

## SHORT NOTE

# Seasonal variation in functional composition and diversity of cladoceran zooplankton of a lotic eutrophic habitat from India

Sameer M. Padhye\*

Systematics, Ecology & Conservation Lab, Zoo Outreach Organization, Coimbatore 641035, Tamil Nadu, India

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**Abstract** – This study explores the seasonal variation in functional composition, diversity and redundancy of Cladocera from an Indian lotic eutrophic habitat using two-year sampling data. Two seasonal clusters distinguishable by faunal and functional diversity patterns were obtained. Cluster A comprised of four functional groups while the ctenopod filter feeders were absent in cluster B. Cluster A had more number of species, higher functional divergence and lower redundancy than cluster B. Relatively, higher divergence values observed during the cluster A time period could be associated with set of functionally varied species occurring throughout the season. Decline in redundancy values seen within cluster A might be explained by the loss of littoral and benthic species in the peak of summer due to disappearance of submerged macrophytes and an increased nutrient load. Peculiar occurrence of *Moina* species in the most polluted months needs further investigation as a potential local pollution indicator.

**Keywords:** Cladocera / functional composition / functional divergence / functional redundancy / Mula River / nitrates

## 1 Introduction

Anthropogenic effects on environment are decreasing biodiversity and altering functional traits by community wide modifications (Loreau *et al.*, 2001). Such environmental changes can be explored either by assessing variations in biological communities and their environments or with an integrative method considering a set of functional characters along with the species identity (Cadotte *et al.*, 2011; Nevalainen and Luoto, 2017). Trait-based approaches provide a better outlook towards species–environment associations and functional diversity based on these traits estimates the values of particular species traits that effect ecosystem functioning (Tilman, 2001, Verberk *et al.*, 2013).

Freshwater lotic habitats are widely altered, exploited and pollute ecosystems with changes occurring in their morphology, biogeochemistry as well as species communities (Malmqvist and Rundle, 2002). Cultural eutrophication (caused by human-mediated impacts) is a prevalent water quality problem in such habitats primarily caused by artificially increased inputs of phosphorus and nitrogen through various anthropogenic sources (Schindler, 2012). Zooplankton like Cladocera are used as a model community

for studying such changes as variations in their species and functional diversity highlight ecosystem stability and the trophic state (Nevalainen and Luoto, 2017; Rizo *et al.*, 2017).

Literature exists on biological and chemical monitoring of various lotic and lentic habitats across the Indian subcontinent (e.g. Padmavati and Goswami, 1996; Rajaram and Das, 2008) but, to my knowledge, reliable faunal diversity studies incorporating functional traits in the Indian river systems have not been conducted till date. This is especially important as many issues like proper scientific waste disposal and its re-introduction in the environment are yet unresolved in many parts of India.

I conducted this study to explore the temporal variation in functional composition and diversity of zooplankton fauna in a eutrophic lotic system, Mula in Western India. High load of untreated sewage is still released into this river causing nutrient enrichment (MPCB website; river: Mula, site code: 2193). Preliminary biomonitoring studies have shown that there seem to be characteristic seasonal faunal patterns associated with changes in water flow, dissolved oxygen and nutrients (Vanjare *et al.*, 2010; Padhye and Dahanukar, 2015).

The specific aims of this study were (A) exploring the cladoceran functional composition and its seasonal variation in the eutrophic lotic site and B) checking significant differences in some functional diversity measures between seasons based on inferential analyses.

\*Corresponding author: [sameer.m.padhye@gmail.com](mailto:sameer.m.padhye@gmail.com)

