Arabian Journal of Geosciences (2021) 14: 2038
https://doi.org/10.1007/s12517-021-08386-4

ORIGINAL PAPER

Unravelling the structural changes of periphyton in relation to environmental variables in a semilotic environment in the Sundarban eco-region, India

Pranab Gogoi[1] · **Archana Sinha**[1] · **Tasso Tayung**[2] · **Malay Naskar**[2] · **Soma Das Sarkar**[2] · **Mitesh H. Ramteke**[2] · **Sanjoy Kumar Das**[2] · **K. Lohith Kumar**[2] · **V. R. Suresh**[2,3] · **Basanta Kumar Das**[2]

Received: 6 May 2021 / Accepted: 4 September 2021 / Published online: 21 September 2021

Abstract

The aim of this study was to understand the ecohydrological interactions of periphyton assemblages in a canal (*Bishalakhi*) located in the Indian Sundarban. Sixteen environmental variables and periphyton (scrapped from a known area of submerged natural substrates) were collected seasonally (pre-monsoon, monsoon, and post-monsoon) from three sampling stations between July 2017 and September 2018. Data was analyzed to determine periphyton diversity, abundance, spatiotemporal dynamics, and their relationship with environmental variables using R-software. Eleven environmental variables (water temperature, water depth, water velocity, specific conductivity, total alkalinity, salinity, Mg^{2+}, PO_4–P, TP, SiO_4–Si, and transparency) showed significant difference ($p<0.05$) across seasons. In total, 74 taxa of periphyton under 42 genera and 6 taxonomic groups were recorded. Diatom dominated the periphyton community in terms of diversity and abundance. All the recorded periphytic groups positively correlated with PO_4–P and transparency and negatively correlated with water velocity and water depth. *Cyanophyceae* and Chlorophyceae showed a negative correlation with specific conductivity. Canonical correspondence analysis between five environmental variables (specific conductivity, water velocity, Ca^{2+}, total nitrogen, and dissolved oxygen) that explained 94.70% of the variation and species abundance resulted in three constrained canonical axes in order of CCA1 (0.99) > CCA2 (0.93) > CCA3 (0.93). The majority of the diatom (36 species) had a strong affinity with dissolved oxygen and total nitrogen. The water velocity and specific conductivity were found to influence the distribution of species (Phormidium sp., Ankistrodesmus falcatus, Diploneis sp., Synedra sp., Eunotia sp., and Nitzschia recta) in the canal environment. The results of this study advance the current understanding of the relationship between periphyton and its environment and may aid for better planning of periphyton-based aquaculture in the semilotic canals of Indian Sundarbans.

Keywords Periphyton assemblage · Environmental parameters · Canal · Sundarbans

Introduction

Periphyton is a complex community of microorganisms that include algae and *Cyanobacteria* along with bacteria, fungi, protozoa, and microcrustaceans; it is attached to any natural or artificial and living or dead substrate and, consequently, provides food source (rich in proteins, vitamins, and minerals) to trophic food chains (Silva and Felisberto 2015). The photoautotrophic periphyton species, e.g., phytoplankton, play a vital role in primary production. The ubiquitous nature of this community can be attributed to its ability to grow even in light-limited(Kiffney and Bull 2000) and nutrient-limited(Morin et al. 1999) environment. In general, the succession of periphyton begins with an initial colonization of diatoms, followed

Responsible Editor: Broder J. Merkel

✉ Pranab Gogoi
pranabgogoi@gmail.com

[1] ICAR-Central Inland Fisheries Research Institute Kolkata Centre, CGO complex, Sector I, Salt Lake City, Kolkata, West Bengal Pin:700064, India

[2] ICAR-Central Inland Fisheries Research Institute, Barrackpore, Kolkata, West Bengal Pin:700120, India

[3] ICAR-Central Marine Fisheries Research Institute, Ernakulam, Kochi, Kerala PIN:682018, India

by filamentous green algae and *Cyanobacteria*(Peterson and Grimm 1992). Their colonization depends on several factors, such as substrate types (Algarte et al. 2017), light intensity (Tuji 2000), grazing pressure (Das et al. 2014; Munoz et al. 2000), nutrient availability (Dunck et al. 2013), intensity and duration of water level (Biggs and Thomsen 1995), and temperature (Francoeur et al. 1999). Larned (2010) has provided a broader concept to understand the periphytic population and their interaction to environmental variation. Several factors, such as disturbances, stressors, resources, hydraulic conditions, and biotic interactions, govern the heterogeneity of assemblage pattern and growth of periphyton. In eutrophic waters, the surplus production of periphyton is frequently associated with the assemblages commonly dominated either by filamentous green algae or cyanophytes (Davis et al. 1990). This excessive periphyton growth can be harmful to the aquatic ecosystem which may lower dissolved oxygen concentrations (Horne and Goldman 1994). Moreover, excessive nutrients can change periphyton assemblage structure wholly, leading to the dominance of *Cyanobacteria*(Peterson and Grimm 1992).

Studies on periphyton dynamics in freshwater especially on the succession, colonization pattern, impact of light and photoperiodicity, nutrient limitation, nutrient relationship, and meta-analysis have been conducted worldwide (Larned 2010). According to Dunck et al. (2013), the distribution pattern and structural dynamics of periphytic algae depend on the variation in environmental parameters some of which are regulated by human activities. Moreover, the implications of environmental disturbances and hazards such as flow velocity (Murdock et al. 2004), physical processes (Effendi et al. 2016), and the use of agrochemicals and pesticides (Dalton et al. 2015) on the streams have been extensively studied.

Canals (with a length of 1,26,334 km) are the second most (26%) important source of irrigation in India (Agricultural Census 2010–2011), providing an omnipotent resource for fish production. These canals are seasonal as well as perennial in nature with hard-scaped and earthen banks, primarily used for irrigation. In origin, the Sundarban canals are natural tidal canal connected to the various distributaries/creeks existed in the delta. The natural forms of these resources in Sundarbans were excavated by the State Government for freshwater resource by erecting/setting up of sluice gates in the connecting channel of the parent river. The present study was carried out in the earthen canals with muddy substrates. The majority of these canals are still underutilized in terms of sustainable fisheries. These canals could be promoted for periphyton-based aquaculture, which is an eco-friendly approach and has a positive effect in the production of the cultivable fish species, as well as, in improving water quality (Ranjeet and Hameed 2015). A periphyton-based system is the production of naturally available heterogenous group of organisms attached to substrates, which provides a natural food base to the resident fishes. Since, the climatic variability has adversely impacted on the biological diversity coupled with irreversible global warming, thus it creates an anarchic pathway, and disrupts the sustainability of ecosystem functioning. Indian Sundarban delta is also frequently experienced with varying natural catastrophes including several cyclonic storms in the region (Biswas et al. 2014). The bamboo-based periphyton patches are a cheap alternative to combat climatic adversities in the Sundarban waters, can provide a sustainable source for income generation and thus, and enhance livelihood security (Ghosh et al. 2019).

The coastal ecosystems are facing anthropogenic stress mainly due to the increasing human population density; accelerating the high degree of spatiotemporal variability in environmental parameters (Bosak et al. 2012). Tiny microalgae (including periphytic) are the foremost living forms to respond to changes in the environment due to their rapid growth rate (Resh 2008). The frequent alteration of these water variables not only resulted in the dominance of particular group of algae within the periphytic communities but also has hampered the functional properties of the tidal semilotic ecosystem. The assessment of the periphyton community structure has mostly been restricted to rivers, lakes, and reservoirs of Indian waters (Dutta et al. 2018; Pandit et al. 2014; Das et al. 1994). In fact, the biological quality assessment using periphytic organisms as a model and their associations with hydrological determinants have been thoroughly studied in freshwater ecosystems (Moresco et al. 2015; Dela-Cruz et al. 2006; Kelly et al. 1998) but rarely studied in subtropical tidal canals (Hameed 2003; Iwaniec et al. 2006). Being bestowed with distinct wetland ecotypes—creeks, canals, backwaters, and bheries—the Sundarban eco-region remains unexplored in terms of biological assessment of the periphytic community. Till now, studies are mostly confined to tidal creek and estuarine waters (Basu et al. 2021; Chaudhuri et al. 2012; Sarkar and Bhattacharya 2010), with canal ecosystems as unexplored experimental unit. Moreover, the current literature survey is more inclined towards phytoplankton community; no such focus is paid for attached algal composition. Thus, establishing the biological significance of these model periphytic community in Sundarban water stands unique and would frame a strong baseline for periphyton assemblage database from Sundarbans. Hence, this study aimed at evaluating the structural variations of periphyton community assemblage in relation to hydrological parameters across seasons in the *Bishalakhi* canal, Sagar Island, Sundarbans. The study hypothesized that the different environmental parameters found along the canal influence the structure and composition of the periphytic community over a seasonal period.

Materials and methods

Study area

The Indian Sundarbans is an important mangrove area of the world and an extremely fragile ecosystem. Sagar Island is a tide-dominated island in the Indian Sundarbans, only 6.5 m above the mean sea level (Mukharjee 1983). The island has some mangrove patches and is surrounded by two major rivers namely Hooghly and Mooriganga. The present study was carried out in the *Bishalakhi* canal (21°46′47.3″ N; 88°05′30.6″ E) in Sagar Island, which is a tidal canal connected to the river Mooriganga. Human settlements are densely located on both the banks of the canal. The canal provides freshwater supply for agriculture, livestock rearing, and household activities including fishing for the locality year-round. Generally, the canal remains 2.4−3.0 m deep during peak monsoon and 1.0 −1.6 m during winter. The study area was considered as semilotic about 1.5 km long and ~27.0 m wide and located in the vicinity of the river having very little natural base flow (velocity 0.14 to 0.40 m/sec) depending on the riverine tidal influx into the canal. Both the banks of the canal are covered by herbaceous and shrubby vegetations. The establishment of culvert fitted with sluice gate near the canal mouth has created a hydrologic control point. The sluice gate is frequently operated during the rainy season to reduce the inundated water that spreading over agricultural field. The map (prepared by using QGIS 2.18) of the study area is shown in Fig. 1.

