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Plankton dynamics and their relationship with environmental factors shape fish community structure in fluvial ecosystem: A case study

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ABSTRACT

Phytoplankton and zooplankton serve as bioindicators and are critical components for the functioning of ecosystem and support a wide range of ecosystem services. To understand the interrelationship between plankton, fish and habitat parameters; aforementioned parameters were recorded seasonally from six sites, representing different habitat types along the stretches of Ib River, a tributary of Mahanadi River system in India. A total of 47 phytoplankton and 14 zooplankton species were recorded. Maximum density and diversity of phytoplankton and fish were observed at downstream sites while those of zooplankton were recorded in upstream sites. Maximum phytoplankton and zooplankton were recorded in summer season. A high correlation of species richness was observed with water and air temperature, dissolved oxygen (DO), pH, conductivity, turbidity, total dissolved solids (TDS) and total nitrogen. Plankton always had complex interactions with ecological abiotic factors and variations in the distribution of plankton affect the fish diversity of the region. Canonical correspondence analysis (CCA) was used to establish relationship between important fish species and environmental variables. Maximum plankton abundance in the winter months also coincided with maximum fish diversity corroborating an existing positive relationship between the plankton and fish. The study helps in better understanding the influence of plankton and habitat parameters in determining fish community structure and its importance to ecosystem services.

Keywords: Biodiversity, Diversity, Ecosystem, Ib River

Introduction

The productivity of any aquatic ecosystem depends on the amount of plankton present in the water body (Guy, 1992). Phytoplankton and zooplankton are the fundamental biological components from which energy is transferred to higher organisms through the food chain (Tas and Gonulal, 2007). The fauna of an aquatic ecosystem directly or indirectly relies on them. They also serve as bioindicators and are a reliable tool for determining the status of water pollution (Contreras *et al*., 2009). Plankton are thus vital components for the functioning of ecosystems and support a wide range of ecosystem services (ES) *viz.,* form the basis of food-webs supporting production of higher trophic levels (a provisioning ES) and act as a sink of CO_2 (a climate regulation ES) (Tweddle *et al*., 2018). Distribution and abundance of plankton are affected by seasons and physico-chemical parameters of the water body (Raymond, 1983). Seasonal changes in the water flow of river eventually affect the plankton diversity and abundance and thus alter the ecosystem services offered by this valuable resource.

Human civilisation has always been affected by rivers and for proper management of rivers there should be balance between needs and ecological integrity (Edwards, 1995). Planktonic algae play a central role in the functioning of rivers as they are major producers of organic carbon, food source for planktonic consumers and represent the primary oxygen source in many low-gradient rivers (Wehr and Descy, 1998). Excessive supplies of inorganic nutrients may cause problems in long stretches of rivers with eutrophication, which may pose threat. As algal communities of river systems consist not only of suspended algae, but also of benthic assemblage of macrophytic forms, smaller epilithic species, epiphytes and sediment-dwelling forms (Reynolds, 1996; Wehr and Descy, 1998) as well as; planktonic algae are important in river management. Mahanadi, the third-largest peninsular river in India, drains an area of about 1,32,000 km^2 in Chhattisgarh, Odisha, Jharkhand and Maharashtra with a total length of 860 km (Singh *et al*., 2013). River Ib, with a length of 251 km (Jain *et al*., 2007) is one of the principal tributaries of Mahanadi over which the World's longest dam, Hirakud, has been constructed. As only limited study has been carried out on the plankton diversity of this river, the present study was undertaken to document plankton diversity in relation to fish diversity and habitat characteristics of the river Ib.

Materials and methods

Study area

A total of 6 sites covering different habitat types in upstream, midstream and downstream stretches of Ib River, were selected (Fig. 1). Plankton samples were collected from sites Barghat (21°51.817 N; 83°56.846 E) and Sundargarh (22°08.059 N; 84°00.655 E) from the lower stretch; Bhogapalli (22°11.741 N; 84°06.032 E) and Samdama (22°24.637 N; 83°57.765 E) from middle stretch; Pamsala (22°29.105 N; 83°55.499 E) and Ranikombo (22°50.143 N, 83°54.141 E) from upper stretch during January 2016 to May 2017 representing four seasons *i.e.* July 2016 (monsoon), November 2016 (early winter), February 2017 (late winter) and May 2017 (summer).

Plankton collection

Plankton was collected by sieving 100 l of water using 20 µm mesh plankton net for phytoplankton and 50 µm mesh for zooplankton. Water was collected using a bucket from 5 collection points along a 'Z' shaped transect line laid on wetted width of river at each sampling location, ensuring 20 l from each point adding to a total 100 l. The filtrate was collected and fixed in the field in 0.05% formalin. A binocular stereozoom microscope using a Sedgwick- rafter type counting cell (1 ml capacity) as detailed by Escaravage and Prins (2002) was used for enumeration of plankton. The average value of 10 subsamples counted from each sample was used for the analysis. All the organisms encountered were represented in absolute numbers. Counting and identification were done as per APHA (2005). Phytoplankton and zooplankton were identified based on standard literature (Koste; 1978; Wehr and Sheath, 2003; Bellinger and Sigee, 2010).

Fish sampling

During each sampling visit, data on diversity of fish was also documented from each sampling site. Experimental fishing was done using the expertise of fishermen in addition to visiting associated markets and landing centres. The sampling strategy and procedure followed was as described by Chandran *et al*. (2019).