## 2 Material and methods

Secondary data (fauna and environment) of the Mula river site from years 2009 (5 samples collected in months of January, March, May, September and November; one sample per month) and 2010 (10 samples collected from January until December 2010 except July and August; one sample every month) were used for analysis (for more information, please refer to [Vanjare et al., 2010](#); [Padhye and Dahanukar, 2015](#)). A similar collection strategy was followed for both the years to collect cladocerans, which involved sampling five aliquots of 1-L samples from a 2 m zone along the littoral region. The area of collection was gently disturbed for a few seconds to obtain benthic elements, if any. These were then concentrated using a 100  $\mu\text{m}$  filter in a single 100 ml cup and immediately preserved in 5% formaldehyde. The 2009–2010 samples were originally scored for presence/absence of species while the 2010 samples involved counting species abundances (due to the different objectives of both the studies). The final dataset, therefore, was converted into a presence/absence data for all analyses. Two species, *Karualona karua* (King, 1853) and *Simocephalus mixtus* (Sars, 1903) were deemed cross contaminants while *Diaphanosoma sarsi* (Richard, 1894) was overlooked in the 2009 collections thereby modifying the species data. Environmental data, such as total nitrates and Biological Oxygen Demand (BOD), were taken from the Maharashtra Pollution Control Board database (MPCB website) while pH, temperature and salinity were measured using a multiparameter probe. Monthly average rainfall data was obtained from an online weather source ([Weather Atlas website](#)) (Supplementary information Table 3 for environmental data).

The traits considered for the study were, (A) mean body length, (B) egg clutch number, (C) proportion of eye size to total length (in %), (D) feeding type based on the type of filtration mechanism (Daphniid feeding type, Chydorid feeding type, Ctenopod feeding type and Ilyocryptid feeding type) and (E) habitat type (pelagic, littoral and benthic). The first three traits were continuous and calculated from measuring 10 parthenogenetic females while the latter two were categorical (for more descriptions on the traits, please refer to [Rizo et al., 2017](#)) (Supplementary Information Table 1 for species specific trait data).

The two seasonal clusters of zooplankton fauna published earlier ('Winter-Summer-Pre-Monsoon' and 'Post-Monsoon until Winter' groups *sensu* [Padhye and Dahanukar, 2015](#)) were initially assessed for reliability using the two-year combined faunal dataset by Unweighted Pair-Group Method using Arithmetic averages (UPGMA). Presence/absence of faunal data was converted into a distance matrix using Jaccard index for the clustering. Bootstrap values for nodes and cophenetic correlation coefficient were calculated to assess the efficacy of the clustering. A principal component analysis (PCA) of the environmental variables was carried out to explore the environmental patterns between the two clusters (results of clustering and PCA given in the Supplementary information Figs. 1 and 2). Further analyses were conducted using the two clusters (Cluster A: Winter-Summer-Pre-Monsoon group; Cluster B: Post-Monsoon until Winter group).

Nonmetric Multidimensional Scaling (NMDS) was performed using two dimensions with 5000 random starts to

visualize species associations with the two clusters. The significance of species association was tested using One-way Nonparametric permutational MANOVA (PERMANOVA; [Anderson, 2001](#)) with the null hypothesis claiming no difference in the fauna between the clusters. Jaccard index was used for calculating the distances and the model was run using 5000 permutations. Homogeneity of dispersion was checked before performing the PERMANOVA (results in Supplementary information Tab. 4).

Functional composition of the faunal groups in the seasonal clusters was visualized as an average linkage hierarchical dendrogram using Gower distance. Two functional diversity indices were calculated using the functional traits data, namely, (A) functional divergence, which measures species distances from the center of gravity of the functional trait space for presence/absence data ([Villéger et al., 2010](#)) and (B) functional redundancy, which is a measure of the species number belonging to a specific functional group that performs similar ecosystem functions ([Laliberte et al., 2010, 2014](#)). Variation in the functional diversity between the clusters if/any was evaluated for statistical significance using a one-way PERMANOVA by means of 'Gower' distance.

All analyses were performed using RStudio (v 3.6.2; [RStudio Team](#)). Principal component analysis was performed using the base R packages. Hierarchical clustering, nonmetric multidimensional scaling, homogeneity of dispersion and PERMANOVA were performed using the 'vegan' package ([Oksanen et al., 2013](#)). Functional composition and divergence were calculated using the 'dbFD' function from the FD package ([Laliberte et al., 2014](#)) while functional redundancy was calculated using the SYNCSA package ([Debastiani and Pillar, 2018](#)).

