Moinidae	Absent	large	reduced	medium length	rounded, large	absent	absent	long, pectinate
Diaphnosoma excisum (Sars 1885)	Sididae	elongated, rectangular	large, preterminal	projected	short	large	absent	absent	serrated
Diaphnosoma sarsi (Richard 1894)	Sididae	ovoid	large, terminal	large	short, bramched	large	absent	absent	serrated

at Site I (3.19 to 3.74) followed by Site III (2.49 to 2.77) and Site II (1.85 to 2.27) (Table 4). The *R* value was highest in the M period at all of the three sites. Site I has higher species diversity compared to Site II and Site III. Buza's and Gibson's evenness index (*E*) index was also highest at Site I. *E* values were highest in PrM and least in M periods at all there sites. Simpson's index values had similar ranges for Site I and Site III. Brillouin index (*HB*) values were highest at Site I followed by Site III and Site II. The *HB* values were highest in the PrM period.

Other values of species diversity indices, viz., Menhinick's richness index (D_{mn}), Pielou's evenness index (*J*), Berger-Parker Dominance (*d*), and Fisher alpha (α), presented in Table 4 exhibited similar trends, where Site I had the highest value ranges, followed by Site III and Site II. The D_{mn} and α-values were highest in the M period at all of the three study sites, whereas, *HB* and *J*-values were highest in the PrM.

One way ANOVA results indicated that the variation in the *H*' value between different seasons was statistically insignificant ($P = 0.05$), while between different sites it

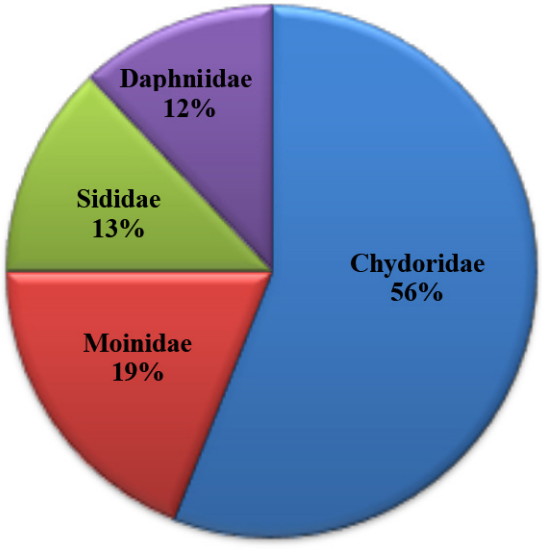

Fig. 2. Percentage composition of cladoceran families recorded at the three study sites during the study period.

Table 3. Season-wise mean density (individuals L^{-1}) of cladoceran species recorded in three study sites between April, 2019 and March, 2020. n = 4 for each site and season. PrM, premonsoon; M, monsoon; PoM, postmonsoon