Environmental variables

Physical parameters such as habitat type (mid-channel, shoreline, pool, riffle or others), water colour, water depth, water velocity, wetted area, channel width, substrate, riparian vegetation and aquatic vegetation were assessed during each season. The abundance of riparian vegetation (trees, shrubs, herbs and others) and aquatic vegetation (floating, submerged, emerged and others) were assessed in terms of percentage cover. Physico-chemical parameters *viz,* water temperature, air temperature; pH, dissolved oxygen (DO), electrical conductivity, total dissolved solids (TDS) and turbidity were recorded using multi-parameter equipment (HI 9829, Hanna Instruments, UK). Water velocity and depth were determined by water flow meter and depth meter respectively. Each parameter

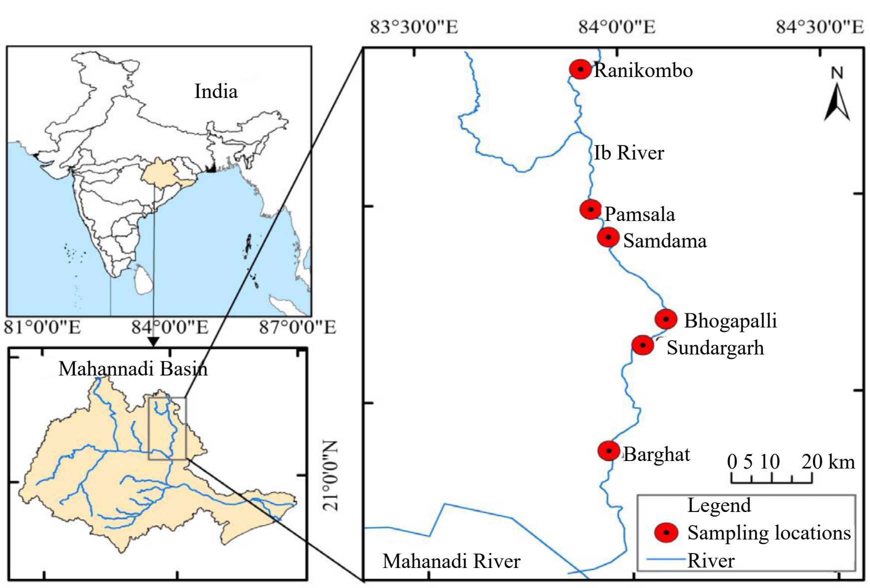

Fig. 1. Sampling sites in Ib River

was measured three times from various transects of each site on every visit and the mean values were used for analyses.

Soil samples were collected using Ekman's grab. Composite samples collected from various sites were transported to the laboratory, dried and stored in polythene bags. The dried soil samples were ground and sieved through a 2 mm sieve. Physical parameters *viz,* pH and electrical conductivity along with chemical parameters such as available phosphorus (Ammonium molybdate -Meta vanadate yellow colour complex method) total nitrogen (Micro-Kjeldahl distillation apparatus) and organic carbon (Rapid titration method) were analysed at the regional centre of ICAR-Central Soil Salinity Research Institute, Lucknow.

Data analysis

PAST software 3.15 (Hammer *et al*., 2001) was used for estimating different plankton diversity indices. Principal component analyses (PCA) was performed to reduce the dimensionality of the data by constructing a data matrix, represented by habitat values and catch numbers of species (columns) for each of the sites (rows). Only principal components with Eigen values >1 were considered for interpretation. Canonical correspondence analysis (CCA) (Ter Braak, 1986) was used to identify the relationships of environmental variables with fish assemblage. Correlation analysis was performed between physico-chemical variables of water, fish and plankton density. Statistical analyses were carried out to estimate correlation coefficients between different pairs of parameters and t-test was applied to check the significance using SPSS version 12 and Microsoft Excel 2007.

Results and discussion

Phytoplankton abundance, distribution and seasonal variation

A total of 47 phytoplankton species (Table 1) belonging to 33 genera of classes Chlorophyceae, Bacillariophyceae, Euglenophyceae and Cyanophyceae

Table 1. Phytoplankton and zooplankton species composition and distribution recorded from the six sampling locations in river Ib

Species		Barghat	Sudargarh	Bhogapalli	Samdama	Pamsala	Ranikombo
Phytoplankton							
Chlorophyceae							
1.	*Ankistrodesmus falcatus*	✓	✓	✓	✓	✓	✓
2.	*Characium accuminatum*	✓	✓	✓	✓	✓	✓
3.	*Chlorella vulgaris*	✓	✓	✓	✓	✓	✓
4.	*Clostridium* spp	✓	✓				
5.	*Clostriopsis longissima*	✓	✓	✓			
6.	*Closterium* spp	✓	✓			✓	✓
7.	*Coelastrum reticulatum*	✓	✓		✓		
8.	*Cosmarium aequale*	✓	✓	✓	✓	✓	✓
9.	*Cosmarium reniforma*	✓	✓	✓	✓		✓
10.	*Crucigenia crucifera*	✓	✓	✓			
11.	*Dictyosphaerium pulchellum*	✓	✓	✓	✓	✓	✓
12.	*Oedogonium* spp	✓	✓	✓		✓	✓
13.	*Pandorina morum*	✓	✓	✓	✓		✓
14.	*Pediastrum simplex*	✓	✓	✓	✓		
15.	*Pediastrum tetras*	✓	✓	✓	✓		✓
16.	*Scenedesmus dimorphus*	✓	✓		✓	✓	
17.	*Scenedesmus quadricauda*	✓	✓	✓	✓	✓	✓
18.	*Spirogyra* spp	✓	✓	✓	✓	✓	✓
19.	*Tetraedron* spp	✓	✓				
Bacillariophyceae							
20.	*Achnanthes trigibba*					✓	✓
21.	*Achnanthes affinis*					✓	✓
22.	*Achnanthes microcephala*	✓	✓	✓	✓	✓	✓
23.	*Cyclotella meneghiniana*	✓	✓	✓			✓
24.	*Cymbella turgidula*	✓	✓	✓	✓	✓	✓
25.	*Fragilaria* spp	✓	✓	✓	✓		
26.	*Navicula cuspidata*	✓		✓			
27.	*Nitzschia amphibia*	✓	✓		✓		
28.	*Nitzschia palea*	✓	✓	✓	✓		
29.	*Nitzschia* spp	✓	✓	✓			✓
30.	*Pinnularia acrospaeria*	✓	✓	✓	✓		