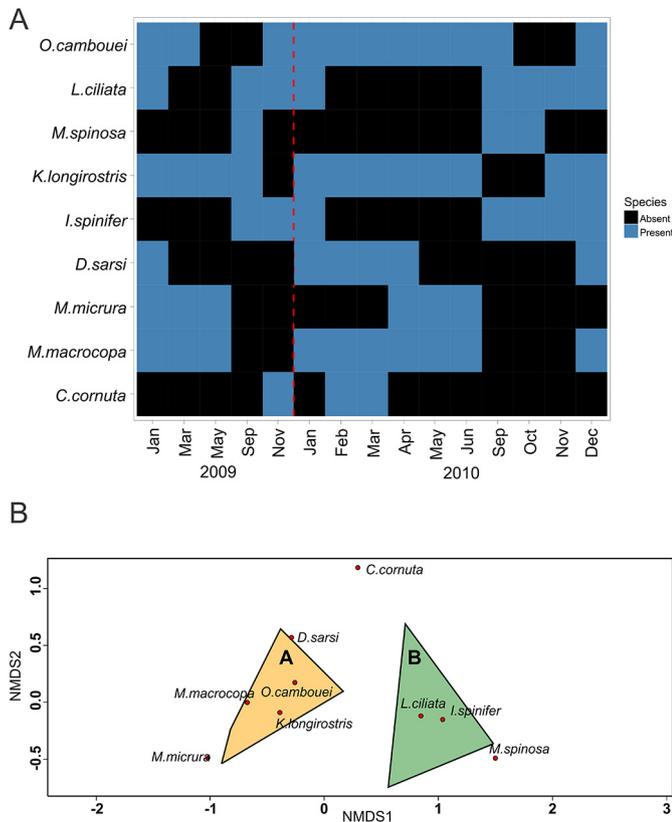
## 3 Results

A total of nine species representing four families were observed at the site for both the years. Chydorid Cladocera were the most species rich group with four species followed by Moinidae with two species ([Fig. 1A](#)).

Nonmetric multidimensional scaling (stress=0.04) showed certain clear associations with pelagic filterer species such as *Moina macrocopa* (Straus, 1820) observed in cluster A and the small littoral *Macrothrix spinosa* (King, 1853) in cluster B ([Fig. 1B](#)). These two clusters were significantly different based on one-way PERMANOVA ([Tab. 1A](#)).

A maximum of four functional groups (F.groups henceforth) were obtained. Functional group 4 representatives occurred in more than 75% of the samples ([Fig. 1A](#)). The functional groups could be mainly classified by feeding types and habitat preferences (details on the functional group characteristics given in Supplementary information Tab. 2). All functional groups were represented in cluster A while one group was absent in cluster B ([Fig. 2A](#)). Pelagic filter feeders besides one rare occurrence of *C. cornuta* were absent from cluster B ([Fig. 2A and B](#)).

Cluster A samples showed higher overall functional divergence (cluster A range=0.75–0.94; cluster B range=0.65–0.8) and lesser redundancy (cluster A range=0.19–0.24; cluster B range=0.24–0.28) than cluster B for both the years. Monthly pattern of functional divergence was dissimilar in



**Fig. 1.** (A) Species composition of the study site over 2 years (red line separates the 2 years 2009 and 2010 respectively). (B) Non-metric multidimensional scaling of the sampling data showing the two groups using Jaccard index.

**Table 1.** PERMANOVA results to test statistical significance of (A) species composition and (B) functional diversity values between the two seasonal clusters (Df: degrees of freedom; SS: sum of squares).

A. Species composition				
	Df	SS	$R^2$	$p$
Clusters	1	1.69	0.57	<0.001
Residuals	13	1.27	0.48	
Total	14	2.89	1.00	
B. Functional diversity				
	Df	SS	$R^2$	$p$
Clusters	1	0.15	0.32	<0.001
Residuals	13	0.33	0.68	
Total	14	0.49	1.00	

both the years but decreased from winter to summer months within cluster A (Fig. 2C). Functional redundancy values displayed a consistent trend with lowest values observed in the peak summer months (April/May) (Fig. 2D). The difference in the functional divergence and redundancy indices between the two clusters was statistically significant (Tab. 1B).