Sampling procedure

Three sampling stations were selected for the collection of samples which reasonably represented the determinants of key sites in the canal. Station 1 (S1) was chosen at the mouth of the canal near the sluice gate, S2 in the midst of the canal in terms of distance, and S3 at the place, where the canal takes a turn (Fig. 1). Sampling across the seasons (three samples in each season) was performed from July 2017 to September 2018. In Indian Sundarbans, the monsoon season lasts from July to October and experiences the maximum rainfall during this period. The post-monsoon (November−February) period is characterized by negligible rainfall, and the pre-monsoon (March−June) is a dry period with the occasional rains and thunderstorms (Chaudhuri et al. 2012). In the canal, water temperature (WT) was measured in situ using the degree centigrade thermometer (P-601466), pH with a digital pH meter (HANNA instruments), and specific conductivity (Sp. Con.) by digital conductivity meter (Multiline P4-82362). The salinity, dissolved oxygen (DO), and total alkalinity (TA) were measured by following standard methods (APHA 2012), and transparency (Tran.) was measured by employing Secchi disc (Strickland and Parsons 1972). Subsurface water samples (0.5 m depth) were collected at all selected locations by using the standard water sampler based on the design of "Ruttner water sampler" (Das Sarkar et al. 2019), and those were immediately transferred to pre-rinsed polyethylene bottles (1L). Water samples were then brought to the laboratory in cold condition and analyzed for nutrients, viz., NO_3−N, total nitrogen (TN), PO_4−P, total phosphorous (TP), SiO_4−Si, Ca^{2+}, and Mg^{2+} following recommendations and methods described in APHA (2012). Flow velocity was measured using the portable digital flowmeter (JDC Electronic SA, Switzerland), and depth was measured by a portable depth sounder (Hondex Bx−7, Japan).

For periphyton community structure study, seasonal samples were collected from the submerged natural substrates

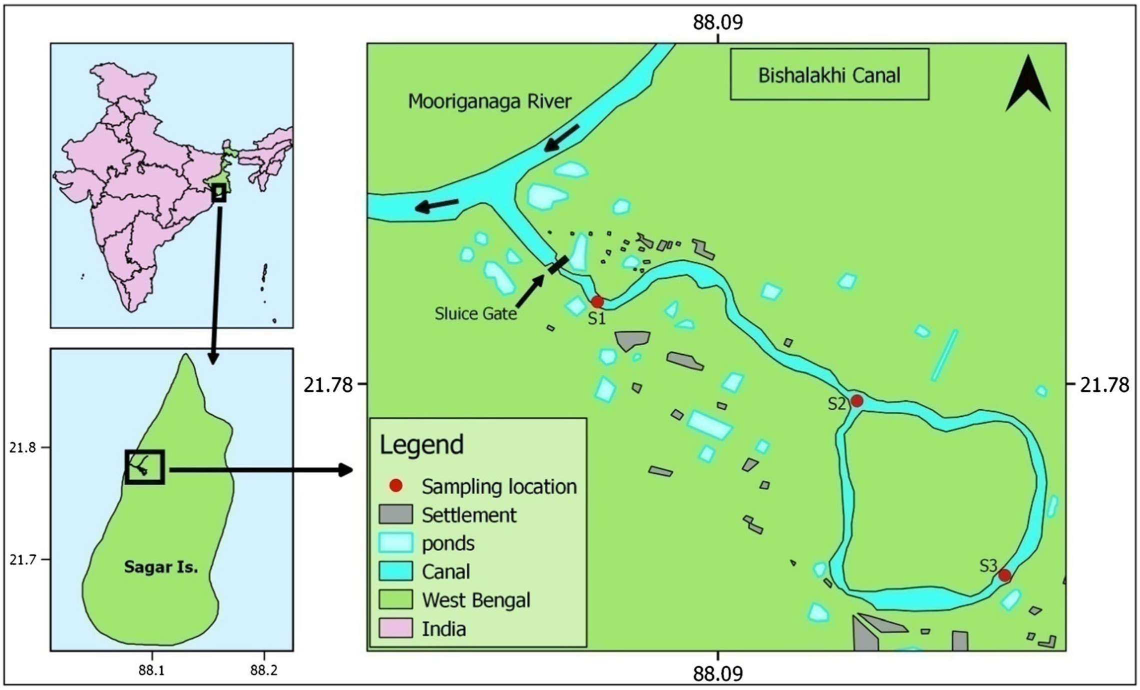

Fig. 1 Map of the study area and sampling locations in *Bishalakhi* canal Sundarbans

(wooden logs/stones) from the respective stations. Periphyton mass was scrapped out using a clean flat blade "scalpel" from a known area (4x4 cm in each spot) at three spots of the natural substrates (Brown and Austin 1971) and then combined into a single composite sample. The scrapped area was measured by using a digital caliper (Mitutoyo: CD−6″ASX). Each sample was handled carefully to minimize the loss of attached organisms. The concentrated samples were transferred to small polyethylene vials and preserved in 4% buffered formalin for analyzing their diversity and abundance. The scrapped mass (periphyton) was shaken by using electrical vortex shakers (Spinix Vortex Shakers−3020) for 5 min to achieved maximum numbers of single individuals from the periphyton matrices. The Sedgwick−Rafter counting cell (S−R Cell) was used for enumeration of periphyton by employing a trinocular light microscope at 400x magnifications (Axioster plus−Carl Zeiss, Nikon Eclipse) and identified up to genus or species level based on the standard taxonomic identification keys (Prescott 1962; Ward and Whipple 1992; Thomas 1997; Cox 1996; Belinger and Sigee 2010). The recognized periphytic algal taxonomic names were further confirmed with AlgaeBase (Guiry and Guiry 2020). Invertebrates were counted and classified at a broad taxonomic group (Nematoda) under a trinocular microscope. Nematode were transferred to glycerol solution and mounted on a slide following Seinhorst (1959) and identified up to genus/species level wherever possible following taxonomic keys (Eyualem-Abebe et al. 2006). The abundance of periphytic organisms was expressed in the "number of individuals per unit area" (ind. cm^{-2}).

Data analysis

The aim was to determine the association between periphyton and environmental variables. However, some exploratory analyses were carried out, which provided insight into the periphyton structure as well as environmental variables. Season and spatial pattern of environmental variables as well as periphyton were investigated, applying two-way ANOVA. Further, post hoc Duncan's test identified pair-wise season-specific or station-specific differences for those variables. The Pearson's correlation was used to diagnose the pair-wise association between water quality parameters and periphyton groups.

Two aspects of periphyton community structure were investigated: diversity and differential abundance. Diversity indices comprising Shannon diversity (Shannon and Weinner 1949), Simpson's index of diversity (Simpson 1949), richness (Margalef 1958), evenness index (Pielou 1977), and Menhinick index (Whittaker 1977) were computed to investigate overall periphyton diversity. All the diversity indices were then subjected to one-way ANOVA, examining seasonal differences in diversity. Additionally, the graphical representation of *k*-dominance curve was used to investigate the dominance pattern across the seasons (Warwick et al. 2008). Differential abundances analysis relied on widely used "Bray-Curtis" dissimilarity measure suitable for community structure data. Hierarchical cluster analysis and nonmetric multidimensional scaling (NMDS) tool were applied to examine the similarity of community composition and differential abundance pattern among samples, and analysis of similarity (ANOSIM) further examined their statistical significance. Canonical correspondence analysis (CCA) was carried out to examine the empirical relationship between environmental factors and periphyton species. There was a total of sixteen possibly interrelated variables recorded for nine samples, which indicated a multicolinearity problem in CCA. Thus, weight or contribution of the environmental variables on the species scores could get affected by multicollinearity. Moreover, the number of measured environment variables (=16) exceeded the number of samples (= 9), which would result in an unexplainable inflated species−environment association. Thus, CCA was applied after eliminating the multicolinearity problem. First, the test of significance of pair-wise Pearson's correlation diagnosed the multicolinearity. Then, two-step strategies were followed to eliminate those problems. Firstly, partial least square technique (PLS) (Mevik et al. 2019) was applied to select environmental variables, which maximized the species-environment correlation, and then CCA was applied by using those selected variables. All the diversity analyses were carried out by using *vegan*(Oksanen et al. 2019) library under R-software (R Core Team 2019).

Results

Physical and chemical factors

The variation in water quality variables of the *Bishalakhi* canal in different seasons (pre-monsoon, monsoon, and post-monsoon) are presented in Table 1. Out of sixteen environment variables, eleven variables (WT, depth, water velocity, Sp. Con., TA, Salinity, Mg^{2+}, PO_4−P, TP, SiO_4−Si, and Tran.) were significantly different among seasons (Fig. 2), and only four variables (depth, water velocity, PO_4−P, SiO_4−Si) differed significantly among stations. Specific conductivity and total alkalinity decreased from the pre-monsoon to post-monsoon. The canal water remained alkaline throughout the study period. No significant variation was observed in the magnitude of DO across the seasons; however, only a small fluctuation of DO was observed over space and time. Analysis of Pearson's correlation coefficient showed positive correlations of water temperature with pH ($r = 0.515$), Sp. Con. ($r = 0.918$; $p \leq 0.01$), TA ($r = 0.754$; $p \leq 0.05$), and negative correlation with water velocity ($r = -0.253$), DO ($r = 0.078$) Ca^{2+} ($r = 0.504$), and Mg^{2+} ($r = 0.650$). Similarly, TA also had a significant positive correlation with salinity ($r = 0.732$; $p \leq 0.05$). Strong correlations were observed between salinity and nutrient

Table 1 Variations of water quality parameters of *Bishalakhi* canal Sundarbans

Parameter/season	Pre-monsoon	Monsoon	Post-monsoon	*p* value
WT (°C)	32.3 ± 0.2^{a}	30.4 ± 0.3^{b}	28.0 ± 0.3^{c}	0.001
pH	7.5 ± 0.1^{a}	7.5 ± 0.1^{a}	7.4 ± 0.1^{a}	0.623
Depth (feet)	4.1 ± 0.86^{a}	8.7 ± 0.75^{b}	5.8 ± 0.55^{c}	0.001
Flow (m/sec)	0.16 ± 0.02^{a}	0.36 ± 0.04^{b}	0.23 ± 0.35^{c}	0.001
DO (mgl^{-1})	6.2 ± 0.1^{a}	6.1 ± 0.1^{a}	6.3 ± 0.1^{a}	0.232
Sp. Con. (mS/cm)	30.3 ± 1.1^{a}	1.1 ± 0.1^{b}	27.6 ± 0.8^{a}	0.001
TA (mg l^{-1})	130 ± 12.2^{a}	100.0 ± 3.1^{b}	93.7 ± 0.3^{b}	0.026
Salinity (ppt)	13.2 ± 1.6^{a}	0.3 ± 0.03^{b}	6.2 ± 1.5^{c}	0.001
Ca^{2+} (mg l^{-1})	29.4 ± 1.5^{a}	32.1 ± 8.0^{a}	36.5 ± 2.1^{a}	0.608
Mg^{2+} (mg l^{-1})	29.1 ± 2.3^{b}	27.5 ± 3.5^{b}	41.1 ± 2.4^{a}	0.027
NO_3−N (mg l^{-1})	0.04 ± 0.01^{a}	0.06 ± 0.008^{a}	0.05 ± 0.006^{a}	0.152
TN (mg l^{-1})	0.08 ± 0.004^{a}	0.09 ± 0.011^{a}	0.08 ± 0.02^{a}	0.602
PO_4−P (mg l^{-1})	0.06 ± 0.006^{a}	0.02 ± 0.002^{b}	0.07 ± 0.006^{a}	0.001
TP (mgl^{-1})	0.09 ± 0.005^{a}	0.04 ± 0.002^{b}	0.10 ± 0.005^{a}	0.001
SiO_4−Si (mgl^{-1})	4.5 ± 0.3^{b}	6.9 ± 0.4^{a}	$4.2+0.1^{b}$	0.001
Tran. (cm)	46.5 ± 0.3^{a}	30.1 ± 1.1^{c}	36.9 ± 0.6^{b}	0.001