Contd................

Species		Barghat	Sudargarh	Bhogapalli	Samdama	Pamsala	Ranikombo
Euglenophyceae							
1.	*Euglena acus*	✓	✓	✓	✓	✓	✓
2.	*Euglena limnophila*	✓	✓	✓	✓		✓
3.	*Euglena spirogyra*	✓	✓	✓	✓	✓	
4.	*Euglena viridis*	✓	✓	✓	✓	✓	
5.	*Lepocinclis fusiformis*	✓	✓	✓		✓	
6.	*Lepocinclis ovum*	✓	✓	✓	✓	✓	
7.	*Lepocinclis* spp	✓	✓	✓	✓		✓
8.	*Phacus caudatus*	✓	✓		✓	✓	✓
9.	*Phacus inflexus*	✓	✓		✓	✓	
10.	*Phacus pleuronectes*	✓	✓	✓	✓	✓	
11.	*Strombomonas* spp	✓	✓	✓	✓		✓
Cyanophyceae							
12.	*Anabaena* spp	✓	✓		✓		
13.	*Merismopedia glauca*	✓	✓		✓	✓	✓
14.	*Microcystis aeruginosa*					✓	✓
15.	*Raphidiopsis indica*	✓	✓	✓	✓		✓
16.	*Spirulina laxissima*	✓	✓		✓		✓
Dinophyceae							
17.	*Peridinium* spp					✓	✓
Zooplankton							
Rotifera							
1.	*Brachionus falcatus*	✓	✓	✓	✓	✓	✓
2.	*Brachionus quadridentatus*	✓	✓	✓	✓	✓	✓
3.	*Scaridium longicaudum*	✓	✓	✓	✓	✓	✓
4.	*Euchlanis* spp	✓	✓	✓	✓	✓	✓
5.	*Keratella tropica*	✓	✓			✓	✓
Cladocera							
6.	*Alona rectangula*	✓	✓	✓	✓	✓	✓
7.	*Bosmina longirostris*	✓	✓	✓	✓	✓	✓
8.	*Moina brachiata*	✓	✓	✓	✓	✓	✓
9.	*Daphnia carinata*	✓	✓	✓	✓	✓	✓
Copepoda							
10.	*Macrocyclops* spp	✓	✓	✓	✓	✓	✓
11.	*Cyclops bicuspidatus*	✓	✓	✓	✓	✓	✓
12.	*Cyclops scutifer*	✓	✓	✓	✓	✓	✓
Ostracoda							
13.	*Cypris* spp	✓	✓	✓	✓	✓	✓
Protozoa							
14.	*Monas* spp	✓	✓	✓	✓	✓	✓

were recorded from the study area. Chlorophyceae was found to be the dominant class (40.4%) followed by Bacillariophyceae and Euglenophyceae (23.4%). Presence of three dominant Classes of phytoplankton *viz*, Chlorophyceae (green algae), Cyanophyceae (blue-green algae) and Bacillariophyceae (diatoms) agree with the findings in other rivers of India (Negi and Rajput, 2011; Panigrahi and Patra, 2013). Members of Chlorophyceae were recorded in significant numbers throughout the year with most abundance in summer and least in monsoon season. Most abundant genus recorded was *Euglena* (*E. acus, E. limnophila, E. spirogyra* and *E. viridi*). The most dominant species as per relative abundance were *Characium accuminatum* and *Phacus pluronectes*. The total number of phytoplankton species recorded from Barghat, Sundargarh, Bhogapalli, Samdama, Pamsala and Ranikombo were 43, 42, 33, 32, 22 and 25 respectively. Maximum phytoplankton density was observed at Sundargarh (28.59%) followed by Barghat (27.67%) and least in Ranikombo and Pamsala (8.85%). A total of 43 species were recorded from the lower stretch, 33 from the middle stretch and 25 from the lower stretch. Increase in algal density and diversity in the downstream site; Sundargarh, was perhaps due to the nutrient load in the water from the catchment area during monsoon and lower water current. On the other hand, in upstream area, phytoplankton density were lower possibly due to higher water current, the difference in basin morphometry and lesser nutrients. The high values of the phytoplankton number in the downstream areas reflect eutrophic conditions and may be caused due to increased levels of phosphorus and nitrogen (Mc Caul and Crossland, 1974). *Tetraedron* spp. was recorded only from the lower stretches of the river, whereas *A. trigibba, A. affinis, Microcystis aeruginosa* and *Peridinium* spp. only from the upper stretches. Diatoms, *A. trigibba* and *A. affinis* and dinoflagellate *Peridinium* spp. have been reported to be less pollution tolerant showing a preference for more transparent water (Unni and Pawar, 2000). This might be the reason for their occurrence only from the upstream sites, where there are fewer human interventions.

