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Periphytic rotifers: A comprehensive study on species composition, substrate specificity and habitat preference down a tropical riverine system

Ротифери во перифитонот: Интегрална студија за видовиот состав, супстратната специфичност и преференцата кон хабитати во тропски речен систем

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Abstract

The occurrence and distribution of periphytic rotifer assemblages from five different substrata in relation to physicochemical parameters were studied for one year (June 2016 – May 2017) along middle and lower stretches of the Periyar River, Kerala. Taxonomic studies revealed the presence of 63 species of periphytic rotifers belonging to 26 genera, 17 families, and 3 orders. Lecanidae was found to be the most abundant family followed by Colurellidae and Philodinidae. Canonical correspondence analysis elucidates the role of temperature, dissolved oxygen, phosphate, and nitrate in the distribution and abundance of rotifer families. Correspondence analysis illustrates the distribution of rotifers were mainly confined to leaves and roots. Principal component analysis marked the dominance of the pre-monsoon period contributed by the abundance of Lecanidae, Colurellidae, and Philodinidae families. The study came out with some important baseline information regarding the species composition, substrate specificity, and regional preference of periphytic rotifers in relation to the environmental parameters from the river Periyar.

Key words: Periphyton; Periyar; Substrate specificity; Rotifer

Апстракт

Врската помеѓу присуството и распространувањето на заедниците на ротифери во перифитонот со физичко-хемиските параметри од пет различни супстрати беа изучувани во тек на една година (јуни 2016 – мај 2017) по средниот и долниот тек на реката Перијар, Керала. Таксономските анализи покажаа присуство на 63 видови перифитонски ротифери од 26 родови, 17 фамилии и 3 редови. Lecanidae беше најзастапената фамилија, а по неа следуваа Colurellidae и Philodinidae. Канонската кореспондентна анализа ја покажа улогата на температурата, растворениот кислород, фосфатите и нитратите во распространувањето и абундантноста на ротиферските фамилии. Кореспондентната анализа дополнително покажа дека ротиферите се најчесто поврзани со листовите и корењата. Со помош на PCA (Principal component analysis) се докажа значењето на предмонсунскиот период за

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абундантноста на фамилиите Lecanidae, Colurellidae и Philodinidae. Во оваа студија е прикажана важна основна информација за видовиот состав, супстратната специфичност и регионалната преференца на перифитонските ротифери во врска со еколошките параметри од реката Перијар.

Клучни зборови: перифитон, Перијар, супстратна специфичност, ротифери

Introduction

The lotic ecosystem is usually characterized by two complex assemblages of microbiota; that on floating water is known as zooplanktons and that of submerged substrates is known as periphyton. Periphyton is a complex assemblage of algae, bacteria, fungus, protozoans, microinvertebrates, and detritus attached to the submerged surfaces of aquatic ecosystems (Azim et al., 2002). It forms a bio-film over submerged objects and provides a suitable niche for the organisms to colonize and exploit. Periphyton plays a crucial role in maintaining the integrity of a freshwater ecosystem by forming the basis of food web interactions. It also acts as an important ecological indicator and helps in the purification of water by the adsorption and absorption of nutrients.

In aquatic water bodies, zooplankton groups play a major role in integrating food-web interactions at lower tropic levels by providing energy to higher levels. Rotifers form an important component of zooplankton. The diversity, seasonality, and abundance of rotifers greatly contribute to the existence and distribution of other biotic components. Rotifers act as a principal component of periphytic bio-film due to its abundance, rapid turnover rate and it forms an important link in the food chain at the lower trophic level.

Major factors influencing periphytic rotifer diversity are substratum type, submersion time, water currents, nutrients, chemical properties of water, grazing, and light availability (Wu, 2017). Each of these parameters individually contributes to rotifer diversity but the simultaneous interaction of all these factors produces the ultimate result (Hulyal & Kaliwal, 2008). Periphytic rotifers can be found attached to different substrata like a plant (epiphyton), rocks and stones (epilithon), wood (epixylon), and sediments and litters (epipelon) (Allan &Castillo, 2007). The distribution pattern of rotifers is also influenced by the biochemical parameters of a locality either individually or in combinations (Shah et al., 2017).

Rotifer diversity of Indian subcontinent is widely scattered in different regions ranging from northern Himalayas to Southern Peninsula. Taxonomic studies on freshwater Rotifers of Tamil Nadu was carried out by Sharma and Sharma (2009) and documented 139 species (149 taxa) belonging to 38 genera and 20 families including 38 new records from the state and 20 new reports from to southern India. Rotifer diversity of the hill state of Nagaland of North East India was carried out by Sharma et al. (2017) and reported total of 150 species belonging to 37 genera and 19 families. Venkataramana et al. (2015) from their studies in Chikkadevarayana canal of Cauvery River has identified 27 species belonging to 15 genera and 9 families of which Brachionidae was the dominant. Rotifera assemblage including a total richness (S) of 162 species belonging to 19 families and 35 genera was recorded from Mizoram State by Sharma and Sharma (2015). Plankton samples collected from Deepor Beel, Assam, revealed 155 species of Rotifera, belonging to 35 genera and 20 families (Sharma & Sharma, 2015). Species composition and abundance of rotifers (Rotifera: Eurotatoria) in Kole wetland of Kerala, India recorded a total of 40 species of rotifers belonging to 15 genera and 10 families Fathibi et al. (2020).