## 4 Discussion

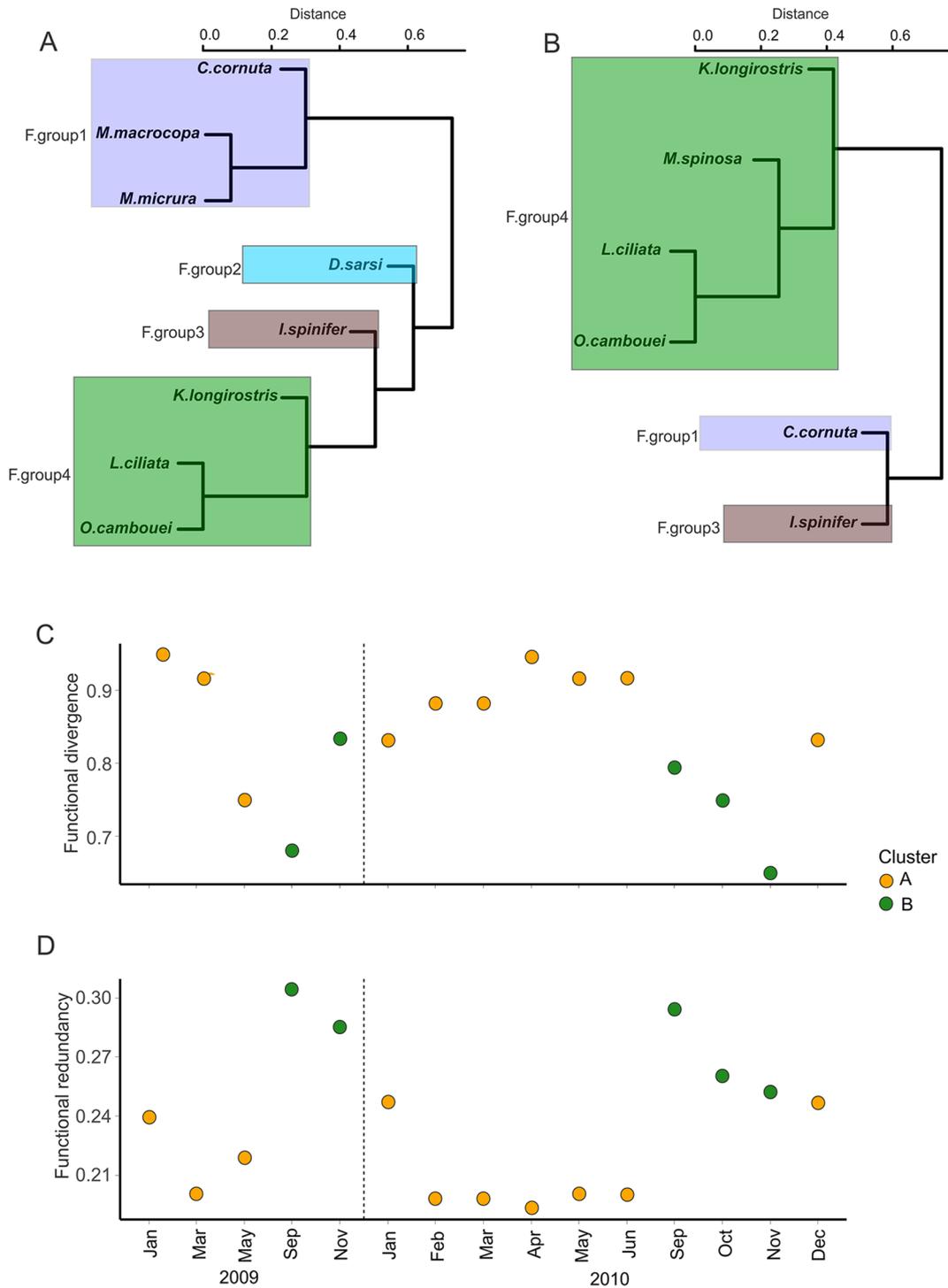
Water flow in River Mula varies temporally based on the water release from the water catchment areas (water

reservoirs) located upstream of this river. The flow is maximum in the monsoon and post monsoon season when the rainfall is high and usually almost stopped by the winter season. Water quality, visibility and aquatic vegetation also alters consequently during this seasonal transition (SMP pers. obs.) where variables such as nutrients and BOD increase gradually, especially in the late months of the summer (April/May of cluster B). Reduced water flow (leading to a higher water retention time) and environmental variability in turn is known to influence zooplankton abundance and composition in lotic habitats wherein changes such as trophic state modification, water temperature and visibility variation can impact their densities (Viroux, 2002; Thorp and Mantovani, 2005; Czerniawski and Pilecka-Rapacz, 2011). Study results clearly showed species communities being associated with specific seasonal clusters characterized by specific local environmental conditions (Fig. 1B; Supplementary information Figs. 1 and 2).

