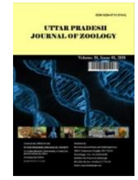
UTTAR PRADESH JOURNAL OF ZOOLOGY

41(1): 15–29, 2020
ISSN: 0256-971X (P)



STRUCTURAL AND FUNCTIONAL DIVERSITY OF PERIPHYTON COMMUNITY FROM THE WESTERN NAYAR RIVER OF GARHWAL HIMALAYA

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AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between both authors. Author MS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author AKD managed the analyses of the study and the literature searches. Both authors read and approved the final manuscript.

Received: 10 December 2019
Accepted: 16 February 2020
Published: 04 March 2020

Original Research Article

ABSTRACT

The importance of periphyton in aquatic productivity is well accepted by the limnologists all over the world as it provides community structure and primary productivity that support a wide range of aquatic organism. River ecosystem is essential for sustenance of living organisms. Western Nayar River is one of the important sources of drinking water for the rural and urban population of Pauri district (Uttarakhand) as well as it harbors a good spectrum of biodiversity. In view of lacuna in literature, attempt has been taken to study the structural and functional community structure of Periphyton along with the important physio-chemical parameters. Monthly samples were collected from each site on the Western Nayar River for a period of two years (January 2015 to December 2016) for the analysis of various physico-chemical (water temperature, current velocity, conductance, turbidity, pH, dissolved oxygen, total hardness, total alkalinity, nitrate and phosphate) and biological parameters (periphyton). The idea was to understand whole community structure of periphyton and the impact of physio-chemical parameter. A total of 19 periphytic genera belonging to five classes, were found in the Western Nayar River during 2015 and 2016. Periphyton was embodied by five classes, Bacillariophyceae, Chlorophyceae, Cyanophyceae, Ulvophyceae and Zygnematophyceae at all the four investigation sites in the river. During the year 2015, periphyton community of Western Nayar river was represented by 18 genera belonging to five classes, Bacillariophyceae (9 genera), Chlorophyceae (2 genera) Cyanophyceae (3 genera) Ulvophyceae (2 genera) and Zygnematophyceae (2 genera). The mean density varied from $394.5833\times10^3\pm183.739$ at S-1, $674.625\times10^3\pm293.0523$ at S-2, $401.667\times10^3\pm214.371$ at S-3 and $365.042\times10^3\pm177.343$ at S-4. The total density differed significantly ($p=0.004$) between the four stations during 2015 while it was insignificant ($p=0.10$) during 2016. Overall it was observed that there was close similarity between winters and lowest in the monsoon in all the station studied during both the year. SIMPER results revealed 20.39% and 14.13% average dissimilarity between the four stations during 2015 and 2016 respectively. Canonical correspondence analysis revealed significant relation between environmental variables and the periphyton taxa. CCA indicated that total alkalinity, DO, water turbidity, nitrate, Current velocity, pH and total hardness were of primary importance and favored the growth and abundance of *Cladophora, Spirogyra*, S*ynedra, Phormidium*, *Spirulina*, *Stigeocolonium, Amphora* and *Nitzchia.*

Keywords: Community structure; environmental parameters periphyton; Western Nayar River.

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1. INTRODUCTION

Freshwater biodiversity encompasses ecosystems including streams, rivers, lakes, ponds groundwater and wetlands. These ecosystems provide a home to many species including periphyton, phytoplankton, macrophytes, zooplankton, macroinvertebrates, fish and other biota. Periphyton is an essential component of floral biota in aquatic systems which provide community structure and primary productivity to the aquatic ecosystem. Role of periphyton in the metabolic conversion and partial removal of biodegradable material in rivers has also been realized by many workers [1,2]. Nymphs and larvae of insects also dwell around algal matters.

Diatoms are effective biological indicators for monitoring the changes in water quality because they respond and integrate the effects of changes in their environment and, for this reason; they need not to be sampled as often as chemical parameters [3]. Diatom indices have been developed to monitor eutrophication [4,5,6], organic pollution [7] and human disturbances [8] and in recent years diatoms, have been widely applied for the purpose of biomonitoring of the aquatic bodies. Use of diatoms to monitor environmental changes during the routine water quality surveys in Europe, North America, Australia, New Zealand, Japan, India and Brazil are made by Prygiel and Bukowska [9], Stevenson and Pan [10], Hill et al. [11], Potapova and Charles [12], Chessman and Townsend [13], Rimet [14] and Alakananda et al. [15].