Note: Values are means ± SD means followed by the same letter are not significantly different at 5% probability level

variables, viz., PO_4−P (r = 0.707; $p\leq0.05$), TP (r = 0.694; $p\leq0.5$), NO_3−N (r = 0.810; $p\leq0.01$), and TN (r = 0.535). Water velocity had strong positive correlation with depth (r = 0.987; $p\leq0.01$) and significant negative correlation with PO_4−P (r = − 0.833; $p\leq0.01$), TP (r = − 0.819; $p\leq0.01$) and Tran. (r = − 0.875; $p\leq0.01$). Depth was significantly positively correlated with SiO_4−Si (r = 0.893; $p\leq0.01$) and negatively correlated with PO_4−P (r = − 0.832; $p\leq0.01$) and Tran. (r = − 0.891; $p\leq0.01$) (Table 2).

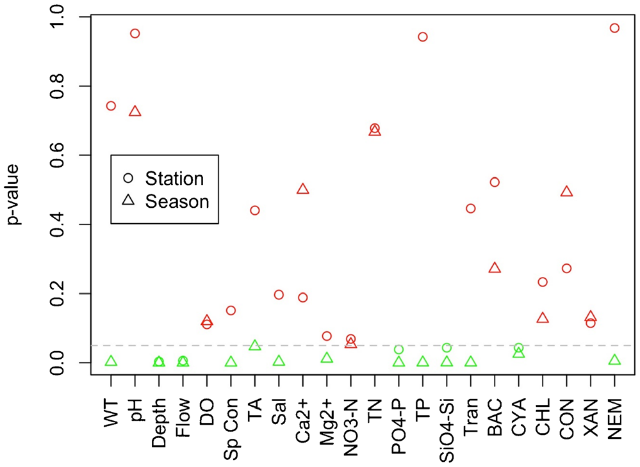

Fig. 2 Test of significance of environmental variables and periphyton groups. The gray dotted line denotes the threshold 5% level of significance (p value = 0.05). Green and red color denoted for significant (p value <0.05) and insignificant (p value > = 0.05), respectively

Periphyton abundance and compositions

The periphyton community was represented by 74 taxa distributed among 42 genera and 6 taxonomic groups from the *Bishalakhi* canal. Diatoms invariably constituted the bulk of the population across seasons (Fig. 3). Bacillariophyceae dominated in terms of abundance (58.35 x 10^3 ± 36.32 x 10^3 ind. cm^{-2}) and diversity across the stations. A total of 49 species of diatoms were recorded, in which pennate diatoms dominated throughout the year. The most common diatoms belonging to the Orders Bacillariales and Naviculales. Maximum species diversity was recorded from the genus *Nitzschia* Hassall, 1845 (16 species), followed by *Navicula* Bory, 1822 (10 species). Apart from those two, some other genera, viz., *Fragilaria* Lyngbye, 1819; *Pinnularia* Ehrenberg, 1843; *Amphora* Ehrenberg ex Kützing, 1844; *Gomphonema* Ehrenberg, 1832; *Amphipleura* Kützing, 1844, *Gyrosigma* Hassall, 1845 and species, viz., *Bacillaria paxillifera* (J. F. Gmelin) Linnaeus, 1791; *Cymbella lanceolata* (C. Agardh) Kirchner, 1878; *Synedra ulna*(Nitzsch) Ehrenberg, 1832; *S. acus* Kützing, 1844; and *Cylindrotheca closterium*(Ehrenberg) W. Smith, 1853, were also contributed substantially to the total diatom assemblages. The abundance of *Cyanophyceae* showed an increasing trend from the monsoon to the post-monsoon season. The mean seasonal abundance of periphyton was maximum during post-monsoon (1.11x10^5±56.47x10^3 ind. cm^{-2}) and minimum during monsoon (43.15x10^3±25.75 x 10^3 ind. cm^{-2}). On the whole, the quantitative abundance of periphyton ranged from 15.25 x 10^3 to 15.9 x 10^4 ind. cm^{-2} across the sampling stations. *Cyanophyceae* was dominated by four genera, viz., *Dolichospermum* Bory ex Bornet and Flahault, 1886; *Anabaenopsis* Miller, 1923; *Lyngbya* C. Agardh ex Gomont, 1892; and *Cylidrospermum* Kützing ex É. Bornet and C. Flahault, 1886, irrespective of seasons. The algal group *Chlorophyceae* was represented mostly by *Ankistrodesmus* Corda, 1838; *Monoraphidium* Komárková-Legnerová, 1969; *Schroederia* Lemmermann, 1898; *Scenedesmus* Meyen, 1829; and *Selenastrum* Reinsch, 1867, while Zygnematophyceae (Conjugatophyceae) was represented by only one genus *Spirogyra* Link, 1820, across the seasons. *Chromadorina* sp. was recorded in scarce forms with low abundance belonging to the nematode group during the study period. The results of two-way ANOVA showed that *Cyanophyceae* group differed significantly ($p\leq0.05$) over the season as well as stations (Fig. 2). The spatiotemporal variation in other periphytic groups was not found to be statistically significant (p>0.05). The seasonal mean percentage abundance of periphyton in the *Bishalakhi* canal is shown in Table 3.

The Shannon−Wiener diversity (H'), Margalefs species richness (d) and Pielou's evenness index (J') in the *Bishalakhi* canal ranged from 2.55 to 3.23, 1.78 to 3.51, and 0.74 to 0.88, respectively (Fig. 4). The H' was the highest at

Table 2 Karl Pearson correlation matrix of water variables and periphytic groups in *Bishalakhi* canal Sundarbans (n = 9)

Variables	WT	pH	Depth	Flow	DO	Sp. Con	TA	Salinity	Ca^{2+}	Mg^{2+}	NO_3-N	TN	PO_4-P	TP	SiO_4-Si	Tran.	BAC	CYA	CHL	ZYG	XAN	NEM
WT	1																					
pH	0.515	1																				
Depth	−0.266	−0.025	1																			
Flow	−0.253	−0.057	**.987****	1																		
DO	−0.078	−0.044	−0.555	−0.579	1																	
Sp. Con.	**.918****	0.386	0.069	0.088	−0.31	1																
TA	**.754***	0.449	−0.474	−0.53	0.251	0.575	1															
Salinity	0.44	0.092	**−.808****	**−.819****	0.365	0.133	**.732***	1														
Ca^{2+}	−0.504	−0.559	−0.059	−0.123	0.16	−0.411	−0.232	−0.241	1													
Mg^{2+}	−0.65	−0.344	−0.068	−0.071	0.398	**−.800****	−0.366	0.095	0.004	1												
NO_3–N	−0.056	0.13	0.45	0.494	−0.382	0.154	−0.562	**−.810****	0.122	−0.428	1											
TN	0.099	0.421	0.262	0.272	−0.165	0.105	−0.307	−0.535	−0.127	−0.096	**.738***	1										
PO_4–P	−0.172	−0.138	**−.832****	**−.833****	0.516	−0.517	0.137	**.707***	0.067	0.535	−0.567	−0.297	1									
TP	−0.228	−0.08	**−.798****	**−.819****	0.587	−0.576	0.193	**.694***	0.106	0.585	−0.632	−0.321	**.976****	1								
SiO_4–Si	0.175	0.239	**.895****	**.893****	−0.539	0.481	−0.143	−0.647	−0.302	−0.374	0.454	0.307	**−.944****	**−.924****	1							
Tran.	0.504	0.118	**−.891****	**−.875****	0.513	0.18	0.662	**.940****	−0.277	0.042	−0.634	−0.387	**.716***	**.672***	**−.680***	1						
BAC	0.076	0.388	−0.635	**−.732***	0.518	−0.236	0.491	0.499	0.233	0.145	−0.355	0.064	0.607	**.693***	−0.619	0.469	1					
CYA	−0.564	0.004	−0.296	−0.323	0.187	**−.716***	−0.444	−0.086	0.367	0.339	0.185	0.218	0.565	0.549	−0.562	−0.03	0.486	1				
CHL	−0.574	−0.124	−0.178	−0.154	−0.073	−0.66	−0.393	0.134	−0.02	0.411	−0.203	−0.362	0.536	0.516	−0.44	0.065	0.046	0.638	1			
CON	−0.12	0.292	−0.539	−0.521	0.375	−0.279	0.015	0.169	0.114	−0.117	0.096	−0.077	0.437	0.453	−0.532	0.304	0.423	0.61	0.515	1		
XAN	−0.388	−0.053	−0.475	−0.497	0.341	−0.552	−0.265	0.100	0.382	0.166	0.082	−0.012	0.622	0.578	−0.651	0.207	0.476	**.912****	0.602	**.724***	1	
NEM	**.762***	0.049	**−.709***	**−.677***	0.18	0.582	**.747***	**.794***	−0.203	−0.37	−0.421	−0.328	0.325	0.255	−0.393	**.834****	0.207	−0.395	−0.289	0.049	−0.144	1

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

BAC, Bacillariophyceae; CYA, *Cyanophyceae*; CHL, Chlorophyceae; ZYG, Zygnematophyceae; XAN, Xanthophyceae; NEM, *Nematoda* station S1 during pre-monsoon and lowest at station S2 during monsoon. The *d* values also showed a similar trend with the maximum at S1 during pre-monsoon and the lowest at station S2 during post-monsoon. The evenness index indicated uniform pattern of periphytic associations across the stations. The value of Menhinick diversity index (*D*) was found to be in a range between 0.062 and 0.258, which appeared to be uniform distributions of periphyton across the stations except at station S1 during monsoon. In the present study, the canal exhibited moderate periphyton diversity in the system, which was evident from the values of *d* and *H′* index. The indices also varied slightly across the stations, reflecting a more stable system. The results of ANOVA (one-way) showed no significant variations of diversity indices across seasons in the canal.