Species	Site I				Site II				Site III			
	PrM	M	PoM	Mean	PrM	M	PoM	Mean	PrM	M	PoM	Mean
Alona affinis	6.25 ± 1.32	4.25 ± 0.65	4.88 ± 1.65	5.13 ± 1.02	8.50 ± 1.58	4.75 ± 1.04	5.63 ± 0.75	6.29 ± 1.96	3.25 ± 1.19	1.00 ± 0.71	1.38 ± 0.75	1.88 ± 1.21
Alona pulchella	4.38 ± 0.48	2.25 ± 0.87	3.38 ± 0.75	3.33 ± 1.06	-	-	-	-	-	-	-	-
Alona rectangula	2.63 ± 0.75	0.75 ± 0.65	2.50 ± 1.08	1.96 ± 1.05	7.13 ± 1.11	3.88 ± 1.89	4.13 ± 0.63	5.04 ± 1.81	7.13 ± 1.11	3.88 ± 1.89	5.00 ± 1.96	5.33 ± 1.65
Alona verrucosa	-	-	-	-	-	-	-	-	3.50 ± 2.04	0.63 ± 0.75	3.13 ± 1.11	2.42 ± 1.56
Alona sp.1	2.50 ± 0.82	1.75 ± 0.65	2.25 ± 0.65	2.17 ± 0.38	-	-	-	-	-	-	-	
Alona sp.2	1.25 ± 0.96	-	0.38 ± 0.48	0.54 ± 0.64	-	-	-	-	1.63 ± 1.44	1.00 ± 0.71	1.63 ± 0.85	1.42 ± 0.36
Chydorus parvus	3.13 ± 1.11	1.88 ± 0.48	2.63 ± 0.75	2.54 ± 0.63	4.88 ± 0.85	3.63 ± 1.03	5.63 ± 1.25	4.71 ± 1.01	2.75 ± 1.55	2.25 ± 0.65	3.25 ± 0.65	2.75 ± 0.5
Chydorus sphaericus	3.00 ± 0.58	1.25 ± 0.65	2.50 ± 0.91	2.25 ± 0.9	2.75 ± 1.04	0.75 ± 0.65	1.13 ± 0.85	1.54 ± 1.06	3.00 ± 0.58	1.25 ± 0.65	2.38 ± 1.11	2.21 ± 0.89
Coronatella rectangula	2.75 ± 0.65	0.75 ± 0.65	2.75 ± 1.50	2.08 ± 1.15	-	-	-	-	-	-		-
Daphnia lumholtzi	4.13 ± 1.93	2.88 ± 0.63	4.38 ± 0.63	3.79 ± 0.80	-	-	-	-	-	-	-	-
Schapholeberis kingi	4.38 ± 1.25	2.25 ± 0.87	2.13 ± 0.48	2.92 ± 1.26	6.38 ± 1.49	3.25 ± 1.44	5.25 ± 3.18	4.96 ± 1.58	4.25 ± 0.96	3.00 ± 2.58	4.13 ± 1.80	3.79 ± 0.69
Moina brachiata	5.38 ± 1.25	2.50 ± 0.91	1.75 ± 1.32	2.88 ± 1.35	-	-	-	-	5.13 ± 1.6	3.25 ± 0.29	3.38 ± 0.63	3.92 ± 1.05
Moina macrocopa	-	-	-	-	4.25 ± 0.50	3.13 ± 1.11	3.75 ± 0.96	3.71 ± 0.56	-	-	-	-
Moina micrura	5.13 ± 0.63	4.13 ± 1.49	4.88 ± 1.03	4.71 ± 0.52	11.13 ± 1.49	5.63 ± 1.80	8.50 ± 0.71	8.42 ± 2.75	7.25 ± 2.22	4.63 ± 1.93	5.63 ± 1.80	5.83 ± 1.32
Diaphnosoma excisum	3.50 ± 1.68	1.38 ± 1.25	2.50 ± 0.71	2.46 ± 1.06	-	-	-	-	2.75 ± 1.04	-	1.88 ± 1.11	1.54 ± 1.40
Diaphnosoma sarsi	-	-	-	-	2.13 ± 0.95	1.00 ± 0.91	1.25 ± 0.29	1.46 ± 0.59	-	-	-	-

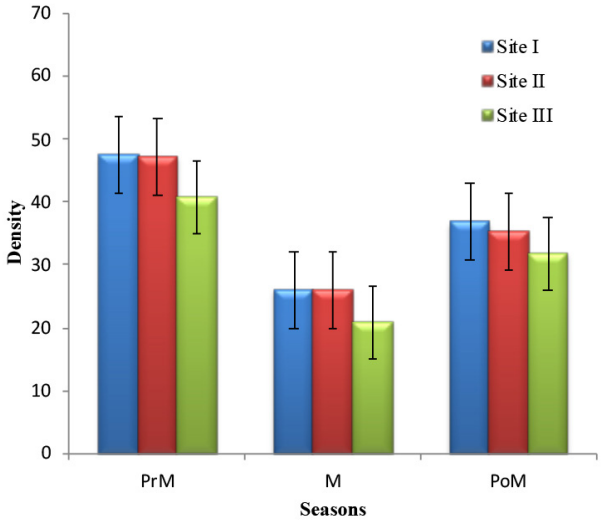

Fig. 3. Seasonal comparison of cladoceran density at the three study sites during the study period.

was statistically significant ($P < 0.001$). Similarly, variation in E values was found to be statistically insignificant ($P > 0.05$) between different seasons, but, statistically significant between different sites (at $P < 0.05$) (Table 5). Cluster analysis using the Bray-Curtis similarity index (unweighted pair group method with arithmetic mean, UPGMA) value based on species distribution (i.e., diversity and density) indicated that Site I and Site III were more similar to each other as compared to Site II (Fig. 4).