Periphyton has been widely used for water quality investigation because they have blooming growth, reproduction and short life cycles. Therefore, algae have been used as an ecological indicator of the disturbance by many researchers [16,17,18,19].

The periphyton community is the slippery covering that attach to stones, rocks and other stable substrates in the river water ecosystem. Periphyton gets food from dissolved and suspended organic matter. Periphyton purifies water by absorption of nutrients metals and provides food resource to the entire food web. The distribution and abundance of periphyton varies seasonally due to multiple factors like temperature, light, water current, substrate composition, water chemistry and flash floods.

Periphytic algae of a riverine ecosystem belong to various groups such as Chlorophyta (green algae), Bacillariophyceae (diatoms) and Cyanophyceae (phylum cyanobacteria) etc. The cell structure, photosynthesis, metabolisms and nutrient requirements of algae is quite comparable to the plants and could be suitable indicators of water quality. According to Subha and Chandra [20], the blue green algae (phylum cyanobacteria) and euglenophyceae (phylum Euglenozoa) are numerous at contaminated sites.

The quantitative studies on periphytic communities are scarce presumably due to the difficulties involved in the separation of algal cells from a substrate. The attached algal flora is highly developed in running (lotic) as well as in standing (lentic) waters and form an essential community of all water bodies. The flora forms an extraordinarily heterogeneous and complex association due to variability and distribution of natural substrate. The terminology applied to the various algae in individual habitats is almost as varied as the number of investigations [31,22]. Microorganisms growing on sticks, aquatic macrophytes, and submerged surfaces are designated as periphyton [23]. Organisms included in this group are the filamentous algae, bacteria, attached protozoa, rotifers, algae and free-living microorganisms that swim, creep or lodge among the attached forms. The photosynthetic components include a diverse assemblage of algal forms that colonize nearly every available substrate in the aquatic system.

According to Bootsma et al., [24], the Periphyton provides a niche for exploitation, increasing biodiversity and promoting speciation through competition. While working on lake, Schindler et al. [25], opined that the littoral zone often serves as the spawning ground for pelagic fish species and provides habitat during the larval or juvenile stage of their life cycle. The energy transfer within this zone through periphyton can have an important impact on whole lake processes. The periphyton is reported to have close connection with plankton as they are also originated in similar manner [26-29].

In Garhwal Himalayan rivers various studies on dynamics and diversity of aquatic flora have been conducted [27-38] but a correlative study on riparian vegetation with periphytic community structure including zoo-benthos has not been attempted so far. In view of lacuna in literature and specific objective, present study is undertaken as Periphyton are the pivotal primary producers in aquatic ecosystems and used as a food for fishes and invertebrates.

The idea is to understand the quality of riparian vegetation and its impact on riverine ecosystem including detritus, periphyton and macrozoobenthos as all these parameters are inter-related.

2. METHODOLOGY

2.1 Study Area

The Nayar Basin lies in Pauri Garhwal district of Uttarakhand Himalaya bounded by Tehri in North, Chamoli in East, Almora in South East, Nanital in south and Dehradun in West. The River Western Nayar exploited for present study originates from the Dhoodhatoli Mountain at an elevation of 3116 m. The Dhoodhatoli Khatil – anticline divide the basin of the Eastern Nayar and Western Nayar which made the confluence at Satpuli at 620 masl. After confluence at Satpuli, the river enters in a gorge from Marora to Vyasghat where it finally confluences with the river Ganga. The Western Nayar valley presents a unique set of ecological characteristics over a complex variety of systems that incorporate forests, meadows, grasslands, marshes and rivers, as well as wildlife, geology and several other phyto-geographically distinctive peculiarities. The occurrence of diverse topographical and climatic factors has resulted in the remarkable biodiversity of the river as a result of which flora also correspondingly differ over its different parts. The present study is conducted at Seoli, Inkleswar, Sankarsain, and Chippalghat in the river Western Nayar (Fig. 1).