Periphyton has received little attention in the riverine ecosystems of Kerala when compared to other tropical lotic water bodies. Most of the studies regarding rotifers were confined with planktonic rotifers and there have been no systematic and authentic records on periphytic rotifers from river Periyar. The role of environmental parameters in determining the distribution of periphytic rotifers on different substrata along Periyar was evaluated in the present study using various statistical tools.

Materials and Methods

Study area

Periyar, a tropical perennial river located in Southern 5 India is the longest river with the largest discharge potential. The river originates in the Sivagiri peaks (1800 m above sea level) of Western Ghats and ends up in the Arabian Sea after flowing through a stretch of 225 Km. It flows along the banks of many industrial, commercial, and agricultural areas. Periyar River has high economic value as major hydroelectric projects and dams of Kerala are associated with this river, and water from this river is the main source for drinking and irrigational purposes across the state. Studies indicate that river Periyar is gradually deteriorating due to various anthropogenic and agricultural activities, domestic and industrial runoff from nearby townships, and sand mining (Joseph, 2004).

Five sampling stations were selected along the middle and lower stretch of river Periyar (Fig. 1). Station 1 (S1): Pooyamkutty is located in the middle stretch of the river Periyar and less influenced by anthropogenic activities. Station 2 (S2): Kuttampuzha, located in the middle stretch of the river Periyar. It receives domestic effluents and agricultural runoff from the nearby agricultural area. Station 3 (S3): Thattekadu, located in the middle stretch and this station is one of the picnic spots and receives domestic sewage, agricultural and laundry waste. Station 4 (S4): Aluva, located along lower stretches where the river receives an enormous amount of sewage, garbage dumps, and industrial effluents from the nearby town. Station 5 (S5): Varappuzha, located along lower stretches, and the area receives an organic and chemical load from towns and industries located around the area. This station is also greatly influenced by the seawater intrusion during tidal cycles. Geographical co-ordinates of the selected sites are given in Table 1.

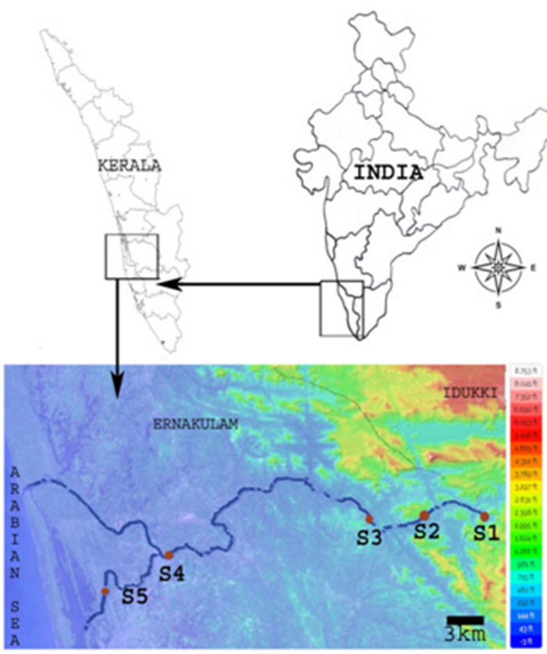

Figure 1. Map showing the study area.

Table 1. Details of the sampling stations

Stations	Latitude	Longitude
S1 (Pooyamkutty)	10.1605° N	76.7769° E
S2 (Kuttampuha)	10.1525° N	76.7396° E
S3 (Thattekadu)	10.1040° N	76.7005° E
S4 (Aluva)	10.0758° N	76.2714° E
S5 (Varappuzha)	10.1004° N	76.3570° E

Sampling procedure

Month-wise sampling was carried out for a period of one year (June 2016 - May 2017) from the five selected stations. From each station, samples were collected from five different substrate such as log, leaf, root, rock, and wall. Samples were collected by scrapping 5 cm^2 surface area of each substratum using scalpel, blade, and brushes. The scrapped contents were washed into a tray and transferred to a sampling vial (Biggs & Kilroy, 2000; Baba et al., 2011). The rinsed sample was preserved with 4% formalin and then raised to 10 ml using distilled water. One ml of this sample was taken to Sedgwick rafter for enumeration and the results were expressed in the number of individuals per unit area (no. /cm^2). All samples were examined under an inverted microscope (Carl Zeiss Primovert, Germany) equipped with phase contrast. Rotifers were identified using standard books, keys, and literature (Edmondson, 1959; Sharma & Sharma, 1999; Stemberger, 1979; Shiel, 1945; Ricci & Melone, 2000; Segers, 2004; Dang et al., 2015).

Water quality parameters such as temperature, pH, dissolved oxygen (DO), and conductivity, were carried out on-site using Cyberscan PCD 650 multi-parameter probe (Eutec instruments, Singapore). Water samples were brought back to the lab in dark conditions, under 4° C for the determination of remaining physicochemical parameters. The concentration of phosphate, nitrate, sulphate, and chloride was determined using the standard methods (APHA, 2005).

Statistical analysis

Data processing and statistical analysis were performed using the software PAST version 3 (Hammer, 2019). Periphytic rotifer species data and environmental data were subjected to normality tests using Monte-Carlo 999 permutation test. Principal Component Analysis (PCA) was performed to know the difference in the distribution and abundance of the periphytic rotifer families among three seasons (Jolliffe, 2002). Peripytic rotifer species data were square-root transformed before analysis to down weigh the contribution of abundant species. Canonical Correspondence Analysis (CCA) was performed to demonstrate the relationship between environmental variables and periphytic rotifer assemblages (Braak &Verdonschot, 1995). Environmental variables were subjected to Pearson's (Linear r) correlation to identify the significant variables ($p<0.05$) and were standardized using the formula (X-Mean)/SD. Species data were square-root transformed before analysis. Correspondence Analysis (CA) is also an ordination method like PCA and is used to analyze the preference range of rotifer families to a particular geographical region and substrate. Cluster analysis was conducted using the algorithm UPGMA and Bray-Curtis similarity index to know the percentage of similarity within the substrata and stations regarding periphytic rotifer distribution and abundance.