Maximum number of phytoplankton species were recorded in summer (51.39%), followed by winter (34.88%). Sundargarh recorded the maximum phytoplankton species in summer season (14.47%), while the least number of species was recorded at Pamsala during monsoon (1.29%). Phytoplankton density was found to be maximum during summer season (Fig. 2). Chlorophyceae was the most dominant group in all seasons followed by Euglenophyceae. The low population density in rainy season may be attributed to unfavourable conditions particularly high velocity of water current and fluctuating physico-chemical conditions of the water, which corroborates with reports of Thomas and Prasad (2007). The abundance of phytoplankton community in winter season could be attributed to the impact of nutrients through surface runoff during monsoon. Phytoplankton community increases more in number after winter and reaches its peak during early summer, utilising available phosphate and nitrogen. During winter and early summer, the phosphate and nitrogen contents decrease with the increase in autotrophs. The results of the present study indicate that a moderate flow of water is beneficial for increasing phytoplankton population during summer and winter months. Similar results were also observed by Le Quere *et al*. (2005). Chlorophyceae had the highest peak in summer as reported by other researchers (Jagadeeshappa and Vijayakumara, 2013). Laskar and Gupta (2009),

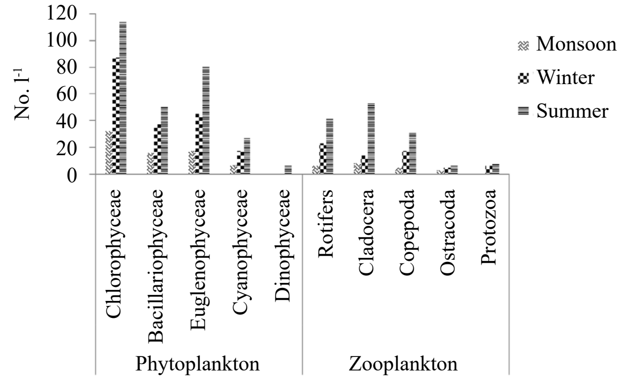

Fig. 2. Seasonal variation in different phytoplankton and zooplankton groups

Hussein and Gharib (2012) and Ganai *et al*. (2010) have also reported dominance of Cyanophycae in summer season as observed in the present study. Luxuriant growth of Euglenoids in summer and minimum in monsoon was also observed by Hassan *et al*. (2010).

Diversity indices were estimated for each sampling site (Table 2). Shannon Weiner diversity value was found to be more than three in all sites indicating high phytoplankton diversity with maximum in downstream sites. High diversity index indicates mature environment (Le Bris and Glemarec, 1995). High phytoplankton diversity recorded in the study also indicates the river to be of productive status. Dominance values were low in all the sites showing there was no dominance of any species. Evenness index values were also high and did not vary much between sites. Low dominance values and high evenness values suggest a healthy environment where many species coexist. Various species were occupying different ecological niche that indicates good health of the water body. Desai *et al*. (2008) studied phytoplankton of the Sharavati River basin and reported the highest Shannon Weiner diversity index and species richness among different sites as 2.69 and 3.27 respectively. Ramesha and Sophia (2013) studied the plankton diversity of river

Table 2. Phytoplankton and zooplankton diversity indices of Ib River

Site / Index	Barghat		Sudargarh		Bhogapalli		Samdama		Pamsala		Ranikombo	
	P	Z	P	Z	P	Z	P	Z	P	Z	P	Z
No. of Species	43	13	42	14	33	13	32	13	22	14	25	14
Dominance Index	0.027	0.103	0.029	0.088	0.035	0.086	0.036	0.091	0.052	0.078	0.051	0.079
Simpson Index	0.973	0.897	0.971	0.912	0.965	0.914	0.964	0.909	0.948	0.922	0.949	0.921
Shannon Index	3.685	2.385	3.629	2.525	3.421	2.499	3.388	2.472	3.015	2.585	3.084	2.578
Evenness Index	0.926	0.836	0.897	0.892	0.927	0.937	0.925	0.912	0.927	0.948	0.874	0.941
Margalef Index	8.382	3.462	8.129	3.687	7.458	3.641	7.347	3.432	5.425	3.340	6.200	3.290
Equitability Index	0.979	0.930	0.971	0.957	0.979	0.974	0.977	0.964	0.975	0.979	0.958	0.977

P= Phytoplankton Z= Zooplankton

Seetha of Western Ghats and reported the maximum index value of 2.72 during summer season. It was evident that phytoplankton in Ib River is more diverse and balanced. The overall range of the values of indices indicates good health of the river.