Discussion

The distributions of cladocerans are affected by various factors including, temperature, rainfall, water quality, nutrients, macrophytes, flood pulse etc. (Ghidini et al. 2009; Kiss et al. 2014). High species diversity of zooplankton in perennial water bodies indicates low pollution and thus, plays a pivotal role in the stability of aquatic ecosystems (Manickam et al. 2015). The diversity of zooplankton species tends to be low in stressed and polluted ecosystems and vice versa (Bass, Harrel 1981). The present analysis revealed the presence of 16 species of cladocera, belonging to four families and seven genera. Site I, Site II and Site III supported 13, 8 and 10 cladoceran species. respectively. The analysis indicated that Site I, which was routinely manured with organic fertilizer and fish feed, had a moderate amount of organic matter as a food resource for plankton growth and was well maintained, unpolluted and stress-free. As Site II received a year round continuous supply of household debris and sewage from other nearby domestic sources, the organic load was highest among all the sites and was thus polluted and eutrophic. Site III had a low nutrient level due to absence of organic matter from any anthropogenic sources, reflected by insufficient aquatic vegetation. It has been mentioned that any community dominated by relatively fewer species reflects environmental stress and vice versa (Plafkin et al. 1989). In the present study, significantly higher cladoceran diversity was found in cleaner stress-free water conditions

Table 5. Analysis of variance ($P = 0.05$) of different diversity indices comparing seasonal values (temporal variation) and spatial values at three study sites (df, degrees of freedom), bolded numbers indicate significant values

Parameter	Source of variation	df	*F*	*P*-value	*F* critical
Shannon-Weiner index (*H'*)	Between seasons	2	0.231509797	0.800106	5.143253
	Between sites	2	**28.77171**	0.000842	5.143253
Evenness index (*E*)	Between seasons	2	0.901235	0.454734	5.143253
	Between sites	2	**7.790244**	0.021492	5.143253

Table 4. Different diversity indices comparing the seasonal variations in Cladocera population at three study sites between April 2019 and March 2020 (expressions of the indices described in the text). PrM, premonsoon; M, monsoon; PoM, postmonsoon

Diversity indice	Site I				Site II				Site III			
	PrM	M	PoM	Range	PrM	M	PoM	Range	PrM	M	PoM	Range
Taxa (*S*)	13.0	12.0	13.0	12.0 – 13.0	8.0	8.0	8.0	8.0	10.0	9.0	10.0	9.0 – 10.0
Dominance (*D*)	0.09	0.11	0.09	0.09 – 0.11	0.14	0.12	0.13	0.12 – 0.14	0.10	0.11	0.09	0.09 – 0.11
Simpson (1 – *D*)	0.91	0.89	0.91	0.89 – 0.91	0.86	0.88	0.87	0.86 – 0.88	0.90	0.89	0.91	0.89 – 0.91
Shannon (*H'*)	2.50	2.35	2.47	2.35 – 2.50	1.89	1.81	1.83	1.81 – 1.89	2.10	1.83	2.07	1.83 – 2.10
Evenness (*E*)	0.94	0.88	0.91	0.88 – 0.91	0.83	0.76	0.78	0.76 – 0.83	0.82	0.69	0.79	0.69 – 0.82
Brillouin	1.78	1.08	1.41	1.08 – 1.78	1.47	1.10	1.32	1.10 – 1.47	1.56	1.17	1.42	1.17 – 1.56
Menhinick	1.89	2.39	2.12	1.89 – 2.39	1.17	1.57	1.35	1.17 – 1.57	1.57	1.97	1.77	1.57 – 1.97
Margalef (*R*)	3.19	3.74	3.49	3.19 – 3.74	1.85	2.27	2.02	1.85 – 2.27	2.49	2.77	2.70	2.49 – 2.77
Pielou's (*J*)	0.98	0.95	0.96	0.95 – 0.98	0.91	0.87	0.88	0.87 – 0.91	0.91	0.83	0.90	0.83 – 0.91
Fisher alpha (α)	5.91	8.94	7.01	5.91 – 8.94	2.77	3.95	3.23	2.77 – 3.95	4.24	6.00	5.02	4.24 – 6.00
Berger-Parker (*d*)	0.13	0.16	0.11	0.11 – 0.16	0.23	0.19	0.23	0.19 – 0.23	0.17	0.19	0.16	0.16 – 0.19