Cluster A having a higher functional variety than cluster B could partly be associated with respective species richness of both the clusters (Fig. 2A). Cluster A incorporated a longer time frame of nearly six months (December until June; Supplementary information Fig. 1) during which maximum number of species were observed (Fig. 1A). Long term monitoring of two Finnish lakes showed that zooplankton functional composition altered through the nutrient enrichment process with small filterers and epibenthic species reacting to it the most (Nevalainen and Luoto, 2017). Similarly, epibenthic, *I. spinifer* and *L. ciliata* along with the small filterer *C. cornuta* completely disappeared during the peak of summer (Apr/May) when the nutrient load (here nitrates) was high (Fig. 1A). This ‘summer’ phase observed in the earlier study (Padhye and Dahanukar, 2015) was almost separated within cluster A (except for March 2009 sample; Supplementary information Fig. 1) based on the combined dataset. During the same phase though, both the big-sized filter feeding *Moina* species from F.group 1 were commonly and abundantly observed (Vanjare *et al.*, 2010; Padhye and Dahanukar, 2015). This observation along with previously published reports on occurrence of *Moina* species in eutrophic habitats (e.g. Xu, 1992; Suárez-Morales *et al.*, 1994) would warrant some indicator value for these species at a local scale. More focused studies still need to be carried out for substantiating these observations (e.g. studying whether the faunal patterns are the outcome of the ‘size efficiency hypothesis’ (Dodson, 1974; Gliwicz, 1990)) as indicator species selection has to be rigorously tested (Hodkinson and Jackson, 2005).

Complex functional composition in a species community does point to better ecosystem functioning (Hooper and Vitousek, 1997; Bellwood *et al.*, 2004), though, no specific inferences could be made from this study due to lack of data on (A) taxa like Rotifera and Copepoda, which constitute a major portion of freshwater zooplankton and equally important in ecosystem functions (Thorp and Covich, 2001) and (B) variables such as chlorophyll alpha, grazing rates of cladocerans *etc.*

The divergence patterns in cluster A were not comparable for both the years, but, values on average, were relatively higher than cluster B (Fig. 2C). Species loss that occurred over time within cluster A happened in a manner preserving the distinctness in functions. Even in the peak of summer, at least 2



**Fig. 2.** (A and B) Functional composition of cladocerans collected from the studied site for (A) Cluster A and B Cluster B, respectively (each colored box represents one functional group; the species shown in the clusters are based on total species found and hence do not reflect monthly changes). (C and D) Plots showing the (C) functional divergence and (D) functional redundancy across the sampling months of both years (two colors represent clusters A and B; dashed line separates the 2 years 2009 and 2010, respectively).

functionally divergent species were observed (*Moina* species from F.group 1 and *Kurzia longirostris* from F.group 4). Most of the species observed in cluster B were littoral scrapers (F.group 4), suggesting a lesser functionally distinct and more redundant species community. This could result in consistent

lower divergence and higher redundancy values seen in cluster B. Redundancy does depend on the species richness within a functional group with high values implying an ‘insurance’ against functional loss (Chalcraft and Reserits, 2003; Laliberte et al., 2010). The steady monthly decline in

redundancy from post monsoon (Oct/Nov) to summer (May) could then be explained by either loss of species from functional groups or loss of entire functional group with increasing eutrophic conditions (Figs. 1A and 2B). Relationship between species richness and functional trait diversity though, is variable depending on relevant factors like traits selection and environmental filtering (Mayfield *et al.*, 2010; Cadotte *et al.*, 2011 and references therein).

Anthropogenic disturbances such as waste discharge and introduction of exotic species modify urban aquatic ecosystems affecting the taxonomical and functional composition of a range of faunal communities consequently altering fundamental ecosystem processes (Gallardo *et al.*, 2011). This is especially pertinent in case of a developing country such as India where effective wastewater management by and large is still an issue resulting in species loss in some taxa (e.g. Kharat *et al.*, 2003–fishes). Extensive studies, thus, must be planned and carried out to assess the impact of pollution on freshwater biodiversity in Indian rivers.

## Supplementary Material

Supplementary Tables 1 to 4 and Figures 1 to 2.

The Supplementary Material is available at <https://doi.org/10.1051/limn/2020011>.

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