Cumulative dominance (*k*-dominance) curves were plotted (Fig. 5)season-wise to comprehend the ranked abundances of periphyton, expressed as cumulative abundance (in percentage of total abundance) against the species rank in decreasing order of relative abundance (Warwick et al. 2008). It reflected that the species abundance was unambiguously more diverse during the pre-monsoon than the other seasons since the curve did not overlap. More accurately, only 12 species dominated the community during monsoon and post-monsoon which contributed 80% of the total abundance, while 22 species contributed 80% cumulative abundance during pre-monsoon. The curves in respect of monsoon and post-monsoon indicated similar dominance patterns in the periphyton abundance.

Species similarity

Cluster analysis and NMDS were applied to find out the degree of similarity of the species compositions among samples (season station) of the *Bishalakhi* canal. The group average similarity attained the maximum (74.95%) between the monsoon and post-monsoon seasons at station S3, indicating very low variability in the periphyton composition during monsoon and post-monsoon seasons at station S3. Similarly, low level of similarity (47.71%) was observed in the pre-monsoon between stations S1 and S2 and S3. NMDS with two ordinates resulted in the stress value of 0.038 which is a reasonably good value for the sample grouping. Further, NMDS plot also revealed similar species compositional pattern among samples, as observed in the cluster analysis. The 2nd NMDS axis distinctly separated the pre-monsoon assemblages from those of post-monsoon and monsoon, with regard to the periphyton species composition (Fig. 6). ANOSIM reaffirmed the significant ($R = 0.531$; significance: 0.025) difference of periphyton species composition among seasons.

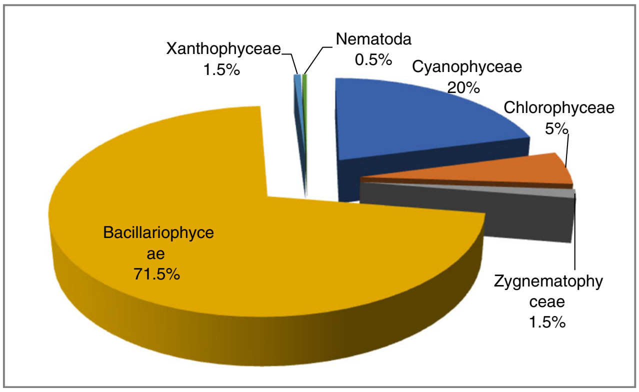

Fig. 3 Compositions of periphytic groups in *Bishalakhi* canal Sundarbans

Influence of physicochemical parameters on periphyton distribution

Table 2 shows that Bacillariophyceae was correlated positively with TP ($r = 0.693$; $p \leq 0.05$) and SiO_4−Si ($r = 0.62$), while significantly negatively correlated with water velocity ($r = -$ 732; $p \leq 0.05$). *Cyanophyceae* was correlated negatively with Sp. Con. ($r =$ 0.71; $p \leq 0.05$). Chlorophyceae exhibited a positive correlation with TP and a negligible correlation with WT and Sp. Con. All the recorded algal groups had a positive correlation with PO_4−P and TP. Nematoda showed significant positive correlation with WT ($r = 0.762$; $p \leq 0.05$), TA ($r = 0.747$; $p \leq 0.05$), salinity ($r = 0.794$; $p \leq 0.05$) and Tran. ($r = 0.834$; $p \leq 0.01$), and negatively correlated with water velocity ($r = -0.677$; $p \leq 0.05$) and depth ($r = -0.709$; $p \leq 0.05$). All the periphytic groups showed a negative correlation with the water velocity and depth resulted from the correlation matrix (Table 2).

The results of PLS revealed that five components explained 94.70% of the variation in environmental variables, and the variation explained in species abundance ranged from 50 to 99%. The variables with the highest loading were selected to represent each component of environmental variables, resulting in five filtered variables, namely Sp. Con., water velocity, Ca^{2+}, TN, and DO (Table 4). CCA analysis with those selected environmental variables resulted in 70% of species−environment variability by the three constrained canonical axes (in terms of Inertia). Species environment correlation of three axes were in order of CCA1 (0.99) > CCA2 (0.93) > CCA3 (0.93). CCA1 distinctively separated the periphyton community structure of pre-monsoon season from that of post-monsoon and monsoon season. The variables which were relatively more associated with CCA1, including Sp. Con. (−0.99) > water velocity (0.34), and TN (− 0.31) in order of magnitude than DO and Ca^{2+}. Similarly, TN exhibited the highest positive association (0.8 1) with CCA2 axis, followed by DO (0.30). CCA1 scores of 47 species (BAC = 36; CHL=6; CON=1; CYA=2; NEM=1, XAN=1) were positive and had an affinity towards salinity, DO, and Ca^{2+}. The same scores of 28 species (BAC = 18; CHL = 2, CON = 1; CYA = 5; NEM = 1; XAN = 1) are being showed negative; thereby, they had an affinity towards Sp. Con. (Figs. 7 and 8).

Table 3 Seasonal mean (average across stations) percentage abundance of periphyton in *Bishalakhi* canal

Groups	Sl no.	Genera/species	PRM	MON	POM
Cyanophyceae	1.	*Dolichospermum* sp.	3.49	9.68	9.70
	2.	*Anabaenopsis* sp.	0.22	0.33	0.32
	3.	*Lyngbya* sp.	1.27	13.91	12.90
	4.	*Phormidium* sp.	0	0.77	1.42
	5.	*Cylindrospermum* sp.	0.11	1.72	0.89
	6.	*Oscillatoria prolifica* Gomont, 1892	0.82	0	0
	7.	*O. princeps* Vaucher ex Gomont, 1892	7.34	0	0
		Total	13.25	26.41	25.23
Chlorophyceae	8.	*Scenedesmus* sp.	0.22	0.50	0.49
	9.	*Ankistrodesmus fulcatus*(Corda) Ralfs, 1848	0.11	3.40	4.41
	10.	*Monoraphidium* sp.	0.96	1.51	1.60
	11.	*Selenastrum* sp.	0.22	0.02	0.03
	12.	*Schroederia indica* Philipose, 1967	0.56	0.05	0.07
	13.	*Chlorella* sp.	0.86	0	0
	14.	*Oedogonium* sp.	0.22	0	0
		Total	3.15	5.48	6.60
Zygnematophyceae (Conjugatophyceae)	15.	*Spirogyra* sp.	1.47	1.21	1.24
	16.	*Desmidium* sp.	0	0.16	0.16
	17.	*Gonatozygon* sp.	0.11	0	0
		Total	1.58	1.37	1.40
Bacillariophyceae	18.	*Fragilaria* sp.	1.10	3.33	1.31
	19.	*Cymbella* sp.	2.26	0	0
	20.	*Cymbella lanceolata* (C. Agardh) Kirchner, 1878	1.87	8.10	8.49
	21.	*C. cymbiformis* C. Agardh, 1830	0.93	0	0
	22.	*Pinnularia* sp.	2.11	0.15	0.22
	23.	*Amphora* sp.	0.41	0.08	0.21
	24.	*Amphora ovalis* (Kützing) Kützing, 1844	0.66	0	0
	25.	*Frustulia rhomboides*(Ehrenberg) De Toni, 1891	1.47	0	0
	26.	*Hantzschia* sp.	0.28	0	0
	27.	*Rhopalodia* sp.	0.13	0	0
	28.	*Diploneis* sp.	0	0.02	0.01
	29.	*Bacillaria paxillifera* (J.F.Gmelin) Linnaeus, 1791	3.08	2.75	2.71
	30.	*Synedra* sp.	0	3.29	3.32
	31.	*Synedra ulna*(Nitzsch) Ehrenberg, 1832	17.69	1.54	1.61
	32.	*S. acus* Kützing, 1844	9.90	0.07	0.11
	33.	*Gomphonema* sp.	0.26	2.78	2.56
	34.	*G. truncatum* Ehrenberg 1832	3.60	0	0
	35.	*Amphipleura* sp.	0.13	0.05	0.07
	36.	*Brachysira* sp.	1.20	0.50	0.49
	37.	*Stauroneis* sp.	0	0.33	0.32
	38.	*Navicula* sp.	2.62	10.18	10.34
	39.	*N. veneta* Kützing, 1844	0.26	0	0
	40.	*Navicula radiosa* Kützing ,1844	0.26	0.07	0.11
	41.	*N. cryptocephala* Kützing, 1844	0.53	0	0
	42.	*N. angusta* Grunow, 1860	0	1.27	1.30
	43.	*N. gregaria* Donkin, 1861	2.20	0.05	0.07
	44.	*N. digitoradiata* (W.Gregory) Ralfs, 1861	0.53	0	0
	45.	*N. rhynchocephala* Kützing, 1844	1.86	0.02	0.03
	46.	*N. subrhynchocephala* Hustedt, 1935	0.80	0	0

Table 3 (continued)

Groups	Sl no.	Genera/species	PRM	MON	POM
	47.	*N. pelliculosa* (Kützing) Hilse, 1863	0	0.16	0.16
	48.	*N. protractoides* Hustedt, 1957	0.39	0	0
	49.	*Eunotia* sp.	0	0.05	0.03
	50.	*Gyrosigma* sp.	0.93	3.71	3.74
	51.	*Nitzschia* sp.	2.55	12.42	13.05
	52.	*N. dissipata* (Kützing) Rabenhorst, 1860	0.22	0	0
	53.	*N. dubia* W. Smith, 1853	0.94	0	0
	54.	*N. reversa* W. Smith, 1853	0.93	0	0
	55.	*N. scalaris*(Ehrenberg) W. Smith, 1853	0.26	0	0
	56.	*N. palea* (Kützing) W. Smith, 1856	5.13	1.19	1.37
	57.	*N. sigmoidea*(Nitzsch) W. Smith, 1853	2.00	1.94	1.91
	58.	*N. obtusa*(Nitzsch) W. Smith, 1853	0.28	3.35	3.36
	59.	*N. recta* Hantzsch ex Rabenhorst, 1862	0	3.25	3.37
	60.	*N. filiformis* (W.Smith) Van Heurck, 1896	0	0.33	0.32
	61.	*N. subacicularis* Hustedt, 1922	0	0.16	0.16
	62.	*N. acicularis* (Kützing) W. Smith, 1853	0	0.16	0.16
	63.	*N. alpina* Hustedt, 1943	1.17	0	0
	64.	*N. intermedia*(Hantzsch) Grunow, 1880	1.42	0.77	0.78
	65.	*N. fibulafissa* Lange-Bertalot, H. 1980	2.50	0	0
	66.	*N. pusilla* Grunow, 1862	0.22	0	0
	67.	*Cylindrotheca closterium*(Ehrenberg) W. Smith, 1853	1.40	3.81	3.92
	68.	*Stenopterobia sigmatella* (W. Gregory) R. Ross, 1986	2.40	0	0
	69.	*Tetracyclus* sp.	1.00	0.02	0.03
	70.	*Campylodiscus* sp.	0.26	0	0
	71.	*Surirella* sp.	0.28	0	0
		Total	80.42	65.90	65.64
Xanthophyceae	72.	*Centritractus* sp.	0.48	0.35	0.36
	73.	*Tribonema* sp.	0	0	0.43
		Total	0.48	0.35	0.79
Nematoda	74.	*Chromadorina* sp.	0.88	0.27	0.076
		Total	0.88	0.27	0.07