Results

Abiotic variables

The values of physicochemical parameters from five sampling stations of river Periyar is provided in Table 2. The temperature did not exhibit much seasonal variation although station 5 showed a comparatively higher temperature in pre-monsoon. pH values also did not show considerable differences expect at station five. Dissolved oxygen values showed a gradual reduction from station 1 to station 5 in all seasons and the monsoon period records its highest value. Nitrate has its highest value at station 4 and the pre-monsoon period marked the highest nitrate concentration in all stations. Phosphate concentration is comparatively high during the pre-monsoon period in all the five stations. Conductivity, sulphate, and chloride values were predominantly high at station 5 and these parameters exhibited higher concentration in the pre-monsoon period.

Seasonal distribution of rotifers

Taxonomic studies on periphytic rotifers of river Periyar revealed a total of 63 species belonging to 26 genera, 17 families and 3 orders (Table 3).

Relative abundance of season-wise distribution of rotifers follows the order Lecanidae > Colurellidae > Philodinidae > Epiphanidae > Habrotrochidae > Brachionidae > Adineta > Notommatidae > Dicarnophoridae > Flosculariidae > Gastropodidae > Asplanchnidae > Trichocercidae, Synchetidae > Trichotridae > Lindidae, Testudinellidae (Fig. 2). Lecanidae was found to be the most abundant family with 33.5% of total rotifers followed by Colurellidae (19.70%) and Philodinidae (15.8%). The least represented families were Lindidae and Testudinellidae (0.01%).

Principal Component Analysis (PCA) showed considerable difference in the periphytic rotifer composition among three seasons. The ordination plot resulted from Principal Component Analysis (PCA)

Table 2. Seasonal variation in biochemical parameters from selected stations of river Periyar.

Parameters	Seasons	S1	S2	S3	S4	S5
Temperature (^{0}C)	Monsoon	25.7± 0.31	25.9 ± 0.49	26.4 ± 0.48	27.6 ± 1.0	27.9 ± 1.23
	Post-monsoon	25.0 ± 0.80	26.0 ± 0.77	27.7 ± 1.52	29.5 ± 0.84	30.1 ± 0.62
	Pre-monsoon	26.2 ± 0.61	27.1 ± 1.60	28 ± 1.41	29.7 ± 1.68	30 ± 1.40
pH	Monsoon	6.6 ± 0.22	6.7 ± 0.27	6.9 ± 0.33	7 .0± 0.57	7.4 ± 0.14
	Post-monsoon	6.4 ± 0.36	6.4 ± 0.38	6.6 ± 0.14	6.0 ± 0.18	7.3 ± 0.33
	Pre-monsoon	6.1 ± 0.35	6.0 ± 0.56	6.3 ± 0.57	5.8 ± 0.20	7.5 ± 0.47
DO (mg/l)	Monsoon	8 .0± 0.10	7.8 ± 0.13	7.6 ± 0.17	7.2 ± 0.19	6.8 ± 0.03
	Post-monsoon	8.3 ± 0.61	8.1± 0.41	7.5 ± 0.13	6.8 ± 0.53	6.3 ± 0.40
	Pre-monsoon	7.8 ± 0.42	7.5 ± 0.44	7.1 ± 0.06	6.5 ± 0.29	5.6 ± 0.45
Conductivity (mS)	Monsoon	0.01 ± 0.00	0.04 ± 0.05	0.02 ± 0.00	0.02 ± 0.01	24.0 ± 7.52
	Post-monsoon	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.04 ± 0.01	46.7 ± 6.50
	Pre-monsoon	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.04 ± 0.01	49.1 ± 6.22
Phosphate (mg/l)	Monsoon	0.18 ± 0.11	0.16 ± 0.10	0.20 ± 0.16	0.46 ± 0.20	0.66 ± 0.12
	Post-monsoon	0.52 ± 0.19	0.55 ± 0.33	0.69 ± 0.29	1.0 ± 0.25	1.32 ± 0.31
	Pre-monsoon	1.06 ± 0.07	1.07 ± 0.17	1.16 ± 0.14	1.51 ± 0.35	1.6 ± 0.38
Sulphate (mg/l)	Monsoon	0.12 ± 0.01	0.14 ± 0.02	0.20 ± 0.06	0.24 ± 0.15	10.3 ± 4.9
	Post-monsoon	0.25 ± 0.28	0.3 ± 0.36	0.33 ± 0.42	0.46 ± 0.65	40.9 ± 20.01
	Pre-monsoon	0.17 ± 0.10	0.27 ± 0.12	0.20 ± 0.16	0.37 ± 0.17	60.9 ± 37.85
Nitrate (mg/l)	Monsoon	0.28 ± 0.25	0.33 ± 0.31	0.38 ± 0.34	1.23 ± 0.54	0.81 ± 0.58
	Post-monsoon	0.43 ± 0.06	0.45 ± 0.03	0.51 ± 0.08	2.65 ± 0.28	2.96 ± 0.20
	Pre-monsoon	3.60 ± 2.60	5.0 ± 3.75	5.9 ± 3.78	9.81± 2.32	6.95 ± 1.80
Chloride (mg/l)	Monsoon	62.5 ± 25.0	62.5 ± 25.0	75.0 ± 28.9	087.5 ± 47.9	0349.9 ± 107.98
	Post-monsoon	75. 0± 28.9	75.0 ± 28.9	75.0 ± 28.9	100.0 ± 40.81	1487.0 ± 303.7
	Pre-monsoon	99.9 ± 40.8	87.5 ± 47.9	99.9 ± 40.8	112.5 ± 47.86	1928.8 ± 701.8

Table 3. Periphytic rotifer assemblages from river Periyar.