Zooplankton abundance, distribution and seasonal variation

A total of 14 zooplankton species (Table 1) belonging to 12 genera of different classes such as Rotifera, Cladocera, Copepoda, Ostracoda and Protozoa were recorded from the study area. Rotifera was found to be the most dominant group (35.71%), followed by Cladocera (28.57%). The dominance of rotifers in river Ib followed by cladocerans and copepods was similar to earlier observations (Kadam, 2016; Kar and Kar, 2016) probably due to the flexible feeding habits, parthenogenetic reproduction and high fecundity. The presence of rotifers in high amount indicates eutrophication of water bodies (Schindler and Noven, 1971; Saksena and Sharma, 1981). Water of river Ib is used for washing clothes, bathing and for other domestic purposes in addition to domestic sewage being dumped. This may be leading to both organic and inorganic pollution, which could be the reason for increase in rotifer population. Most abundant genus recorded was *Brachionus* comprising of *B. falcatus* and *B. quadridenta*. Most abundant species, as per relative abundance, was *Macrocyclops* spp. The total number of zooplankton species recorded was almost uniform with 13, 14, 13, 13, 14 and 14 from Barghat, Sundargarh, Bhogapalli, Samdama, Pamsala and Ranikombo sites, respectively. Maximum zooplankton density was observed at Ranikombo (22.9%) followed by Pamsala (21.58%) and in Bhogapalli (11.89%). A total of 14 species were recorded both from the lower stretch and upper stretch and the least (13) from the middle stretch. Low density of rotifers in upstream sites indicates lesser pollution of this stretch because of limited human interactions due to inaccessibility. Upstream sites were characterised with high DO, low temperature, turbidity and conductivity. Kobayash *et al*. (1998) reported negative correlation between zooplankton density, temperature, turbidity and conductivity and positive correlation with DO. Rich diversity and abundance of zooplankton in upstream stretch could be attributed to availability of favourable environment. All the species were recorded from all the three stretches, except *Keratella tropicum,* which was absent in middle stretch.

Maximum zooplankton population was recorded in the summer season (61.27%), followed by winter (28.63%). Ranikombo site recorded maximum population in summer season (15.86%). Cladocerans dominated zooplankton during monsoon and summer, while rotifers dominated during winter (Fig. 2). During winter to the summer seasons, the zooplankton population density had steadily increased which may be due to an increase in phytoplankton population, thus providing better grazing opportunities. Similar findings were reported by Kumar (2001) and Balai *et al*. (2014). Similar to phytoplankton, there are also studies indicating the importance of phosphate and nitrate in controlling the abundance of zooplankton (Barica, 1990; Balai *et al*., 2014). Competition and predation are two factors strongly affecting the structure of zooplankton communities in freshwater ecosystems (Gilbert, 1988). The maximum population of cladocerans in summer could be due to favourable temperature and availability of food in the form of bacteria and suspended detritus; while in monsoon, factors like water temperature, dissolved oxygen, turbidity and transparency play an important role in controlling their density and diversity (Edmondson, 1965; Baker, 1979). The summer peak of copepods may be due to the abundance of diatoms and blue-green algae and rich organic matter on which they feed (Pavan *et al*., 2016). During the study, copepods showed a direct correlation with ostracods and rotifer population, indicating their differential food preference in habitat. Ostracoda occupied fourth position in zooplankton represented by very low population diversity compared to other groups. Akthar *et al*. (2007) and Jagadeeshapaa and Vijayakumara (2013) also observed the dominance of protozoans in summer, as seen in the present study.

Diversity indices were analysed for each site (Table 2). The zooplankton species were almost equally distributed among all sites. The diversity index (0.198) was found to be higher than Tons River as reported by Negi and Mamgain (2013). Margalef species richness index was lower in comparison to phytoplankton richness index, yet values above three in all the sites indicate a clean environment. Evenness index was also higher and with no wide variation between the sites indicating a stable environment along the river. It can be concluded that the diversity of zooplankton was moderately high and rich in population indicating a stable environment. Plankton diversity reported by other authors too revealed the dominance of phytoplankton over zooplankton as observed in the present study (Cantonati *et al*., 2001; Malik and Bharti, 2012).

Fish diversity

A total of 55 species of fishes were recorded during the study from the river. Maximum density and diversity of fish species was observed in downstream sites. Winter season was noted with maximum diversity and density. Chandran *et al*. (2019) reported on the seasonal distribution and dynamics of fish diversity in the Ib River.

Environmental variables

Mean water depths ranged from 1.65 to 3.25 m while the mean current velocity varied between 1.15 and 1.41 m s^{-1} (Table 3). Substrates-type varied between different sites; boulders were dominant in Pamsala (23.33%), sand in Sundargarh (61.5%), trees dominated upstream sites and emergent weeds in midstream areas. The water colour varied from muddy brown during monsoon to slightly green to light green during winter and slightly brownish during summer at all sites (Table 4).

Correlation analysis revealed phytoplankton to have positive correlations with wetted area, substrates like gravel and sand, air and water temperature, pH, turbidity and conductivity. Soil variables like soil pH, EC, total nitrogen and organic carbon were also found to be positively correlated. Negative correlations were observed with velocity, substrates like boulders and cobbles as well as vegetations like trees and herbs. Zooplankton showed a positive correlation with the presence of shrubs. Significant negative correlations were observed with depth, channel width, floating weeds and pH.