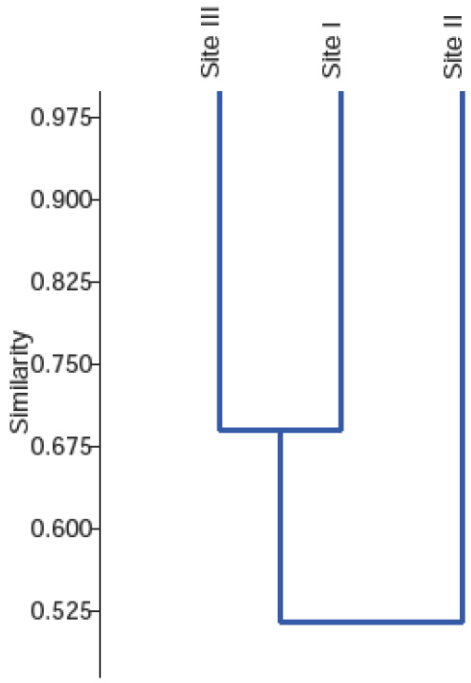

Fig. 4. Cluster analysis using Bray Curtis similarity index (UPGMA, cophenetic correlation = 0.73) for the three study sites based on species diversity and species density.

(the fish pond, Site I). Thus, cladoceran species diversity in these three sites was associated with the eutrophication level of the water bodies and thus, they can be used as an efficient bioindicators. Similar observations were made at Pushkar lake, Ajmer, Uttar Pradesh (Khanna, Yadav 2009); Govindgarh Lake, Rewa; Madhya Pradesh (Patel et al. 2013), Dharmapuri lake, Tamil Nadu (Dhanasekaran et al. 2017); Ukkadam Lake, Tamil Nadu (Manickam et al. 2018); and Ropar Wetland, Punjab (Brraich, Akhter 2019).

Chydorus parvus, Chydorus sphaericus, Schapholeberis kingi, and *Moina micrura* were found at all the three sites. This denotes their wider distribution pattern and higher tolerance to limiting factors in the prevailing conditions. *Alona verrucosa, Alona* sp. 1, *Coronatella rectangula, Daphnia lumholtz, Moina macrocopa* and *Diaphnosoma sarsi* were found exclusively in a single study site during the study period, indicating their narrow distribution pattern and stenotolerance. Among the three study sites, *Moina micrura* had the highest population density (6.32 individuals L^{-1}), followed by *Alona affinis* (4.43 individuals L^{-1}), indicating their high growth rate, success in utilising the available resources over others, high tolerance and wide habitat range. *Alona* sp.2 had the lowest population density. The dominance of the Chydoridae family has been typically recorded in a number of tropical and sub-tropical wetlands in the region, such as in Keoladeo National Park, Bharatpur, Rajasthan (Venkataraman 1990); in selected wetlands of south Rajasthan (Sharma et al. 2012); in some rock pools of Maharashtra (Padhye, Victor 2015) and in selected water bodies of Ludhiana, Punjab (Thakur, Kocher 2016).

The most favourable period for cladoceran population growth was found to be between March to June when food availability and physical conditions were optimum, while the least productive period was between July to October when turbidity was high and food availability was lower. Thus, temperature and availability of food seemed to be the two main limiting factors for cladoceran productivity. Prey-predator dynamics also affect the population density of plankton in water bodies (Lampert, Sommer 1997). Thus, the population density of cladocerans in the study sites may have been affected by fish population density in the community.

Higher species diversity indicates improved health of lake ecosystems. $H' < 1$ indicates highly polluted or eutrophicated condition, H' of 1 to 3 indicates a moderately polluted condition, and $H' > 3$ shows unpolluted conditions (Mason 1988). Thus, the H' index value can be used as an indicator of pollution (Klemm et al. 1990). In the current study, H' values (between 1.81 and 2.50) for the three sites indicated moderate stability of the ecosystems. Thus, the eutrophication levels had moderate values, lowest at Site I and highest at Site II. Other diversity indices showed that Site I had higher species richness and suitable conditions followed by Site III and Site II respectively. Similar observations were found at Satna, Madhya Pradesh (Singh et al. 2002); in South Kerala (Latha, Thanga 2010); at selected wetlands in Ludhiana, Punjab (Thakur, Kocher 2017) and at Ropar wetland, Punjab (Brraich, Akhter, 2019).