FAMILY	SPECIES	FAMILY	SPECIES
LECANIDAE (LE)	*Lecane curvicornis nitida*		*Colurella obtusa*
	Lecane crepida		*Colurella uncinata*
	Lecane signifera		*Colurella sulcata*
	Lecane flexilis	BRACHIONIDAE (BR)	*Brachionus quadridendatus*
	Lecane inermis		*Brachionus diversicornis*
	Lecane doryssa		*Keratella quadrata*
	Lecane leontina		*Keratella cochlearis*
	Lecane ludwigi		*Anuraeopsis navicula*
	Lecanenodosa	NOTOMMATIDAE (NO)	*Cephalodella sp*
	Lecane hornemanni	TRICHOCERCIDAE (TC)	*Trichocera similis*
	Lecane nana	ASPLANCHNIDAE (AS)	*Asplancha* sp.
	Lecane clara	SYNCHAETIDAE (SY)	*Synchaeta* sp.
	Lecane hamata		*Polyarthra* sp.
	Lecane decipiens	TRICHOTRIDAE (TT)	*Trichotria tetractis*
	Lecane bulla	LINDIDAE (LI)	*Lindia* sp.
	Lecane unguitata	DICARNOPHORIDAE (DI)	*Dicarnophorus* sp.
	Lecane pyriformis		*Encentrum* sp.
	Lecane elachis	GASTROPODIDAE (GA)	*Gastropus* sp.
	Lecaneinopinata	EPIPHANIDAE (EP)	*Epiphanes* sp.
	Lecaneobtusa	TESTUDINELLIDAE (TE)	*Testudinella patina*
	Lecane clostrocerca		*Testudinellaelliptica*
	Lecane copies		*Testudinella caeca*
	Lecane rugosa	FLOSCULARIIDAE (FL)	*Lacinularia flosculosa*
	Lecane lunaris crenata	PHILODINIDAE (PH)	*Philodina* sp.
	Lecane cristata		*Rotaria* sp.
COLURELLIDAE (CO)	*Lepadella patella patella*		*Macrotraceala* sp.
	Lepadella patella elongata		*Embata* sp.
	Lepadella discoidae		*Dissotrocha* sp.
	Lepadella ovalis	HABROTROCHIDAE (HA)	*Habrotrocha angusticollis*
	Lepadella acuminata		*Habrotrocha* sp.
	Lepadella aspida	ADINETA (AD)	*Adineta* sp.
	Colurella colurus		

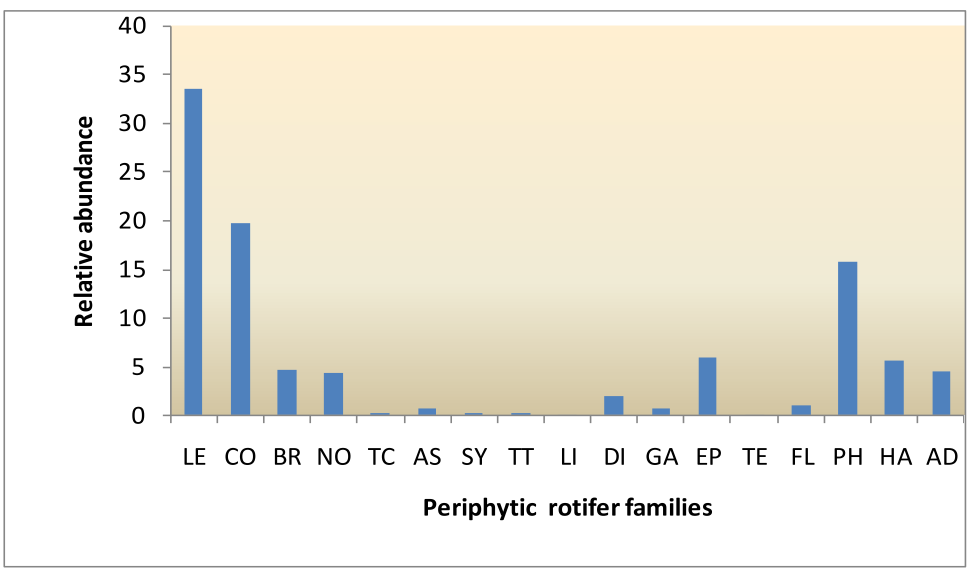

Figure 2. Relative abundance of periphytic rotifer families reported from river Periyar. (Abbrevations for rotifer families were provided in table 3).

shows both scores of the sample (dots) and loadings of variables (vectors) (Fig. 3).