PRM, pre-monsoon; MON, monsoon; POM, post-monsoon

Similarly, 29 species (BAC = 18; CHL = 3; CON = 1; CYA = 5; NEM = 1; XAN = 1) had gradient towards the relatively higher magnitude of TN. The species, including *Oscillatoria prolifica*, *Schroederia indica*, *Spirogyra* sp., *C. cymbiformis*, *Amphora* sp., *Hantzschia* sp., *N. protractoides*, *N. alpina*, *Tetracyclus* sp., *Surirella* sp., and *Tribonema* sp., had relatively more gradient towards TN, as compared to the other species. The species, including *Phormidium* sp., *Ankistrodesmus falcatus*, *Diploneis* sp., *Synedra* sp., *Eunotia* sp. and *N. recta*, had an affinity towards the higher Sp. Con. and water velocity than its average value; and the species, *N. dissipata*, *Cylindrotheca closterium*, *Chlorella* sp., *Oedogonium* sp., and *Gonatozygon* sp., had more gradient towards DO and negatively correlated with water velocity and Sp. Con.

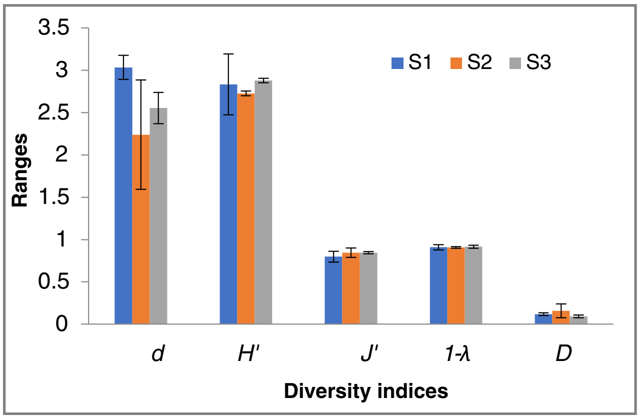

Fig. 4 Univariate measures of periphyton diversity in *Bishalakhi* canal Sundarbans

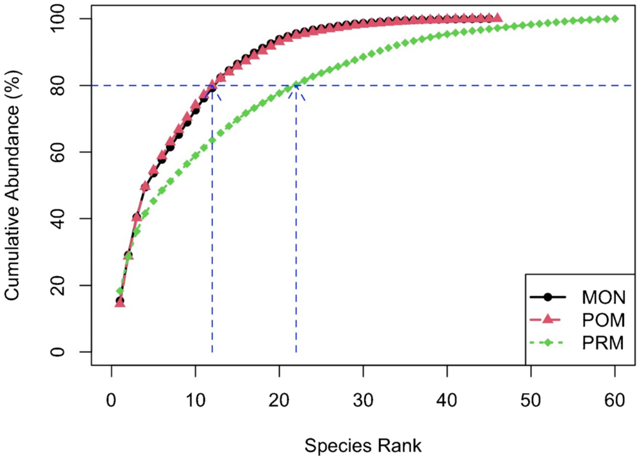

Fig. 5 Cumulative *k*-dominance curve for abundance of periphyton in relation to seasons. MON, POM, and PRM denoted for monsoon, post-monsoon and pre-monsoon, respectively

Table 4 Contribution of water quality variables to extracted components from partial least square method (bold values; selected variables having highest contribution to the component)

Water variables	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5
WT	−0.322	0.308	−0.235	0.031	0.039
pH	−0.221	0.044	−0.327	0.379	−0.366
Depth	−0.188	−0.459	0.116	−0.192	−0.131
Flow velocity	−0.193	**−0.467**	0.109	−0.179	−0.025
DO	0.236	0.213	−0.066	0.108	**−0.735**
Sp. Con.	**−0.407**	0.191	−0.088	−0.102	0.065
TA	−0.134	0.399	−0.264	−0.172	−0.359
Salinity	0.119	0.413	−0.344	−0.161	0.137
Ca^{2+}	0.166	0.076	**0.545**	−0.046	−0.188
Mg^{2+}	0.376	−0.209	−0.202	−0.007	−0.084
NO_3–N	−0.210	−0.207	0.335	0.452	0.137
TN	−0.152	−0.190	0.030	**0.664**	−0.055
PO_4–P	0.354	0.254	−0.187	0.158	0.222
TP	0.370	0.238	−0.198	0.133	0.022
SiO_4–Si	−0.339	−0.328	0.015	−0.170	−0.197
Tran.	0.104	0.442	−0.311	−0.002	0.101

Discussion

Seasonal variations in environmental variables

Water quality is influenced immensely by natural (geological, hydrological, climatic), as well as anthropological factors (Bartram and Balancen 1996). The Sundarban eco-region is one of the ecologically sensitive deltaic tracts which are influenced by extreme climatic anomalies such as tropical cyclones and storm surges. Seawater inundation also could be the result of land use changes in addition to climate change. Studies have revealed that these events have dramatically increased the level of high-risk factors in terms of geomorphological variability on this fragile ecosystem (Sahana et al. 2019). Significant variations of temperature among the seasons during the study period may be attributed to the variations in wind force and freshwater influx coupled with atmospheric temperature (Vajravelu et al. 2018). The canal water remained alkaline across the seasons, as also evident from previous report at *Jharkhali*(Chaudhuri et al. 2012) and *Chemaguri* waters (Manna et al. 2010) in the Sundarbans. DO is a major component which decides the ecological health of an aquatic ecosystem (Chang 2002). The highest and lowest value of DO was recorded during the post-monsoon and monsoon season, respectively. Significant variation in salinity across the seasons was supported by the similar findings of Arumugum et al. (2016) and Perumal et al. (2009). High values of electrical conductivity were recorded during pre-monsoon and post-

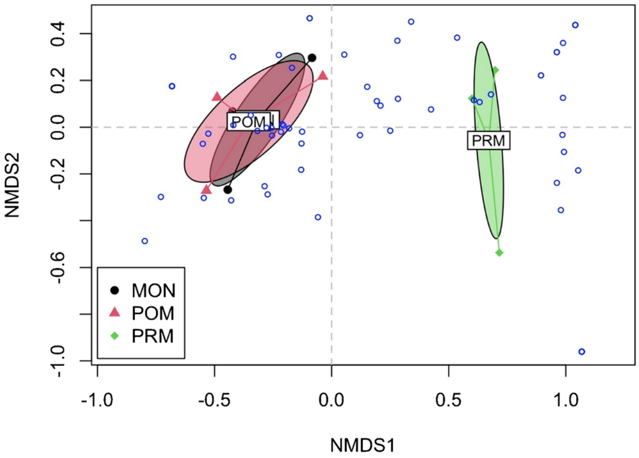

Fig. 6 Nonmetric MDS map showing seasonal differential abundance pattern of periphyton. Blue circle denotes species. MON, monsoon; POM, post-monsoon; PRM, pre-monsoon; filled ellipse denotes standard deviation band

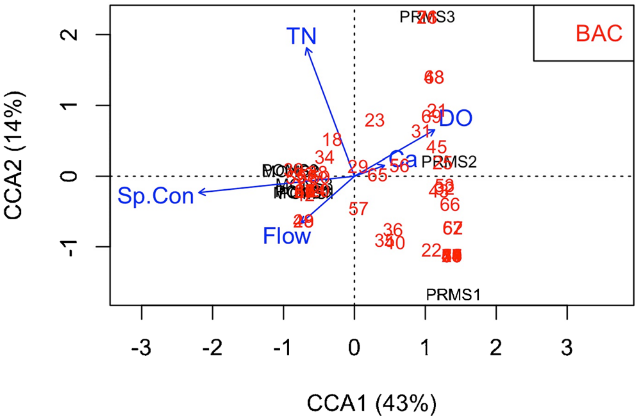

Fig. 7 CCA triplot (periphyton species and environmental variables) showing species−environment association along for the Bacillariophyceae (BAC) group. Number represents the periphyton species mentioned in Table 3

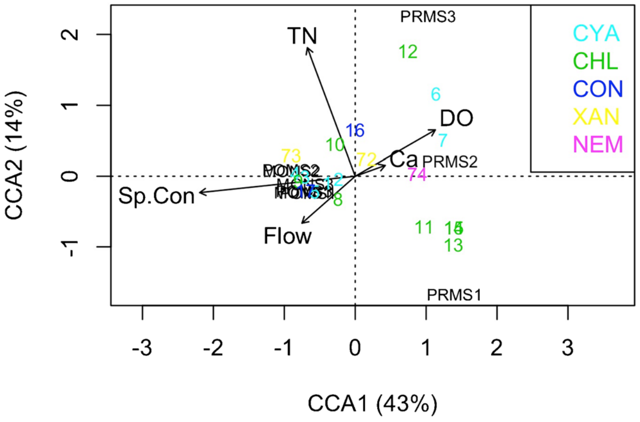

Fig. 8 CCA triplot (periphyton species and environment variables) showing species–environment association along for the periphytic groups (CYAN, CHL, CON (ZYG), XAN, and NEM). Number represents the species serial number in Table 3

monsoon, which could be attributed to higher ionic concentrations, the addition of domestic wastes, and enriched household organic matters (Fokmare and Mussaddiq 2000) into the canal.