One way ANOVA results on the spatio-temporal data showed that there was significant difference in H' values among the sites while it was negligible and insignificant among the seasons. The Bray-Curtis cluster analysis revealed that Site I and Site III were more similar in species community composition, compared to Site II. Thus, it can be inferred, as Site I and Site III had similar faunal composition in comparison to Site II,. However, the relationship of cladoceran diversity and community composition with physicochemical parameters needs to be studied.

Conclusions

The present study revealed the presence of 16 cladoceran species from some selected lateritic soil freshwater wetlands. However, this number is much lower than the overall recorded diversity of cladoceran species (63) in this typical "Rarh belt" of West Bengal (Chakraborty, Mallick 2020). Thus, the study highlights the need of a more extensive, systematic survey of cladoceran species in the area in the future. Moreover, as distribution of cladocerans is affected by various other factors (including, temperature, rainfall, water quality, nutrients, macrophytes, flood pulse etc.) the relationships of cladoceran communities with physico-chemical features of the water bodies needs to be studied.

While wetlands are among the most important, dynamic ecosystems of nature, they are vanishing at a faster rate due to lack of management, anthropogenic stress, rapid urbanization etc. Apart from that, wetlands continuously undergo slow but gradual changes with time. This study highlighted that properly managed water bodies had higher cladoceran species diversity, compared to the others. Moreover, diversity of zooplankton, including cladocerans, is also important for sustainable management of water bodies. Thus, the study indicated the scope of wetland conservation as well as habitat preservation in the region. Cladocerans, being nutritive "natural live feed" for fish and shrimp culture practices, means that proper maintenance of these wetlands can augment cladoceran diversity and thus, in turn fish production in the area. This can create livelihood generation and economic development of the local people in this rural belt.

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References

Adoni A., Joshi D.G., Gosh K, Chourasia SK, Vaishya A.K., Yadav M,. Verma H.G. 1985. *A Work Book on Limnology*. Pratibha Publisher, Sagar.

Bagchi K., Mukherjee K.N. 1983. Diagnostic Survey of Rarh Bengal (Part II). University of Calcutta, Calcutta, pp. 23–29.

Baker R.L. 1979. Birth rate of planktonic rotifers in relation to food concentration in a shallow, eutrophic lake in western Canada. *Can. J. Zool.* 57: 1206–1214.

Bass D., Harrel R.C. 1981. Water quality of a southeast Texas stream. *Hydrobiologia* 76: 69–79.

Battish S.K. 1992. *Freshwater Zooplankton of India*. Oxford & IBH Publishing Company.

Bhat N.A., Wanganeo A., Raina R. 2014. The composition and diversity of net zooplankton species in a tropical water body (Bhoj Wetland) of Bhopal, India. *Int. J. Biodiv. Conserv*. 6: 373–381.

Brower J.E., Zar J.H. 1977. *Field and Laboratory Methods for General Ecology*. WMC Brown Co. Publisher, Dubuque, pp. 124.

Brraich O.S., Akhter S. 2019. Diversity and distribution of zooplankton in Ropar Wetland (Ramsar Site) Punjab, India. *Nat. Environ. Pollut. Technol.* 18: 451–458.

Carling K.J., Ater I.M., Pellam M.R., Bouchard A.M., Mihuc T.B. 2004. Guide to the zooplankton of Lake Champlain. *Scientia Discipulorum* 1: 1–29.

Chakraborty S., Mallick P.H. 2020. Freshwater cladoceran (Cladocera: Branchiopoda) diversity of Lateritic Rarh Belt of West Bengal, India: a review. *Adv. Zool. Bot.* 8: 188–198.

Dadhich N., Saxena M.M. 1999. Zooplankton as indicators of trophic status of some desert waters near Bikaner (NW Rajasthan). J. *Environ. Pollut.* 6: 251–254.

Dhanasekaran M., Bhavan P.S., Manickam N., Kalpana R. 2017. Physico-chemical characteristics and zooplankton diversity in a perennial lake at Dharmapuri (Tamil Nadu, India). *J. Entomol. Zool. Stud.* 5: 285-292.