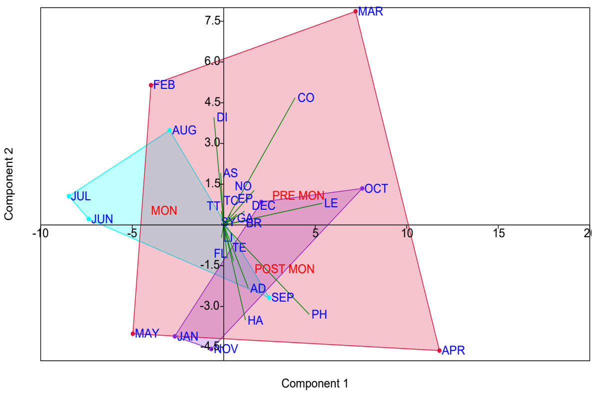

Figure 3. Principal Component Analysis (PCA) depicting periphytic rotifer community composition and seasonal abundance. Rotifer families were represented by the vectors radiating from the origin. Dots on the plot represents months(JUN-June, JUL-July, AUG-August, SEP- September, OCT-October, NOV- November, DEC- December, JAN- January, FEB- February, MAR-March, APR-April) and convex-hull denotes 95% confidence level for corresponding seasons(MON-monsoon, POST MON-post-monsoon, PRE MON- pre-monsoon). Abbreviations for rotifer families were provided in table 3.

Rotifer families were represented by the vectors radiating from the origin. The orientation of vectors on the plot and the distance from the origin indicates the magnitude of dispersion of rotifer families among three seasons. Here vectors for Lecanidae, Colurellidae, and Philodinidae families were diverging more from the origin, and these families showed the maximum abundance of rotifers. Lindidae and Trichotridae families were closer to the origin and showed the least abundance. Months were represented by the dots in the plot which forms convex-hulls for corresponding monsoon, post-monsoon, and pre-monsoon seasons. The area enclosed by the convex hull defines the variance of that particular group and convex-hull for pre-monsoon shows maximum variance compared to other seasons.

Principal Component (PC) 1 and 2 itself contributes to 71.65% of the variation in the data. The covariance obtained by eigenvalue showed 50.38% of the variance for the horizontal axis and 21.28% of the variance for the vertical axis. PC1 has its highest loading in pre-monsoon (April); Lecanidae and Philodinae families contribute to higher scores for PC1 and thus signify the role of these families in the total rotifer abundance of April. PC2 has its highest loading in March and Colurellidae family has a higher score for PC2 and contributes to the major part of total rotifer abundance in March.

Canonical correspondence analysis (CCA)

A total of 17 rotifer families identified (Table 2) and eight environmental parameters (Table 1) recorded were considered when performing CCA. Eigenvalue of

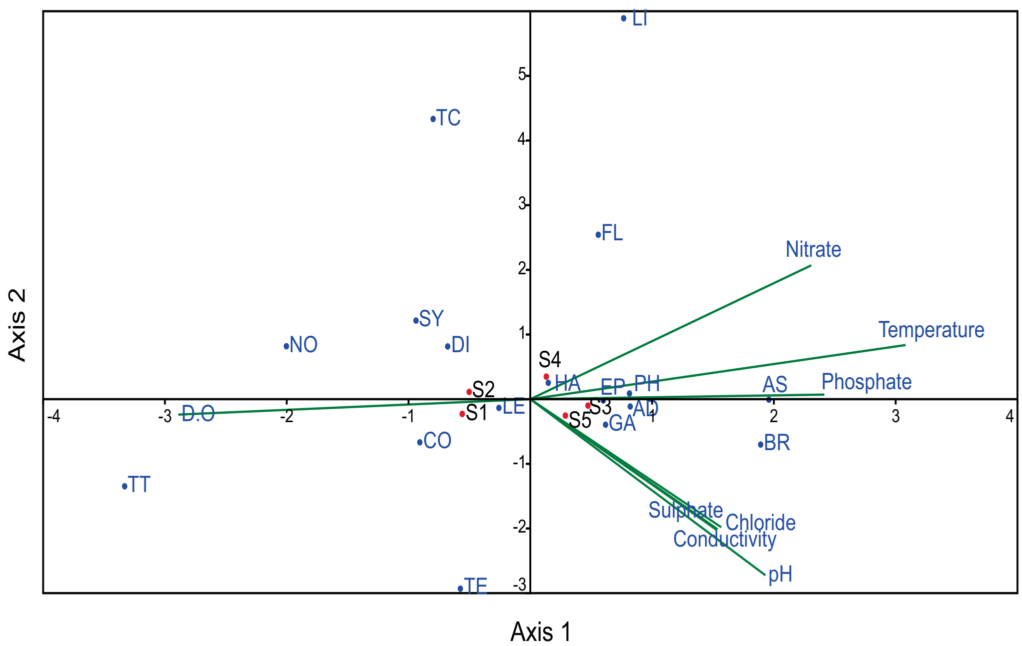

Figure 4. Canonical correspondence analysis (CCA) ordination plot depicting the relationship between environmental parameters and rotifer assemblages. Environment variables were represented by vectors radiating from the origin. Rotifer families were represented by dots on the plot (abbreviations given in table2). Red dots denote selected stations (S1-station 1, S2-station 2, S3-station 3, S4-station 4, S5- station 5).

axis 1 (lambda=0.2) and 2 (lambda=0.1) itself explains 72.35% of the relationship between environmental parameters and rotifer assemblages. In the triplot of CCA, vectors temperature and dissolved oxygen (DO) has the maximum length and strongly influences the rotifer diversity (Fig. 4). The ordination diagram of CCA revealed a strong negative loading of axis 1 with DO (r=-0.723). Colurellidae, Trichotridae, Lecanidae and Notommatidae showed a negative association with axis 1 and illustrate the importance of DO in their abundance and distribution. In the present study low rotifer density was reported from the middle reaches of river Periyar where the concentration of DO was high. Temperature (r=0.770) and phosphate (r=0.604) have positive loadings for axis 1. Brachionidae, Asplanchnidae, Gastropodidae, Philonidae, Adineta, and Epiphanidae have shown a positive association with axis 1 and illustrate the significance of phosphate and temperature in the distribution and abundance of these families.