Environmental variables and species composition dynamics

Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy test and Bartlett's test of sphericity was found to be significant. Principal component analysis performed on 28 environmental variables resulted in 16 variables producing three axes that cumulatively explained 80.73%

Table 3. Physical habitat characteristics of river Ib

Site	Depth (m)	Water velocity (m s^{-1})	Channel width (m)	Wetted area (%)	Habitat type	Riparian vegetation
Barghat	1.41	0.26	610.00	73.33	Homogeneous with dominance of sand and silt	Trees (45%), shrubs (25%) and herbs (10%)
Sudargarh	1.07	0.15	383.33	51.83	Homogeneous with dominance of sand and gravel	Trees (45%), shrubs (20%) and herbs (10%)
Bhogapalli	1.38	0.24	525.00	50.83	Heterogeneous with sand and cobbles	Trees (65%), shrubs (20%) and herbs (15%)
Samdama	0.93	0.32	483.33	52.5	Heterogeneous with sand, cobbles and few boulders	Trees (70%), shrubs (25%) and herbs (20%)
Pamsala	0.92	0.32	350.00	45.83	Heterogeneous with maximum number of boulders, cobbles and pebbles	Trees (75%), shrubs (30%) and herbs (20%)
Ranikombo	0.65	0.33	283.33	41.67	Heterogeneous with maximum number of boulders, cobbles and pebbles	Trees (80%), shrubs (30%) and herbs (20%)

Table 4. Seasonal physico-chemical parameters of river Ib

Parameter	Minimum value (Median±SD)	Maximum value (Median±SD)
Water temperature (°C)	21.9±0.44 (winter, Ranikombo)	29.0±0.26 (summer, Barghat and Sundargarh)
Air temperature (°C)	23.5±0.62 (winter, Ranikombo)	31.2±0.13 (summer, Barghat)
pH	6.84±0.06 (monsoon, Pamsala)	8.10±0.08 (summer, Barghat and Sundargarh)
DO (mg l^{-1})	6.90±0.005 (summer and monsoon, Barghat and Sundargarh)	7.52±0.008 (summer, Ranikombo)
Conductivity (µS cm^{-1})	0.69±0.005 (summer, Pamsala and Ranikombo)	0.98±0.008 (monsoon, Barghat and Sundargarh)
TDS (mg l^{-1})	212.9± 0.05 (summer, Bhogapalli)	319.8±0.08 (monsoon, Barghat)
Turbidity (NTU)	71.6±0.08 (winter, Ranikombo)	104.0±0.82 (monsoon, Sundargarh)
Soil pH	6.5± 0.02 (monsoon, Ranikombo)	7.7± 0.08 (winter, Barghat)
Soil conductivity (dS cm^{-1})	0.376±0.0008 (summer, Ranikombo)	0.123±0.008 (winter, Barghat)
Available phosphorus (mg l^{-1})	5.54±0.008 (summer, Ranikomboi)	11.28±0.01 (winter, Barghat)
Total nitrogen (%)	0.01±0.0008 (summer, Samdamai)	0.04±0.0008 (winter, Sundargarh)
Organic carbon (%)	0.0002±0.0008 (monsoon, Ranikombo)	0.004±0.0008 (winter, Barghat)

of total variance. First axis explained 47.29% variance (44.73% after rotation). Total of 8 variables had high loadings on first axis, 5 on second axis and 3 on third axis. The first axis had high loadings for substrate variables - boulders, cobbles, gravel, sand and silt along with vegetation - trees and herbs along with soil variable - total nitrogen content. The second axis had high loadings for physical variables like depth, velocity and wetted area along with the physico-chemical variable, pH and moderate loading for the physical variable, channel width. The third axis had high loadings for physical parameters like water and air temperature and moderate loading of the physico-chemical variable, DO (Table 5). The negative loadings of parameters in the principal component indicates the negative contribution of the parameter.

Canonical correspondence analysis (CCA) was used to establish relationship between important fish species and environmental variables. CCA resulted in the retention of 14 variables as significant contributors to variation in the ordination. The first ordination axis accounted for 73% of the variance of the species data (Table 5) while second axis accounted for 21.84% variance. Other ordination axes were not accounted as these two axes, cumulatively, could account for more than 94% of variance. Water temperature, depth, channel width, percent wetted area, sand, silt and TDS were positively correlated with first ordination axis, while velocity and vegetation like herbs and shrubs were negatively correlated. Vegetation (submerged, floating and emergent) was positively correlated with second ordination axis. Species were distributed within four groups with respect to significant habitat characteristics. Group one consisted of 6 species (*Osteobrama cotio, Oreochromis mossambicus, O. niloticus, Gudusia chapra, Chanda nama* and *Parambassis lala*) (Fig. 3). Habitat conditions in this group were high TDS, higher water temperature, increased wetted area and high silt percentage. Plankton groups Chlorophyceae and Bacillariophyceae were also associated here. The second group with 5 species (*Garra mullya, G. gotyla, Paracanthocobitis botia, Lepidocephalychthys guntea* and *Pethia ticto*) was associated with the sites with high water velocity, presence of herbs and shrubs. Dominance of plankton groups *viz,* copepoda, rotifera and cladocera along with dinophyceae was also noted here. Group three with 6 species (*Barilius bendelisis, Mystus cavasius, M. bleekari, Labeo boga, Puntius sophore* and *Cirrhinus reba*) was associated with presence of emergent vegetation, herbs and pebbles as substrate. Group four with 3 species (*Catla catla, Labeo rohita* and *Rita chrysea*) was associated with sites having more depth, channel width along with floating and submerged vegetation.