DMCDS Paschim Medinipur. 2019. District Disaster Management Plan, Paschim Medinipur, West Bengal, India. http://wbdmd.gov.in/writereaddata/uploaded/DP/DPPaschim%20Midnapore81896.pdf. Accessed on 14th May, 2021

Forro L., Korovchinsky NM., Kotov AA., Petrusek A. 2008. Global diversity of cladocerans (Cladocera; Crustacea) in freshwater. *Hydrobiologia* 595: 177–184.

Fryer G.A. 1987. New classification of the Branchiopod Crustacea. *Zool. J. Linn. Soc.* 91: 357–383.

Ghidini A.R, Serafim-Júnior M., Perbiche-Neves G., Brito L.D. 2009. Distribution of planktonic cladocerans (Crustacea: Branchiopoda) of a shallow eutrophic reservoir (Paraná State, Brazil). *Pan-Am. J. Aquat. Sci.* 4: 29–305.

Guilin X., Rongshu F., Jianli L., Changru W., Jijun Z. 2004. The community distribution of soil oribatida in Heze Peony Garden. *Acta Ecol. Sin.* 24: 693–699.

Harper D.A.T. 1999. Numerical Palaeobiology. John Wiley & Sons, pp. 468.

Khanna V., Yadav I. 2009. Planktonic diversity in the Holy lake of Pushkar, Ajmer. *Nature Environ. Pollut. Technol.* 8: 339–342.

Kiss A., Ágoston-Szabó E., Dink M., Schöll K., Berczik Á. 2014. Microcrustacean (Cladocera, Copepoda, Ostracoda) diversity in three side arms in the Gemenc Floodplain (Danube River, Hungary) in different hydrological situations. *Acta Zool. Bulg.* 7: 135–141.

Klemm D.J. 1990. Macroinvertebrate field and laboratory methods for evaluating the biological integrity of surface waters. U.S. Environmental Protection Agency.

Krebs C.J. 1999. *Ecological Methodology*. Benjamin Cummings, Menlo Park, pp. 620.

Lampert W., Sommer U. 1997. *Limnoecology: the Ecology of Lakes and Streams*. Oxford University Press, New York.

Latha C., Thanga V.S.G. 2010. Macroinvertebrate diversity of Veli and Kadinamkulam lakes, South Kerala, India. *J. Environ. Biol.* 31: 543–547.

Mallick P.H., Chakraborty S.K. 2015. Does intra-site connectivity influence the dynamics of zooplankton metacommunity in freshwater habitats? *Turkish J. Fisher. Aquat. Sci.* 15: 661–675.

Manickam N., Bhavan P.S., Santhanam P., Bhuvaneswari R., Muralisankar T., Srinivasan V., Karthik M. 2018. Impact of seasonal changes in zooplankton biodiversity in Ukkadam Lake, Coimbatore, Tamil Nadu, India, and potential future implications of climate change. *J. Basic Appl. Zool.* 79: 1–10.

Manickam N., Bhavan P.S., Santhanam P., Muralisankar T., Srinivasan V., Vijayadevan K., Bhuvaneswari R. 2015. Biodiversity of freshwater zooplankton and physico-chemical parameters of Barur Lake, Krishnagiri District, Tamil Nadu, India. *Malaya J. Biosci.* 2: 1–12.

Mason C.F. 1988. *Biology of Fresh Water Pollution*. Longman Scientific and Technical.

McDonald K.L. 2003. The abundance of herbivorous and predatory fishes in relation to *Diadema antillarum* along the west coast of Dominica. *ITME Res. Rep.* 19: 11–21.

May R.M. 1975. Patterns of species abundance and diversity. In: Cody J.M. (Ed.) *Ecology and Evolution of Communities.* Harvard University Press, Cambridge.

Michael R.G., Sharma B.K. 1988. Indian cladocera (Crustacea:

Branchiopoda: Cladocera). *Fauna of India and Adjacent Countries Series*. Zoological Survey of India, Calcutta, pp. 262.

Murugan N., Murugavel P., Koderkar M.S. 1998. *Freshwater Cladocera*. Indian Association of Aquatic Biologists, Hyderabad, pp. 47.

Needham J.G., Needham P.R. 1962. *A Guide to the Study of the Freshwater Biology*. Holden-Dey, San Francisco, pp. 108.