The distribution of nutrients in the canal was primarily based on tidal flow and freshwater flow from the catchment areas. Nutrients, viz., NO_3–N, PO_4–P, and SiO_4–Si, exhibited seasonal variations in the present study. A higher magnitude of NO_3–N during monsoon might be caused by the organic matter being enriched by the monsoonal flow and decomposition of terrestrial runoff from the catchment areas (Karuppasamy and Perumal 2000). The utilization of NO_3–N by photosynthetic organisms could also be one of the reasons to lower the NO_3–N level during pre-monsoon. The inverse trend was observed with regard to PO_4–P concentrations that recorded the maximum during post-monsoon. Silicate values were relatively higher as compared to the other nutrients (NO_3–N, PO_4–P) and showed a similar trend as found in the case of NO_3–N. Biswas et al. (2004) stated that the Sundarban eco-regions are highly productive in respect of nutrient concentrations. On the contrary, Choudhury and Bhadury (2015) reported "nutrient (nitrogen)-limited condition" in Sagar Island owing to the seasonal estimates of N/P ratio, mostly remaining below the Redfield ratio (16:1), further conforming the present findings with respect to the *Bishalakhi* canal. Gogoi et al. (2019) also surmised a lower N/P ratio than the Redfield ratio (16:1) across seasons in the *Kailash Khal*, a tropical wetland of the Indian Sundarbans indicating low bioavailability of nitrogen for phytoplankton productivity.

Periphyton community structure and distribution

The distribution and structural composition of periphyton are rarely attempted in the tropical coastal waters including Indian Sundarbans. While profiling the brackish water epiphytic algae, Naskar et al. (2013) recorded 22 taxa of epiphytic algae primarily dominated by *Cyanophyceae* (50%) from Indian Sundarbans, which is less diverse than the periphyton diversity recorded in the present study. The present study disclosed the dominance of Bacillariophytes (>70%) across the seasons which corroborates with the results of Pandit et al. (2014), Dunck et al. (2013), and Kanavillil and Kurissery (2013). In the present study, the genus *Nitzschia* had the highest number of taxa followed by *Navicula* in the diatom assemblage. This is in line of with the findings of Moresco et al. (2015), where the author reported that the genus *Navicula* contributed the highest number of taxa followed by *Nitzschia* and *Pinnularia* in Guaiapó stream. The expressivity (density and compositions) of Bacillariophytes varies according to the bioavailability of silica in the environment. Furthermore, morphological and physiological characteristics also influence the development of this group, since they have the ability to secrete mucilage and to forming mucilaginous matrices for attachment in substrates (Round 1991). High richness of genus *Nitzschia* and *Navicula* during the study period indicated that the canal has had high organic load and moderate turbidity. The dominance of *Cyanophyceae*, Chlorophyceae, and Xanthophyceae in post-monsoon season in the present study showed conformity with the dominance of these groups from Sundarbans as reported by Naskar et al. (2013). In their findings, salinity, transparency, and nutrient especially nitrate were the major factors associated with the distribution of these epiphytic algae.

The considerable presence of filamentous algae in periphyton matrices across the seasons in this study hinted the environment with low water flow (Biggs et al. 1998). In addition, adequate nutrient concentration coupled with a good amount of light also favors for the growth of these algal groups. Higher abundance of *Cyanophyceae*, Chlorophyceae, and Xanthophyceae in the post-monsoon in our study could be related to rich nutrient received from land runoff and to light availability which facilitated the succession of these community assemblages. The mean seasonal abundance of periphyton was attained to the peak during post-monsoon and gradually decreased over the pre-monsoon and monsoon in our study.

The spatiotemporal dynamics in the periphytic assemblage pattern is not typically ascribed to water quality but often coupled with canal hydrology mostly flow rate, water depth, and hydroperiod. Albeit the periphyton do not possess a prime role in shaping the ecosystem, but their dynamics actively sights characteristics of restored hydrology and monitored ecosystem (Iwaniec et al. 2006). The disturbance-induced events (such as monsoonal floods) are likely to change the hydrological regime in floodplain wetlands, and thereby morpho–functional properties of periphytic communities. A directional pattern of changes in relative abundance of algal species is evident in a fluvial environment after the flood phases.

Firstly, the initial attachment of planktonic *Cyanobacteria* and unicellular diatoms followed by growth of the filamentous Chlorophytes, Cladophora, and *Oedogonium* spp., and finally the stalk-forming diatoms (Pfeiffer et al. 2013). Pfeiffer et al. (2015) provided the information that stalk-forming diatoms like *Gomphonema* and epiphytic algae (with strong attachment) the have ability to defend against such physical disturbances and also regenerate their colonization rapidly. Studies on impact of monsoon rainfall on epilithic diatom community in mainstream and tributaries of Hantangang river, Korea, established the fact that the availability of diatom species coincides with the intensity of rainfall and water quality, which indirectly influenced the assemblage pattern of diatom communities (Cho et al. 2020). The authors suggested that the abundance of *Nitzschia palea* had increased following the intensity of rainfall. In the present study, the total abundance of diatom was gradually decreased over pre-monsoon to monsoon with the major contribution accounted by *Fragilaria* sp., *Navicula* sp., *Cymbella* sp., and *Nitzschia* sp. during monsoon in the canal. Thus, it indicated that the nutrient-rich surface runoff from catchment areas during monsoon coupled with water velocity partially influenced the succession pattern of diatoms in the canal environment. In addition, rainfall altered the water quality conditions in the canal environment, which in turn influenced the composition of epilithic diatoms. However, some of the filamentous algae (*Dolichospermum* sp., *Lyngbya* sp., *Cylindrospermum* sp., and *Spirogyra* sp.) did not influence by the water velocity and gradually increased their abundance from pre-monsoon to monsoon and post-monsoon. It also highlighted the broad tolerance of monsoonal perturbations by these algal species. Cordeiroa et al. (2017) reported that hydrological periods (rainy season) altered the dynamics of periphytic algal community, mostly the diatoms and *Cyanobacteria*. However, the overall periphytic algal community composition did not influence in response to the changes in the hydrological periods in their study.

Periphyton consumes a significant fraction of nutrients such as available carbon, nitrogen, and phosphorus during their growth, resulting in a positive periphyton–nutrient correlation in the present study. Some periphytic groups had a close affinity with the certain environmental variables as shown in the multivariate analysis. A majority of the diatoms (BAC–36) had an affinity (positive) towards DO, TN, and Ca^{2+} hardness in the present study. This result somewhat conformed with the observations made by Nayar et al. (2005) that the distribution and the abundance of diatoms were influenced by the WT, pH, and DO. Sarker et al. (2020) opined that water temperature, salinity, silicate, nitrate, and phosphate were the explanatory variables on the distribution of diatoms in their study in subtropical coastal waters of Bangladesh. The periphyton species such as *Cymbella cymbiformis*, *Amphora* sp., *Hantzschia* sp., *Navicula protractoides*, *N. alpina*, *Tetracyclus* sp., *Surirella* sp., *Oscillatoria prolifica*, *Schroederia indica*, *Spirogyra* sp., *Tribonema* sp. had a positive association with total nitrogen in the canal environment. Furthermore, species, viz., *Nitzschia dissipata*, *Cylindrotheca closterium*, *Chlorella* sp., *Oedogonium* sp., and *Gonatozygon* sp., were found to be negatively correlated with water velocity and Sp. Con., but all those species were marked a positive correlation with dissolved oxygen. No significant spatiotemporal variations of Bacillariophyceae in the present study corroborated with the findings of Chintapenta et al. (2018). The authors speculated that water variables such as DO, salinity, and pH of water influenced moderately, but it reflected a statistically insignificant impacts on the diatom community, in their observations from Delaware tidal wetland. Rodrigues and Rodrigues dos and Ferragut (2013) explained that two variables, total phosphate and water temperature, were the principal determinants for the structural differences of periphytic algal community on seasonal scale. Similarly, the shift in the number of periphytic genera was principally related to the variation in total phosphate and DO concentrations (Kanavillil and Kurissery 2013). In the present study, water variables such as DO, Sp. Con., TN, and Ca^{2+} were the influencing variables for the distribution of periphyton in the canal environment. A study also evidence that *Cyanobacteria* prefer calcium carbonate (calcite)–rich substrates for their growth (Stal 2000), which supports to the present findings that *Cyanophyceae* had close affinity (positive) towards Ca^{2+}. The increase in flow velocity favored species with an effective mechanism of attachment to the substrates. It was observed that species *Ankistrodesmus falcatus*, *Diploneis* sp., *Synedra* sp., *Eunotia* sp., and *N. recta*, which were more inclined towards water velocity and Sp. Con. in the canal environment. Some of the attached/filamentous algae (*Dolichospermum*, *Lyngbya*, *Oscillatoria*, etc.) takes full advantage in the lotic environment by dispersing their reproductive units in a higher percentage as compared to other species (Palmer 1980). However, species *Oedogonium* and *Gonatozygon* were negatively influenced by water velocity in this study. Further, the stock-forming diatoms such as *Cymbella*, *Gomphonema*, and *Diploneis* can quickly spread to the additional substrates, and those species have ability to protect against the water flow (Pfeiffer et al. 2015). There was a marked tendency of higher abundance of *Synedra*, *Fragilaria*, *Gomphonema*, *Nitzschia recta*, *N. obtusa*, *Gyrosigma*, and *C. lanceolata* during monsoon indicated their tolerance against the monsoonal perturbations and broad thermal range. The absence of floating and submerged macrophyte in the canal hinted their abundance and distribution were not influenced by macrophytes richness that in contrast with the findings of Algarte et al. (2017). The author speculated that the species richness of aquatic macrophytes was the main predictor of periphyton species in the wetland environment. The considerable presence of nematode in the periphyton matrices across seasons indicated the role of grazing on periphyton species besides other abiotic factors for their distribution in the canal environment. In this study, no significant spatiotemporal heterogeneity of periphytic groups (except *Cyanophyceae* both spatially and temporally) was found, indicating unvarying community compositions under base flow in the canal environment.

The Margalefs species richness (*d*) and Shannon−Wiener diversity (*H*′) exceeding 2.50 indicates a healthy environment of an aquatic ecosystem (Magurran 1988). In the present investigation, the calculated mean values of *d* and *H*′ were found to be greater than 2.60 in the *Bishalakhi* canal indicating healthy periphyton diversity in the system. The maximum value of *H*′ during premonsoon could be related to the benign environmental conditions which in turn supports the settling of periphyton in the canal. The prevalent turbid condition in the canal water during monsoon was one of the effective factors that can be correlated to low *H*′. Furthermore, the monsoon flood pulses were somewhat perturbed the bottom environment. The continuous flood pulses also do not allow to stabilize/colonize the periphyton species due to the bottom scouring effect resulting in low periphyton diversity during monsoon. The value of *J*′ was 0.82±0.04 across seasons which implied evenly distribution of periphyton and thus undisturbed environmental conditions during the study period. A similar study by Gurumayum and Goswami (2013) reported the value of *J*′ within the range 0.77 to 0.94 from the *Imphal* waters. However, a higher range of *H*′ (3.40−4.30) was reported by Sharma et al. (2008) in a pre-impoundment study of the Tehri Dam on Bhagirathi River. Menhinick index (*D*) is a good indicator of biodiversity since it takes into account the abundance of species (Buzancic et al. 2016). The *D* value in this study reflected a uniform distribution of periphyton in the system. The moderate range of *H*′ value (2.81±0.19) and higher periphyton abundance, coupled with the dominance of Bacillariophyceae all the year-round, indicated that the canal was inclined towards the oligotrophic conditions. The presence of lower abundance of *Cyanophyceae*, Chlorophyceae, Zygnematophyceae, and Xanthophyceae in this study also supports its general notion that the dominance of periphytic algal composition represented as Bacillariophyceae > Chlorophyceae > *Cyanophyceae*(Hynes 1970).