CCA triplot also revealed a strong positive correlation with axis 2 and Nitrate (r=0.810). Families like Trichocerida, Lindidae, Dicarnophoridae, Floscularidae, and Habrotrochidae are positively correlated with axis 2; which clearly defines the role of nitrate in their abundance and distribution. Lecanidae and Testudinellidae families showed a negative association with axis 2. pH (r=-0.750) Conductivity (r=-0.560), Sulphate (r=-0.546), and Chloride (r=-0.512), also showed a strong negative association with axis; thus signifies the role of these environmental parameters in the abundance and distribution of Lecanidae and Testudinellidae.

Station wise distribution of rotifers

Relative abundance of station-wise distribution of rotifers follows the order; station 4 > station 5 > station 3> station 1 > station 2 (Fig. 5). The maximum species was reported from station 4 and the minimum from station 2. Rotifers found to prefer the lower reaches, S4 (28.03%) and S5 (20.78%) to middle reaches.

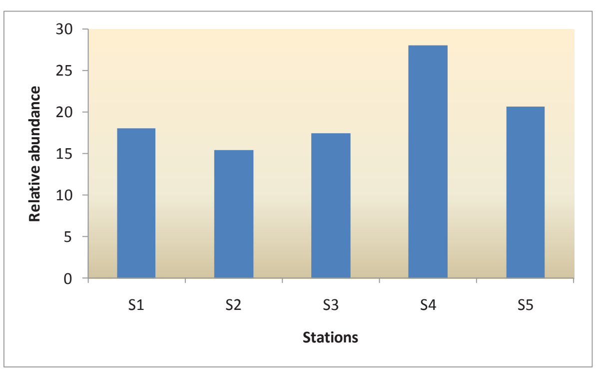

Figure 5. Relative abundance of periphytic rotifers among selected stations.

The ordination plot for Correspondence Analysis (CA) illustrates the distribution of rotifer families along with selected stations (Fig. 6). Among the five stations, station 4 is found to be more diverse and denser compared to other stations. Except station 2, all other stations fall in the 95% ellipse region. Station 2 and 3 has a smaller number of species compared to station 5 and 4. Distribution of Trichocercidae and Lindidae were confined to station 4 whereas Trochotridae was reported only at station 1 and Synchaetidae was limited to station 2. All other families were found to be distributed between these stations.

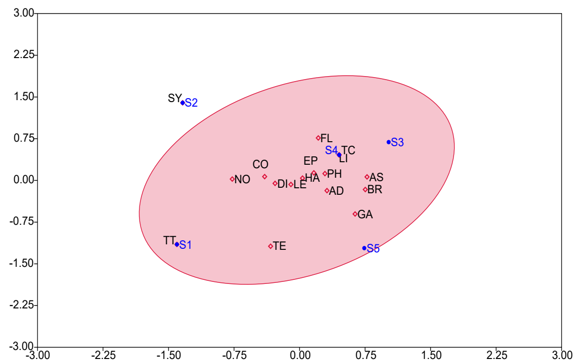

Figure 6. Correspondence Analysis (CA) ordination plot depicting the distribution of rotifer families on selected stations. The ellipse encloses a 95% confidence level. Diamond denotes rotifer families (abbreviations for families were provided in table 2). Stations were represented by dots on the plot (S1-station 1, S2-station 2, S3-station 3, S4- station4, S5-station 5).

Cluster analysis resulted in a dendrogram with two groups of 60% similarity. S1 and S2 (middle stretches) showed 80% of similarity when S4 and S5 (lower stretches) showed 77% similarity. S3 the center lying station forms an outlier in the dendrogram (Fig. 7).

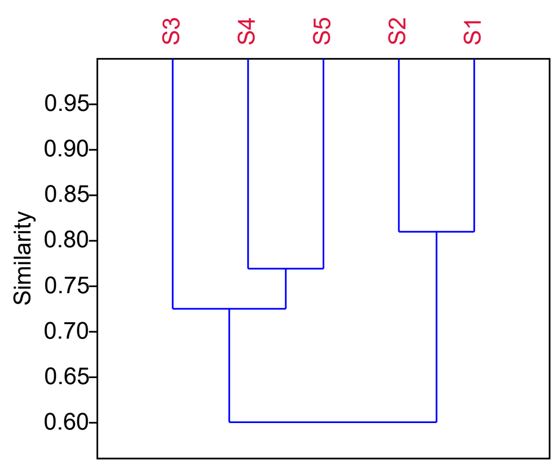

Figure 7. Dendrogram(UPGMA) based on Bray Curtis similarity index depicting the taxonomic

composition of periphytic rotifers along with different stations.

Substrate wise distribution of rotifers

From the present study, the relative abundance of substrate wise distribution of rotifers follows the order leaf > root > wall > rock > log (Fig. 8). Leaf (39.07%) was the most preferred substrate by rotifers and log (10.80%) was the least preferred one.