2.2 Sample Collection

The samples of periphyton were collected by scratching 1 cm^2 surface region of the stones that were submerged in the running water. Incredible consideration was required to pick cobble estimated rocks that were indistinguishable regarding size, profundity and presentation to water current and daylight. The gathered samples were then preserved in 4% formalin and conveyed to the research facility of division of Zoology B.G.R campus Pauri H.N.B. Garhwal University. The volume of the sample was kept up to 50 ml by adding preservative solution. The sample was shaked thoroughly and 1 ml sample was transported to Sidgwick Rafter counting cell for Density and Diversity studies: Algal based periphytic communities were then analysed by Sedgwick- Rafter counting slide using the formulae:

$$n = a \times c \times 1000$$

(Where n = Number of unit of periphyton per cm^2 area. a = average number of units in 1 chamber of 1mm^3 capacity and c = total amount of preservative- 50 ml). Qualitative study was made under microscopic image processing system (MIPS) with the help of several keys and monographs (Hutchinson, 1967) [39,40,41,23].

2.3 Analysis of Physio-chemical Parameters

The measurement of water parameters was done and the sampling process simultaneously. Water temperature, water velocity and dissolved oxygen were estimated on the spot and other parameters were analyzed in the laboratory of Department of Zoology and Biotechnology, HNB Garhwal University Campus Pauri. Various physico-chemical factors were analyzed following the standard methods outlined in Welch [42], Golterman et al. [43] and APHA [23]. The water temperature was recorded by dipping the centigrade thermometer directly into the river. It was also recorded more or less at the same time at all the sampling sites. Float (drift) method was applied to determine the current velocity of the river. An object float on the surface of the river is carried along at a speed corresponding to that of the water current, therefore a plastic container (light weight) is thrown in the river and time taken by it to travel a certain distances (known) is noted with the help of stop watch. The value so obtained is converted into meter per second (m sec^{-1}). This process is repeated at different points of varying depth along a cross-section of river. The mean velocity was calculated from the recorded data. The turbidity was measured by Digital Turbidity Meter in the laboratory. Conductivity was measured with the help of conductivity meter having conductance cell containing electrodes of platinum coated with Pt. black carbon. Alkalinity is the expression of the total quality of base (usually in equilibrium with bicarbonate or carbonate) which is determined by titration with a strong acid [44]. Alkalinity was measured by standard method [23]. 100 ml of sample was taken in flask and added 4-5 drops of phenolphthalein indicator to it which turned the sample pink in colour. This was titrated until colour disappears. To find out the carbonate or phenolphthalein alkalinity (PA) following calculation was done**:** Phenolphthalein Alkalinity (mg l^{-1}) = (A X Normality) of HCL X 1000 X 50/ml of sample.

Hardness is generally measured as concentration of calcium and magnesium ion contents. Hardness as mgl^{-1} $CaCO_3$ = ml of EDTA used X 1000/ml of sample. The dissolved oxygen was estimated on site by the Winkler's Iodometric methods [42].

The pH of the water samples was measured with the help of Digital pH meter in the laboratory of Department of Zoology, B.G.R campus, HNB Garhwal University Uttarakhand. The concentration of nitrate was estimated with the help of Spectrophotometer. Water sample in ice packed container was brought to the laboratory and stored up to 24 hours at 4°C [23]. Phosphate (PO_4-P) in the natural freshwater occurs mostly in inorganic