Table 5. Principal component loadings in river Ib

Component	Principal component 1	Principal component 2	Principal component 3
Total nitrogen	0.7400	0.240	0.316
Water temperature	0.36	-0.222	0.83
Air temperature	0.392	-0.18	0.828
DO	-0.057	0.195	0.568
pH	0.334	-0.883	-0.145
Wetted area	0.372	0.825	-0.199
Channel width	0.179	-0.695	-0.123
Boulders	-0.94	0.093	-0.126
Cobble	-0.969	0.067	-0.135
Gravel	0.92	-0.107	0.2
Sand	0.866	-0.066	0.15
Silt	0.773	0.172	-0.192
Trees	-0.963	0.106	-0.165
Herbs	-0.948	0.107	-0.146
Depth	0.406	0.821	-0.013
Velocity	-0.181	0.891	-0.187

Plankton not only serves as food for commercially important fishes, mammals and other aquatic organisms; but also contributes to more than half of primary production and plays a key role in biogeochemical cycling (Roemmich and McGowan, 1995; MEA, 2005). The changes in the freshwater runoff and inflow further alter the plankton dynamics (Marques *et al*., 2006) affecting productivity of various trophic levels (Binet *et al*., 1995); species shift in plankton (Cloern and Dufford, 2005); alterations in zooplankton distribution (Kingsford and Suthers, 1994); alien species invasions (Bunn and Arthington, 2002); reduction of fish stock (Chicharo *et al*., 2002) and destruction of spawning and nursery areas (Drake *et al*., 2002). Chicharo *et al*. (2006) had reported changes in plankton assemblages due to changes in water flow and anthropogenic assemblages, thereby emphasising the significance of maintaining environmental flow to protect ecosystems. The variation in plankton distribution along Ib River with change in water flow agrees with these observations. Plankton always has complex interactions with ecological abiotic factors like wind, water movements, light, nutrients and biotic factors like bacteria, macrophytes and fish (They *et al*., 2014). Nandan and Patel (1992) observed that high pH values promote algal growth resulting in blooms. Verma and Mohanty (1995) have reported a direct relationship between pH and phytoplankton. In the present study, pH was positively correlated to phytoplankton and negatively with dissolved oxygen. Samuel and Nuzzi (1979) and Muralidhar and Murthy (2015) also observed an inverse relationship between phytoplankton and dissolved oxygen. A positive correlation between phytoplankton abundance, conductivity and TDS as seen in present study, has also been reported by Das *et al*. (2015).

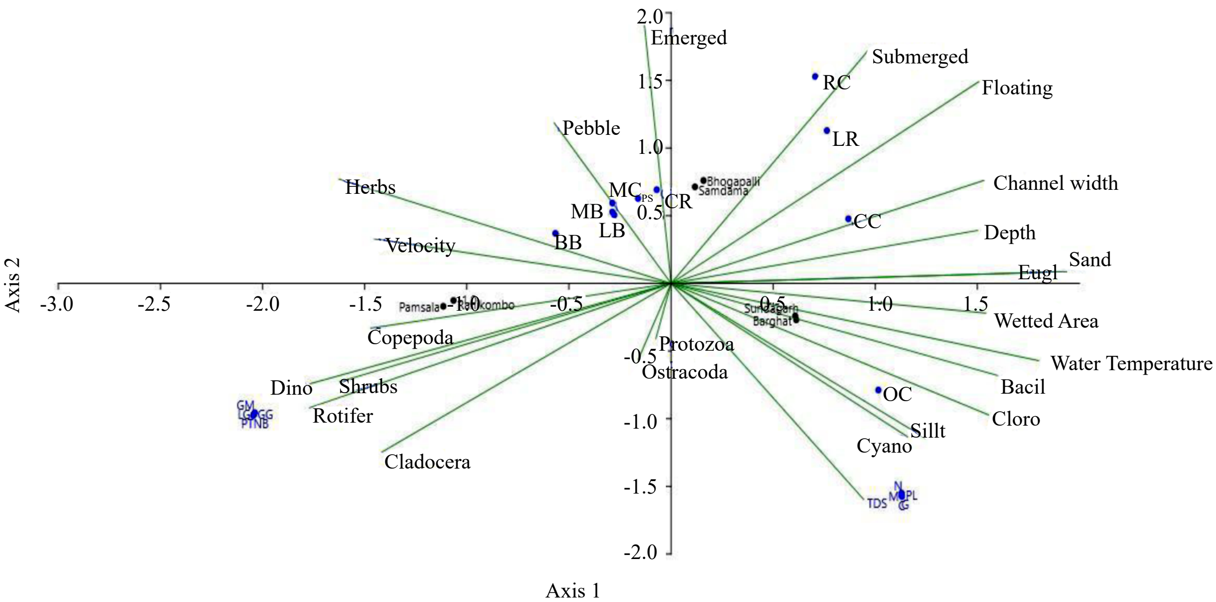

Fig. 3. CCA showing relationship between physico-chemical parameters and fish population of river Ib

CC: *Catla catla*, LR: *Labeo rohita*, LB: *Labeo bata,* CR: *Cirrhinus reba,* PS: *Puntius sophore,* BB: *Barilius bendelisis,* OC: *Osteobrama cotio,* N: *Oreochromis niloticus,* M: *Oreochromis mossambicus,* RC: *Rita chrysea*, MC: *Mystus cavasius,* MB: *Mystus bleekeri,* PL: *Parambassis lala,* C: *Chanda nama,* G: *Gudusia chapra,* GM: *Garra mullya,* GG: *Garra gotyla,* PT: *Pethia ticto,* LG: *Lepidocephalychthys guntea,* NB: *Paracanthocobitis botia*