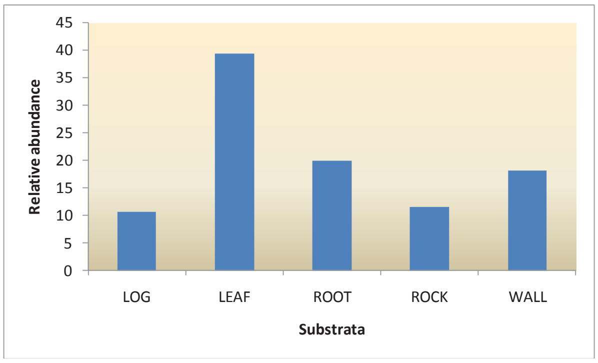

Figure 8. Relative abundance of periphytic rotifers among selected substrate.

The ordination plot of correspondence analysis (CA) (Fig. 9) showed that most of the families were distributed in between leaf, root, and wall; the leaf was located almost in the core position on the plot and considered as the most preferred substrate by rotifers. The distribution of Lindidae family is confined to root whereas Trichocercidae distribution is limited to leaf.

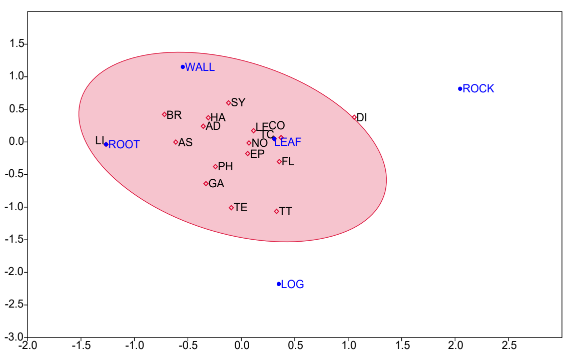

Figure 9. Correspondence Analysis (CA) plot depicting the distribution of rotifer families along the selected substrate. The ellipse encloses a 95% confidence level. Rotifer families were represented by the diamond symbol (abbreviations for were provided in table 2). Dots on the plot denote different substrata.

Cluster analysis resulted in a dendrogram with two groups of 57% total similarity. Root and wall harbour periphytic rotifer assemblages which are similar by 72%. Rock is more different in periphytic rotifer composition from the rest of the substrate (Fig. 10).

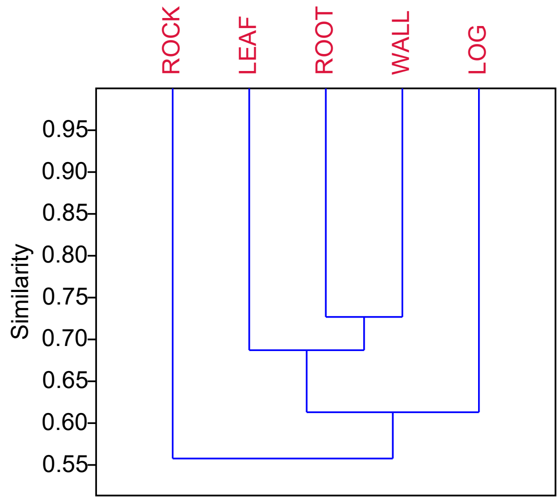

Figure 10. Dendrogram(UPGMA) based on Bray Curtis similarity index depicting the taxonomic composition of periphytic rotifers on the varying substrate.

Discussion

The study came out with some interesting results with the taxonomic composition, seasonal distribution, substrate specificity, and regional preference of the periphytic rotifers in relation to environmental parameters. A total of 63 species of periphytic rotifers belonging to 17 families were recorded and all the statistical analyses were carried out family-wise for convenience.

Factors affecting seasonal distribution of periphytic rotifers

Estimation of relative abundance of seasonal wise distribution of periphytic rotifers resulted in the abundance of Lecanidae family followed by Colurellidae and Philodinidae. Lecanidae is a tropical centered genus (Arora & Mehra, 2003) and the second-largest family among rotifers (Shah et al., 2017). The adaptability of Lecanidae to the diverse geographical regions and extreme environmental conditions marked it as the dominant family (Shah et al., 2017). Similar results were also reported by Sharma (2005) from the Brahmaputra basin. Findings of Sharma et al. (2013) from Jammu Provinces also illustrates that a significant portion of rotifer abundance was contributed by families like Lecanidae and Colurellidae.

Principal Component Analysis

PCA was also conducted to explore the difference in periphytic rotifer species composition among three seasons. From the area enclosed by convex hulls for corresponding seasons and from the loadings and scores of axis 1, the pre-monsoon period is more diverse and denser compared to other seasons. The orientation of vectors on the ordination plot and the distance from the origin indicates the dominance of Lecanidae, Colurellidae and Philodinidae families. In the pre-monsoon period, the water was more stable and the organic load was comparatively higher than other seasons. This might have contributed to the increased nutrient content and subsequent phytoplankton production which resulted in maximum rotifer abundance in the present study. Vanjare & Pai (2013) reported that rotifer abundance from a seasonal pond of Pune was maximum in summer. Jose & Sanalkumar (2012), Gopakumar & Jayaprakas (2003), and Rajagopal et al. (2010) reported that rotifers preferred the pre-monsoon period. Jose & Senthilkumar (2015) reported similar findings from Anicadu Chira, Kerala.