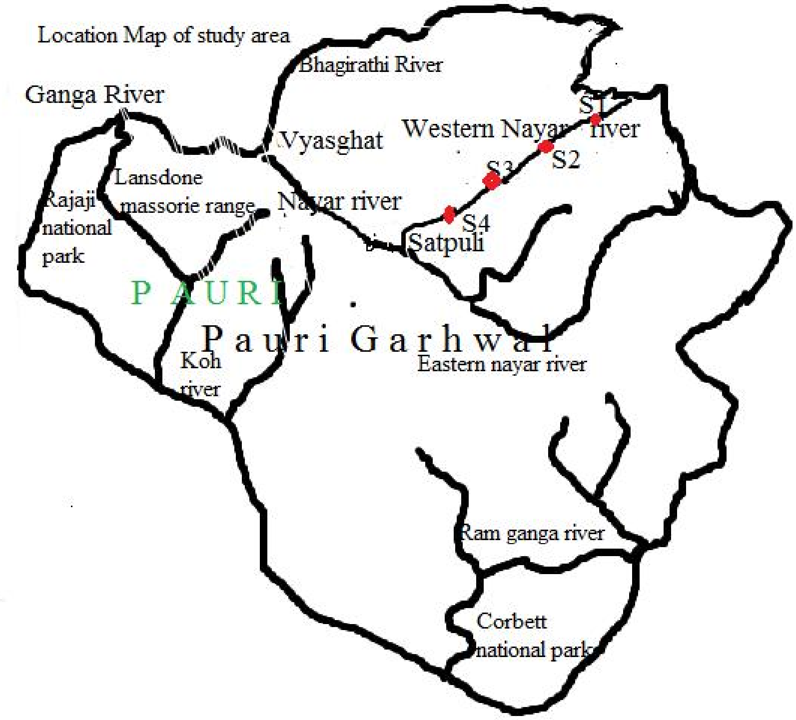


Fig. 1. Map of study area (River Western Nayar in Pauri Garhwal)
S1-Seoli, S2-Inkleswar, S3-Sankarsain and S4-Chippalghat

forms (phosphate) such as H_2PO4, $HPO4^{-2}$ and $HPO4^{-3}$. It may also be present in organic form. Phosphate enters freshwater from atmosphere precipitation and from groundwater and surface runoff. Phosphate (PO_4-P) in the water sample was estimated with the help of Spectrophotometer. The concentration of phosphate in the sample was calculated from the standard curve and expressed as mg l^{-1}; standard curve was prepared between concentration and absorbance from 0.1 mg l^{-1} at the interval of 0.1. Absorbance for standard solution was taken similarly as that of the sample. The absorbance of the sample was taken, and the concentration was calculated by a regression equation (y = a + bX).

2.4 Data Analysis

Data on physico-chemical variables were subjected to canonical component analysis (CCA) for identification of the spatial patterns based on environmental data. A lower triangular Euclidean distance matrix relating to the ordination was constructed [45]. Before calculation of the Euclidean distance resemblance matrix, the data was normalized. Analysis of collinearity was tested by means of a draftsman plot and the associated standard product moment correlation coefficients between all pairs of variables, and pairs with correlations r2 > 0.9 were omitted from the model. The relationships of taxonomic data with environmental variables were examined by means of the biota environment (BIOENV) procedure [46]. To identify which set of environmental variables predicted the multivariate variation in the Insect species assemblages, we performed RELATE. Data on taxonomic composition of all the aquatic insects at the six study sites in were subjected to calculate species diversity indices such as Shannon-Weiner, Simpson's, Evenness and Margalef. They were computed to understand the biotic community of each study station. Shannon-Weiner diversity index helps in species relative abundance, Simpson's diversity index points towards abundance of the most common species. Diversity was expressed in terms of the expected number of species in a sample, ES (51). Evenness index is used for the degree to which the abundances are equal among the species present in a sample or community. Margalef index is having a good discriminating ability and is sensitive to sample size; it is a measure of the number of species present for a given number of individuals.

The statistical analysis of the data was done using data analysis tool pack available in the MS Excel in PC. Shannon-Wiener Diversity Index, Principal Component Analysis (PCA) and Canonical

Component Analysis (CCA) was done with the help of PAST version (2.1) and primer software.

3. RESULTS

3.1 Community Structure of Periphyton

A total of 17 periphytic genera belonging to 5 classes, were found in the Western Nayar river of Uttarakhand during 2015 and 2016 study. Periphyton was embodied by five classes, Bacillariophyceae, Chlorophyceae Cyanophyceae, Ulvophyceae and Zygnematophyceae at all the four investigation sites in the river.

Bacillariophyceae were represented by 9 genera (*Cymbella, Navicula, Amphora, Fragilaria, Achnanthidium, Synedra, Gomphonema, Nitzschia* and *Diatoma).* Chlorophyceae (Green algae) was represented by 2 genera (*Oedogonium* and *Stigeoclonium).*Ulvophyceae was represented by 1 genera (*Ulothrix)* Zygnematophyceae was represented by 2 genera *(Cosmarium* and *Spirogyra)* and the Cyanophyceae (Cyanobacteria) was represented by 3 genera (*Anabaena, Spirulina* and *Phormidium)* in the Western Nayar River during 2015 and 2016.

During the year 2015, periphyton community of Western Nayar river was represented by 17 genera belonging to five classes, Bacillariophyceae (9 genera), Chlorophyceae (2 genera), Ulvophyceae (1), Zygnematophyceae (2) and Cyanophyceae (3 genera).