Conclusion

The present communication insights the periphytic assemblage pattern along with various eco-hydrological regimes across seasons in the canal ecosystem of the Sundarban eco-region. A study accounted for 74 taxa of periphyton under six groups with Bacillariophyceae (diatoms) as the apex contributor in the *Bishalakhi* canal. Biotic−abiotic relationship observed in this study indicates the species-specific preference of environmental conditions. It has been quantitatively established that species *Oscillatoria prolifica*, *Schroederia indica*, *Spirogyra* sp. *Cymbella cymbiformis*, *Amphora* sp., *Hantzschia* sp., *Navicula protractoides*, *Nitzschia alpina*, *Tetracyclus* sp., *Surirella* sp. and *Tribonema* sp. have close affinity towards TN. In addition, water variables such as Sp. Con. and water velocity are the effective factors for the species *Phormidium* sp., *Ankistrodesmus falcatus*, *Diploneis* sp., *Synedra* sp., *Eunotia* sp., and *N. recta*. As such, the water parameters, viz., DO, Sp. Con., water velocity, TN, and Ca^{2+} are the effective variables which have influenced on the abundance and distribution of periphyton in the canal system. Albeit the water variables influenced their distribution in the canal environment overall, but it reflected statistically insignificant impacts on the periphyton community in the semilotic canal environment. Lesser variation in diversity indices across the stations also suggests that periphyton accumulation is not influenced by the natural base flow, and this implies unvarying community composition seasonally. The biomass and biovolume of periphyton in the canal ecosystem have not been attempted in this study; hence, the instant investigation suggests that future studies may be made to focus on the assessment of periphyton assemblage in general and plankton−periphyton interactions in particular in the canal ecosystems of the Sundarbans.

Acknowledgements The analysis of physicochemical parameters by technical staff (Mr. Subhendu Mandal, T. O. and Mr. Arunava Mitra, T. O.) and the other staff associated with the project is duly acknowledged. We also express our thanks to local people around the *Bishalakhi* canal Sundarbans for their constant assistance during sampling. The authors are thankful to the anonymous reviewers for their valuable comments and constructive suggestions which have immensely improved the manuscript.

Data availability statement All the data have been submitted to the Institute Research Committee of ICAR-Central Inland Fisheries Research Institute, Barrackpore, Kolkata, West Bengal, India.

Author contribution Pranab Gogoi: sample collection, taxonomic identification, statistical analysis, interpretation of data, manuscript preparation. Archana Sinha: interpretations of results and manuscript corrections. Tasso Tayung: sample collection, field estimation of water variables, manuscript preparation. Malay Naskar: statistical analysis and interpretations of results. Soma Das Sarkar: manuscript preparation, interpretation of data, taxonomic identification. Mitesh H. Ramteke: sample collection and filed estimation of water variables. Sanjoy Kumar Das: analysis of water variables, draft corrections. Lohith Kumar, K.: map of the study area and manuscript preparation. V. R. Suresh: guidance and manuscript correction. Basanta Kumar Das: overall guidance and correction.

Funding The authors received funding from the Indian Council of Agricultural Research, New Delhi, to carry out the research work under the institutional project "Exploration of Canals Resources of Punjab and Sundarbans for fisheries development (REF/17-20/08)."

Declarations

Ethics approval The authors declare that they have strictly followed all the rules and principles of ethical and professional conduct while completing the research work.

Consent for publication All the authors have agreed to be listed as per the order mentioned in the MS.

Conflict of interest The authors declare that they have no conflict of interest.

References

Algarte VM, Siqueira T, Landeiro VL, Rodrigues L, Bonecker CC, Rodrigues LC, Santana FN, Thomaz SM, Bini LM (2017) Main predictors of periphyton species richness depend on adherence strategy and cell size. *PLoS ONE* 12(7):e0181720

APHA (2012) Standard methods for the examination of water and wastewater, Eds. Rice EW, Baird RB, Eaton AD, Clesceri LS. American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF), 22nd edition, Washington, DC, USA

Arumugum S, Sigamani S, Samikannu M, Perumal M (2016) Assemblages of phytoplankton diversity in different zonation of Muthupet mangroves. *Re Stud Mar Sci* 3:234–241

Bartram J, Balancen R (1996) Water quality monitoring: a practical guide to the design and implementation of Freshwater Quality Studies and Monitoring programmes. UNEP and WHO, Geneva

Basu S, Bhattacharyya S, Gogoi P, Dasgupta S, Das SK (2021) Variation of surface water quality in selected tidal creeks of Sagar Island, Indian Sundarban ecoregion: a multivariate approach. *Appl Water Sci* 11:63

Belinger GE, Sigee CD (2010) Freshwater algae: identification and use as bioindicators. Blackwell Publishing, p 271

Biggs BJF, Thomsen HA (1995) Disturbance of stream periphyton by perturbations in shear stress: time to structural failure and differences in community resistance. *J Phycol* 31(2):233–241

Biggs JF, Stevenson RJ, Lowe RL (1998) A habitat matrix conceptual model for stream periphyton. *Arch Hydrobiol* 143:21–56

Biswas H, Mukhopadhyay SK, De TK, Sen S, Jana TK (2004) Biogenic control on the air water carbon-di-oxide exchange in the Sundarban mangrove environment, northeast coast of Bay of Bengal, India. *Limnol Oceanogr* 49(1):95–101

Biswas SN, Rakshit D, Sarkar SK, Sarangi RK, Satpathy KK (2014) Impact of multispecies diatom bloom on plankton community structure in Sundarban mangrove wetland, India. *Mar Pollut Bull* 85: 3016–3311

Bosak S, Silović T, Ljubesić Z, Kuspilić G, Pestorić B, Krivokapić S, Damir VD (2012) Phytoplankton size structure and species composition as an indicator of trophic status in transitional ecosystems: the case study of a Mediterranean fjord-like karstic bay. *Oceanologia* 54(2):55–286. https://doi.org/10.5697/oc.54-2.255

Brown SD, Austin AP (1971) A method of collecting periphyton in lentic habitats with procedures for subsequent sample preparation and quantitative assessment. Int Rev Hydrobiol 56(4):557–580

Buzancic M, Gladen ZN, Marsovic I, Kuspilic G, Grbec B (2016) Eutrophication influence on phytoplankton community composition in three bays on the eastern Adriatic coast. *Oceanologia* 58:302–316

Chang H (2002) Spatial and temporal variations of water quality in the river and its tributaries, Seoul, Korea, 1993-2002. *Water Air Soil Pollut* 161:267–284

Chaudhuri K, Manna S, Sarma SK, Naskar P, Bhattacharyya S, Bhattacharyya M (2012) Physicochemical factors controlling water column metabolism in Sundarban estuary, India. *Aquat Biosyst* 8:26

Chintapenta LK, Coyne KJ, Pappas A, Lee K, Dixon C, Kalavacharla V, Ozbay G (2018) Diversity of diatom communities in delaware tidal wetland and their relationship to water quality. *Front Environ Sci* 6: 57

Cho IH, Kim HK, Lee MH, Kim YJ, Lee H, Kim BH (2020) The effect of monsoon rainfall patterns on epilithic diatom communities in the Hantangang River, Korea. *Water* 12(5):1471

Choudhury A, Bhadury P (2015) Relationship between N:P:Si ratio and phytoplankton community composition in a tropical estuarine mangrove ecosystem. *Biogeosciences* 12:2307–2355

Cordeiroa RS, Barbosaa JEL, Lima Filhoa GQ, Barbosab LG (2017) Periphytic algae dynamics in lentic ecosystems in the Brazilian semiarid. *Braz J Biol* 77(3):495–505

Cox EJ (1996) Identification of freshwater diatoms from live material. Chapman and Hall Publisher, California, p 158

Dalton RL, Boutina C, Pick FR (2015) Determining in situ periphyton community responses to nutrient and atrazine gradients via pigment analysis. *Sci Total Environ* 515–516:70–82. https://doi.org/10.1016/j.scitotenv.2015.01.023

Das DN, Mitra K, Mukhopadhyay PK, Choudhury DK (1994) Periphyton of the deep water rice field at Pearapur village Hooghly West Bengal, India. *Environ Ecol* 12(3):551–556

Das S, Deshmukhe G, Dwivedi A (2014) Grazing of selected genera of green, red and brown macroalgae. *Appl Ecol Environ Res* 12(3): 717–725

Das Sarkar S, Naskar M, Gogoi P, Raman RK, Manna RK, Samanta S, Mohanty BP, Das BK (2019) Impact assessment of barge trafficking on phytoplankton abundance and Chl *a* concentration, in River Ganga, India. *PLoS ONE*, 14 (9):e0221451. https://doi.org/10.1371/journal.pone.0221451

Davis LS, Hoffman JP, Cook PW (1990) Seasonal succession of algal periphyton from a waste water treatment facility. *J Phycol* 26:611–617

Dela-Cruz J, Pritchard T, Gordon G, Ajani P (2006) The use of periphytic diatoms as a means of assessing impacts of point source inorganic nutrient pollution in south-eastern Austrália. *Freshw Biol* 51(51): 951–972

Dunck B, Nogueira IS, Felisberto SA (2013) Distribution of periphytic algae in wetlands (Palm swamps, Cerrado), Brazil. *Braz J Biol* 73(2):331–346

Dutta R, Dutta A, Bhagobaty N, Bhagabati SK (2018) Periphyton community structure of Namsang stream, Arunachal Pradesh. *J Coldwater Fish* 1(1):113–120

Effendi H, Kawaroe M, Lestari DF, Mursalin PT (2016) Distribution of phytoplankton diversity and abundance in Mahakam Delta, East Kalimantan. *Proc Environ Sci* 33:496–504

Eyualem-Abebe, Andrassy I, Traunspurger W (2006) Freshwater Nematodes-Ecology and Taxonomy. CABI Publishing, Willingford, UK

Fokmare AK, Mussaddiq M (2000) Comparative studies of physico-chemical and bacteriological quality of surface and ground water at Akole (MS). *Pollut Res* 4(1):56–61

Francoeur SN, Biggs BJF, Smith RA, Lowe RL (1999) Nutrient limitation of algal biomass accrual in streams: Seasonal patterns and a comparison of methods. *J N Am Benthol Soc* 18(2):242–260

Ghosh S, Sahu NC, Rahaman FH, Das KS (2019) Periphyton based climate smart aquaculture for the farmers of Indian rural Sundarban Areas, India. *Res J Ext Edu* 19(1):60–72

Gogoi P, Sinha A, Das SS, Chanu TN, Yadav AK, Koushlesh SK, Borah S, Das SK, Das BK (2019) Seasonal influence of physico-chemical parameters on phytoplankton diversity and assemblage pattern in *Kailash Khal*, a tropical wetland, Sundarbans, India. *Appl Water Sci* 9:156

Guiry MD, Guiry GM (2020) AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. http//www.algaebase.org.