Padhye S.M., Victor R. 2015. Diversity and distribution of cladocera (Crustacea: Branchiopoda) in the rock pools of Western Ghats, Maharashtra, India. *Annales Limnol. Int. J. Limnol.* 51: 315–322.

Patel V., Shukla S.N., Patel V. K. 2013. Studies on the diversity of zooplankton and their seasonal variation in Govindgarh Lake at Rewa, Madhya Pradesh, India. *Ind. J. Appl. Res.* 3: 544–546.

Pennak R.W. 1978a. *Freshwater Invertebrates of United States*. 2nd Ed. John Wiley & Sons, New York, pp. 803.

Pennak R. W. 1978b. The dilemma of stream classification. In: Classification, Inventory and Analysis of Fish and Wildlife Habitat. US Fish and Wildlife Service, Washington, DC, Biological Services Program FWS/OBS 78/76: 59–66.

Plafkin J.L., Barber M.T., Poter K.D., Gross S.K., Highes R.M. 1989. Rapid bioassessment protocol for use in streams and rivers for benthic macro invertebrates and fish, EPA/444/4-89/001. Office of Water Regulation and Standard U.S Environmental Protection Agency, Washington DC.

Qadri M.Y., Yousuf A.R. 1980. Influence of physico-chemical factors on the seasonality of cladocera in lake Manasbal. *Geobios* 7: 273–276.

Santhanam R. 1989. *A Manual of Freshwater Ecology: an Aspect of Fishery Environment*. Daya Books, New Delhi.

Sharma B.K. 1991. Cladocera. In: *Animal Resources of India, State of Art*. Zoological Survey of India, Calcutta, pp. 205-223.

Sharma B.K., Sharma S. 2001. Contributions to the cladoceran fauna (Crustacea: Branchiopoda: Cladocera) of Bihar. *Rec. Zool. Surv. India* 99: 31–43.

Sharma B.K., Sharma S. 2017. Crustacea: Branchiopoda (Cladocera). In: Chandra K., Gopi K.C., Rao D.V., Valarmathi K., Alfred J.R.B. (Eds). *Current Status on Freshwater Faunal Diversity of India – An Overview*. Zoological Survey of India, Kolkata, pp. 199–223.

Sharma V., Verma B.K., Sharma R., Sharma M.S., Gaur K.S. 2012. A report on the freshwater cladocera (Crustacea: Branchiopoda) of south Rajasthan (India). *Int. J. Environ. Sci.* 3: 275–296.

Singh S.P., Pathak D., Singh R. 2002. Hydrobiological studies of two ponds of Satna (MP), India. *Ecol. Environ. Conserv.* 8: 289–292.

Sinha B. 2018.Status of studies on zooplankton fauna of Arunachal Pradesh, India. J. Threat. *Taxa* 10: 12552–12560.

Sinha B., Islam M.R. 2002. Seasonal variation in zooplankton population of two lentic bodies at Assam State Zoo cum Botanical Garden, Guwahati, Assam. *Ecol. Environ. Conserv.* 8: 273–278.

Smirnov N.N. 1971. The World Chydorid Fauna. USSR Academy of Sciences, Zoological Institute Nova Series, Leningrad, 101: 539. /in Russian/

Somashekar R.K., Ramaswamy S.N. 1984. Biological assessment of water pollution: a study of the river Kapila. *Int. J. Environ. Stud.* 23: 261–267.

Steele M. K., Heffernan J. B., Bettez N., Cavender-Bares J., Groffman P. M., Grove J. M., Chowdhury R. R. 2014. Convergent surface water distributions in US cities. *Ecosystems* 17: 685–697.

Tasevska O., Kostoski G. Guseska D. 2010. Rotifers based assessment of the Lake Dojran water quality. *Balwois* 25: 1–8.

Thakur A., Kocher D.K. 2017. Diversity and density of cladoceran population in different types of water bodies of Ludhiana, Punjab (India). *J. Entomol. Zool. Stud.* 5: 1568–1572.

Venkataraman K. 1990. New records of cladoceran of Keoladeo National Park, Bharatpur—III. *J. Bombay Nat. Hist. Soc.* 87: 166–168.

Welch P.S. 1948. *Limnological Methods*. McGraw Hill, New York, pp. 381.

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