Canonical Correspondence Analysis

CCA helps in elucidating the relationship between a set of environmental variables and periphytic rotifer assemblages. Vectors for strong positively associated variables show an acute angle and were close to each other. Vectors for strong negatively associated variables show an obtuse angle. From the scores, positive and negative loading of axis 1 and 2; CCA helps to understand which of the environmental variables collectively or individually contributes to the abundance of specific families. On the ordination plot for CCA, vectors for DO and temperature showed maximum length and strongly influence rotifer composition and abundance. In the present study low rotifer density was reported from the middle reaches of river Periyar where the concentration of DO was high. Rajagopal et al. (2010) supports this finding from three different ponds of Tamilnadu and reported that DO showed a negative correlation with zooplankton abundance. A negative association of DO with rotifer density and diversity has also been reported by Cleetus et al. (2015). Esparcia et al. (1989) reported that for a short period some rotifers can tolerate anaerobic or near anaerobic conditions even though most rotifers require oxygen concentration above 1.5 mg/l. Positive loadings of temperature and phosphate for axis 1 and nitrate for axis 2 is also reported from CCA triplot. All life processes, biological and physiological activities are greatly influenced by a wide range of temperatures. The temperature often plays an important role in the population dynamics of rotifers (Gopakumar & Jayaprakas, 2003). A rise in temperature leads to increased metabolic and biological activities which help in increased production and distribution of organisms (Dhanasekaran et al., 2016) affecting the rotifer diversity. In the present study, the majority of rotifer species were found to be tolerant to a wide range of temperature fluctuations. Galkovskaja (1987) stated that, if other factors not limiting, rotifers can reproduce over a wide range of temperatures. Cleetus et al. (2015) reported that rotifer density has a significant positive association with nitrate and phosphate and a combination of variables like phosphate, conductivity, salinity, and the temperature was best in determining the diversity and distribution of the rotifer population. All these environmental factors act collectively to determine species abundance and distribution of periphytic rotifers. This view gains support from Gopakumar & Jayaprakas (2003); a single environmental parameter cannot determine its relation with rotifer abundance and diversity.

Factors affecting the spatial pattern of periphytic rotifers

Relative abundance of periphytic rotifers among selected stations showed that station 4 harbours more species and station 2 harbours a smaller number of species. Station 4 (Aluva) is an important commercial town and a major industrial center. Periyar River flowing through the Aluva region receives a considerable amount of domestic sewage, garbage dumps, and enormous effluents from nearby towns and industries which accounts for the increased nitrate and phosphate content in this station (KSPCB, 1981; Joseph, 2004). Increased anthropogenic activities and domestic sewage discharge cause nutrient enrichment and increased phytoplankton production (Dhanasekaranet al., 2016) thereby influencing the increased rotifer density reported from station 4 in the present study. The ordination plot resulted from CA analysis also showed that most of the families are distributed around station 4. Station 4 harbours 28.03% of total rotifer assemblage, of which *Brachionus* sp., *Keratella* sp., *Lindia* sp., *Dicarnophorus* sp., *Lecane signifera*, and *L. ludwigi* were mainly confined to this station. The presence of these species indicates the eutrophic nature of water and many researchers support *Brachionus* as a eutrophic water quality indicator (Nogueira, 2001). Joseph & Yamakanamardi (2016) has reported a positive correlation between eutrophication and the abundance of *Brachionus* and *Keratella* species. Arora (1966) reported that pollution due to the direct entry of untreated domestic sewage results in higher rotifer abundance. Somany & Pejawar (2003) also reported that the dominance of *Brachionus* genera indicates the onset of eutrophication.

Dendrogram resulted from cluster analysis between selected stations showed that the grouping is purely based on the regional preference of rotifer assemblages and nutrient status of the river. S1 and S2 were closely similar with 80% similarity followed by S4 and S5 with 78% similarity. S1 and S2 were in the middle stretches, pure zones, and harbor similar organisms. S4 and S5 were in the lower stretches, enriched with organic and chemical load showed similar organisms.

Substrate plays an important role in the occurrence and distribution of organisms and many species prefer particular substratum for their colonization. Different species prefer different substratum based on the size, texture, heterogeneity, and surface area of the substrate (Kippen, 2007). The relative abundance of periphytic rotifers among selected substrate showed that leaf harbored 39.07% of total rotifer assemblages. The ordination plot resulted from CA also revealed that most of the periphytic rotifers are distributed around the leaf, it also illustrates the restricted distribution of Trichocercidae to leaf and Lindidae to root. Many rotifer species choose leaf as their preferred substratum due to its large surface area, food availability in the form of algae and detritus, and easy attachment for sessile species. Reice (1980) also reported that higher abundance and distribution of organisms were shown by leaf packs than any other mineral substrates. The present study was also supported by the works of Sharma et al. (2013) which reported that even though rotifers can choose any substrate, they were more abundant on submerged aquatic vegetation. Dendrogram depicting the taxonomic composition of periphytic rotifers on varying substrate resulted in two groups with 55% of total similarity. Leaf grouped with wall and root depicts the 70% of similarity in periphytic rotifer composition in these groups. Rock forms an outlier and differs more from the rest of the groups. Hawkins et al. (1982) reported that some rotifer species prefer organic substrates to mineral substrates. Thus, rotifers exhibit some preference in choosing their substrates for attachment and colonization.

Conclusion

From the present study rotifers were found to prefer leaves as a suitable substratum for their colonization and abundance was found maximum during the pre-monsoon period. CCA illustrates that the combined action of DO, temperature, phosphate, nitrate, conductivity, and sulphate determines the distribution of rotifer assemblages in the Periyar River. Even though some species of rotifers were confined to a particular geographical range and substratum, most of them were evenly distributed between the study areas. The presence of eutrophic indicators like *Brachionus* sp. and *Keratella* sp. clearly showed the eutrophic nature of river Periyar at lower stretches during pre-monsoon. The present study on the seasonal distribution and abundance of periphytic rotifers greatly contributes to understanding the role of environmental parameters in determining its species composition along the river Periyar.

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