Gurumayum SD, Goswami UC (2013) Studies on seasonal and topographical variations of periphyton in the rivers of Manipur. *J Environ Biol* 34:599–604

Hameed HA (2003) The colonization of periphytic diatom species on artificial substrates in the Ashar canal, Basrah, Iraq. *Limnologica* 33:54–61

Horne AJ, Goldman CR (1994) Phytoplankton and periphyton. Limnology, 2nd Edn, McGraw-Hill, New York, pp 226-264

Hynes HBN (1970) The ecology of running water. University of Toronto Press

Iwaniec DM, Childers DL, Rondeau D, Madden CJ, Saunders C (2006) Effects of hydrologic and water quality drivers on periphyton dynamics in the southern Everglades. In: Trexler JC, Gaiser EE, Childers DL (eds) Interaction of hydrology and nutrients in controlling ecosystem function in oligotrophic coastal environments of South Florida, *Hydrobiologia*, vol 569, pp 223–235

Kanavillil N, Kurissery S (2013) Temporal variation of periphyton communities: a 3-year study from northwest Lake Simcoe, Ontario Canada. *Inland Waters* 3(4):473–486

Karuppasamy PK, Perumal P (2000) Biodiversity of zooplankton in Pichavaram mangroves, South India. *Adv Biosci* 19:23–32

Kelly MG, Cazaubon A, Coring E, Dell'Uomo A, Ector L, Goldsmith B, Guash H, Hürlimann J, Jarlman A, Kawecka B, Kwandrans J, Laugaste R, Lindstrom EA, Leitãon M, Marvan P, Padisák J, Pipp E, Prygiel J, Rott E et al (1998) Recommendations for the routine sampling of diatoms for water quality assessments in Europe. *J Appl Phycol* 10(2):215–224

Kiffney PM, Bull JP (2000) Factors controlling periphyton accrual during summer in headwater streams of southwestern British Columbia, Canada. *J Freshwater Ecol* 15(3):339–351

Larned ST (2010) A prospectus for periphyton: recent and future ecological research. *J N Am Benthol Soc* 29(1):182–206

Magurran AE (1988) Ecological Diversity and its measurement. Princeton University Press, Princceton, New Jersey

Manna S, Chaudhury K, Bhattacharyya S, Bhattacharya M (2010) Dynamics of Sundarban estuarine ecosystem: eutrophication induced threat to mangroves. *Saline Syst* 6(1):8

Margalef DR (1958) Information theory in ecology. *Gen Syst* 3:36–71

Mevik BH, Wehrens R, Liland KH (2019) pls: Partial least squares and principal component regression. R package version 2:7–1 https://CRAN.R-project.org/package=pls

Moresco C, Gubiani EA, Rodrigues L (2015) Periphytic diatoms as bioindicators in a tropical stream: from urban to rural environments. *Acta Sci Biol Sci* 37(4):427–437

Morin A, Lamoureux W, Busnarda J (1999) Empirical models predicting primary productivity from chlorophyll *a* and water temperature for stream periphyton and lake and ocean phytoplankton. *J N Am Benthol Soc* 18(3):299–307

Mukharjee KN (1983) Nature and problems of neoreclamation in the Sundarbans. *Indian J Landsc Syst Ecol Stud* 6:1–19

Munoz I, Real M, Guasch H, Navarro E, Sabater S (2000) Resource limitation by freshwater snail *(Stagnicola vulnerata)* grazing pressure: an experimental study. *Arch Hydrobiol* 148(4):517–532

Murdock J, Roelke D, Gelwick F (2004) Interactions between flow, periphyton, and nutrients in a heavily impacted urban stream: implications for stream restoration effectiveness. *Ecol Eng* 22:197–207. https://doi.org/10.1016/j.ecoleng.2004.05.005

Naskar N, Mukherjee A, Naskar K, Hassan MA, Mukhopadhyay S (2013) Studies on brackish water epiphytic algae from Sundarbans in North 24 Parganas district, West Bengal, India. *Res Plant Biol* 3(6):31–41

Nayar S, Goh PLB, Chou LM (2005) Settlement of marine periphytic algae in a tropical estuary. Estuar Coast Shelf Sci 64(2-3):241–249

Oksanen J, Blanchet FG, Friendly M, Kindt R, Legendre P, McGlinn D, Minchin PR, O'Hara R.B., Simpson GL, Solymos P, Henry M, Stevens H, Szoecs E, Wagner H (2019) vegan: Community Ecology Package. R package version 2.5-5. https://CRAN.R-project.org/package=vegan.

Palmer C (1980) Algae and water pollution. The identification, significance, and control of algae in water supplies and in polluted water. Castle House Publications Ltd.

Pandit AK, Farooq S, Shah JA (2014) Periphytic algal community of Dal Lake in Kashmir Valley, India. Res *J Environ Sci* 8:391–398

Perumal NV, Rajkumar M, Perumal P, Rajasegar KT (2009) Seasonal variations of plankton diversity in the Kaduviar estuary, Nagapattinam, southeast coast of India. *J Environ Biol* 30(6): 1035–1046

Peterson CG, Grimm NB (1992) Temporal variation in enrichment effects during periphyton succession in a nitrogen limited desert stream ecosystem. *J N Am Benthol Soc* 11:20–36

Pfeiffer TŽ, Mihaljević M, Stević F, Špoljarić D (2013) Periphytic algae colonization driven by variable environmental components in a temperate floodplain lake. *Ann Limnol* 49(3):179–190

Pfeiffer TŽ, Mihaljević M, Špoljarić D, Stević F, Plenković-Moraj A (2015) The disturbance-driven changes of periphytic algal communities in a Danubian floodplain lake. *Knowl. Manag. Aquat. Ecosyst.* (416), p 02

Pielou EC (1977) Mathematical ecology. John Wiley & Sons, New York, p 385

Prescott GW (1962) Algae of the Western Great Lakes area with an illustrated key to the genera of desmid and freshwater diatoms, Revised edn. WM. C. Brown Company Publishers. Dubuque, Lowa, p 1000

R Core Team (2019) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Ranjeet K, Hameed PVPS (2015) Evaluation of three substrate bound periphyton systems for the farming of Oreochromis niloticus in South India. *J Fish Aquat Sci* 10:276–285

Resh VH (2008) Which group is best? Attributes of different biological assemblages used in freshwater biomonitoring programs. *Environ Monit Assess* 138:131–138

Rodrigues dos S, Ferragut C (2013) The successional phases of periphytic algal community in a shallow tropical reservoir during the dry and rainy season. Limnetica 32(2):337–352

Round FE. 1991. Use of diatoms for monitoring rivers. In: Whitton BA, Rott E, Friedrich G, (Eds.), Use of algae for monitoring rivers. Institute für Botanik: Universität Innsbruck. p. 25–32.

Sahana M, Hong H, Ahmed R, Patel PP, Bhakat P, Sajjad H (2019) Assessing coastal island vulnerability in the Sundarban Biosphere Reserve, India, using geospatial technology. *Environ Earth Sci* 78: 304. https://doi.org/10.1007/s12665-019-8293-1

Sarkar SK, Bhattacharya BD (2010) Water quality analysis of the coastal region of Sundarban mangrove wetland, india using multivariate statistical techniques. In: Sarkar SK. (ed) Environmental management, p258. ISBN: 978-953-307-133-6

Sarker S, Yadav AK, Hossain MS, Rahman CS, Kabird MA, Sharifuzzamanc SM (2020) The drivers of diatom in subtropical coastal waters: a Bayesian modeling approach. *J Sea Res* 163: 101915. https://doi.org/10.1016/j.seares.2020.101915

Seinhorst JW (1959) A rapid method for the transfer of nematodes from fixative to anhydrous glycerin. *Nematologica* 4:67–69

Shannon CE, Weinner W. 1949. The mathematical theory of communication. University of Illinois. 125.

Sharma RC, Bahuguna M, Chauhan P (2008) Periphytonic diversity in Bhagirathi: preimpundment study of Tehri Dam reservoir. *J Environ Sci Eng* 50(4):255–262

Silva FKL, Felisberto SA (2015) Euastrum and Micrasterias (family Desmidiaceae) in lentic tropical ecosystem, Brazil. *Biota Neotrop* 15(1):e20140079. https://doi.org/10.1590/1676-06032015007914

Simpson EH (1949) Measurement of diversity. *Nature* 163:688

Stal LJ (2000) Cyanobacterial mats and stromatolites. In: Whitton BA, Potts M (eds) The Ecology of Cyanobacteria: Their Diversity in Time and Space. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 61–120

Strickland JDH, Parsons TR (1972) A practical handbook of seawater analysis. *Bull Fish Res Bd Canada*:167–311

Thomas CR (1997) Identifying marine phytoplankton. Academic Press, San Diego, California, p 875

Tuji A (2000) The effect of irradiance on the growth of different forms of freshwater diatoms: implications for succession in attached diatom communities. *J Phycol* 36:659–661

Vajravelu M, Martin Y, Ayyappan S, Mayakrishnan M (2018) Seasonal influence of physico-chemical parameters on phytoplankton diversity, community structure and abundance at Parangipettai coastal waters, Bay of Bengal, South East Coast of India. *Oceanologia* 60:114–127. https://doi.org/10.1016/j.oceano.2017.08.003

Ward HB, Whipple GC (1992) Fresh water biology. In: Edmondson WT (ed) Second Ed. John Willey & Sons Inc, New York

Warwick RM, Clarke KR, Somerfield PJ (2008)*k*- Dominance curves, doi: https://doi.org/10.1016/B978-008045405-4.00114-2

Whittaker RH (1977) Evolution of species diversity in land communities. In: Hecht MK, et al. (Eds.), *Evol. Biol.*10: 1–67. Plenum Press, New York