The thermal and nutrient niche of plankton species decide the diversity in the area and thus determine the ecosystem functioning (Vallina *et al*., 2017). Variations in the distribution of plankton affect the ecosystem services offered, as the presence of this valuable resource makes the habitat ideal for fishes. Beaugrand *et al*. (2003) had stressed on how the fluctuations in plankton resulted in the decline of the cod population in the North Sea. The presence and size of fish communities depend upon the habitat that the fish lives in including the plankton. Changes in community size and structure can occur due to changes in habitat, naturally or through anthropogenic activities. Hence, understanding the relationship between fish communities and habitat variables is important to quantify the effect of habitat changes (Amarasinghe and Welcomme 2001; Zhao *et al*., 2006; Fang *et al*., 2008). Cheng *et al*. (2010) and Cendejas *et al*. (2013) reported combined influence of environmental and habitat variable on fish community assemblages. The present study also revealed influence of limnological characteristics (wetted area, channel depth, velocity), macrophyte coverage (herbs, shrubs, emergent vegetation) and some physicochemical parameters (TDS, temperature) on fish community structures and diversity. Since the Bartlet's test of sphericity was significant, PCA was undertaken producing three axes that cumulatively explained 80.73% of total variance. Shetty *et al*. (2015) reported that water temperature, width and pH had significant effect on fish diversity but, DO and velocity did not have any effect. Melo *et al*. (2009) studied the influence of 12 environmental variables (5 physico-chemical and 4 habitat) of lower Mortes River in Brazil; where DO, channel width, depth, type of substrate and riparian vegetation showed significant loadings in PCA analysis. Cantu and Winemiller (1997) reported 7 environmental variables of which DO, pH and depth had significant loadings.

Grouped by CCA scores, four clusters of fish were identified as being highly related to different habitat variables. The first of these clusters was dominated by *O. cotio, O. mossambicus, O. niloticus, G. chapra, C. nama* and *P. lala* and was positively related to TDS, water temperature, wetted area and silt percentage, which were characteristic of lower and middle stretches of the river. Abundance and distribution of these fishes is seasonal and can be erratic depending on season as monsoon has a high impact on this group affecting TDS, temperature and wetted area. This could also signify that these species may be tolerant to environmental changes and their population density could be used as an indicator to reflect changing environmental conditions (Roth *et al*., 1996; Cheng *et al*., 2010). The second group of fish dominated by *G. mullya, G. gotyla, P. botia, L. guntea* and *P. ticto* were related by water velocity and presence of herbs and shrubs.

It should be noted that these fishes were found only in upper stretches of the river characterised by fast flowing clear water, boulders and small vegetation like herbs and shrubs. This group can probably be used as indicators of change in this river. The third group of fish species was dominated by *B. bendelisis, M. cavasius, M. bleekari, L. boga, P. sophore* and *C. reba* and was related to presence of emergent vegetation, herbs and pebbles as substrate. These fishes were most common and were distributed throughout the river. The fourth group with *C. catla, L. rohita* and *R. chrysea* was positively correlated with limnological parameters like depth, channel width along with floating and submerged vegetation and hence were observed more in lower stretches of the river.

Chandran *et al*. (2019) had studied the fish diversity of Ib River and reported maximum diversity and abundance of fish species in downstream sites, which is relatable to the abundant plankton diversity in the downstream stretch in the present study. Out of the 55 species reported in Ib River (Chandran *et al*., 2019), most of the recorded fish species feed on plankton, which could be attributed to positive correlation observed between fish species and abundance of phytoplankton. Diverse and abundant plankton and fish species recorded in downstream stretches may also be attributed to the availability of larger water volume due to development of bundhs, migration of fish and broader river course (Chandran *et al*., 2019), thus bringing about changes in habitat features. Maximum plankton abundance in the winter months also coincides with maximum fish diversity corroborating an existing positive relationship between plankton and fish. Fish population was found to be significantly positively correlated with air and water temperature, pH, conductivity, TDS, turbidity and wetted area. Positive correlations were also found with substrates like gravel, sand and silt. Soil variables like soil pH, EC, total nitrogen and organic carbon were also positively correlated. Negative correlation was observed with DO and vegetation like trees and herbs. The interaction of fish and plankton species with various physical and chemical parameters can provide information and help predict their distribution and abundance in the river.

The interaction of plankton species with various physical and chemical parameters investigated during the present study provides useful information on their distribution and abundance in Ib River. The maximum diversity of phytoplankton was recorded in summer and minimum in monsoon similar to fish diversity pattern. The downstream site, Sundargarh, recorded maximum algal density and fish diversity. Rich diversity and abundance of zooplankton were observed in the upstream stretch. Though the presence of rotifers indicates organic pollution, the plankton diversity indices give an in-depth picture of the diversity, richness and abundance of species. The range of the overall values of indices indicates good health of the river. Physico-chemical parameters of river had a direct and indirect effect on the diversity and distribution of plankton species. The habitat variations along the Ib River are the primary cause for variation in distribution of plankton and thus the services associated with it. The study has relevance and applicability in all water bodies considering the importance of plankton and its interdependence with fish diversity. The present information would serve as an important input as major changes in a watershed can be detected by altered growth pattern of certain potamoplankton species. Ecological changes may also be evaluated by contrasting the community with reference data from unaltered stretches or time periods. Fish being a significant part of diet all over the world, the study helps in better understanding of its interrelationship with plankton and habitat in rivers and its importance to ES offered as seen in the river Ib as a case study.

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