The total density (indiv.cm^{-2}) of periphyton during 2015, ranged from at 125×10^3 (July) to 682.5×10^3 (January) at S-1, 110×10^3 (July) to 985×10^3 (November) at S-2, 77.5×10^3 (August) to 752.5×10^3 (February) at S-3 and127.5×10^3 (July) to 677.5×10^3 (January) at S-4. The total density is 458.436×10^3 at S-1, 783.544×10^3 at S-2, 707.019×10^3 at S-3 and 421.726×10^3 at S-4 (Table 1).

The total density differed significantly ($p=0.004$) between the four stations during 2015 while it was insignificant ($p=0.10$) during 2016.

During the second year (2016) of study, 17 genera belonging to five classes, Bacillariophyceae (9), Chlorophyceae (2), Ulvophyceae (1), Zygnematophyceae (2) and Cyanophyceae (3) were found in Western Nayar. The total density ranged from 100×10^3 (July) to 735×10^3 (January) at S-1, 107.5×10^3 (July) to 810×10^3 (December) at S-2, 90×10^3 (July) to 812.5×10^3 (January) at S-3 and 95 $\times 10^3$(July) to 730×10^3(January) at S-4. The total mean density was 488.619×10^3, 694.706×10^3, 455.114×10^3 and 638.438×10^3 at S-1, S-2, S-3 and S-4 respectively (Table 2).

Table 1. Average density of periphyton from Western Nayar River during 2015

Stations	S1	S2	S3	S4
Cymbella	70.208	138.75	131.458	85.208
Navicula	53.542	70.625	71.25	25
Fragilaria	16.75	25	13.5	19.792
Nitzschia	15	25	25	11.75
Gomphonema	45.417	55.625	50	46.042
Amphora	22.75	74.583	62.292	20.208
Diatoma	18.75	35.458	31.042	21.364
Synedra	60.625	127.083	120.417	61.042
Achnanthidium	42.727	52.292	40.417	35.273
Ulothrix	17.5	30	29.643	16.786
Spirogyra	13	56.25	32.5	33.75
Cosmarium	7	12.5	6.667	18.75
Anabaena	21	10.833	2.5	10.625
Phormidium	24.167	69.545	74.5	16.136
Oedogonium	30	0	0	0
Spirulina	0	0	5	0
Stigeoclonium	0	0	10.833	0
Total density	458.436	783.544	707.019	421.726

Table 2. Average density of periphyton from Western Nayar River during 2016

Station	S1	S2	S3	S4
Cymbella	88.125	117.083	85.000	115.625
Navicula	39.375	63.542	54.583	58.958
Fragilaria	24.250	5.500	30.750	25.556
Nitzschia	18.889	22.778	19.688	21.944
Gomphonema	47.708	45.625	45.000	46.458
Amphora	19.583	43.773	19.167	54.792
Diatoma	22.750	31.364	28.864	29.167
Synedra	70.833	121.875	71.458	117.500
Achnanthidium	43.750	54.167	41.563	38.333
Ulothrix	18.125	35.833	9.375	29.688
Spirogyra	28.750	37.917	11.250	20.417
Cosmarium	12.500	14.000	6.667	11.500
Anabaena	12.000	12.500	0.000	5.000
Phormidium	18.409	75.000	28.000	63.500
Oedogonium	23.571	0.000	0.000	0.000
Spirulina	0.000	10.000	3.750	0.000
Stigeoclonium	0.000	3.750	0.000	0.000
Total density	488.619	694.706	455.114	638.438

Table 3. Monthly variations in Shannon-Wiener Diversity Index (H′) computed for Periphyton of the Western Nayar River during two years of study

Month wise Shannon diversity index of Periphyton at different Sampling stations during 2015 and 2016												
2015	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
S1	2.374	2.318	2.128	2.208	1.874	2.012	1.879 F	1.999	2.027	2.391	2.46 P	2.236
S2	2.341P	2.066	2.135	2.04	2.295	2.005	1.803 F	2.002	2.101	2.038	2.249	2.212
S3	2.244	2.214	2.118	1.904	2.252	2.009	1.848 F	1.966	2.069	2.11	2.124	2.342 P
S4	2.29	2.222	2.394 P	1.927	2.327	2.079	2.075	2.049	1.838F	1.997	2.208	2.373
2016												
S1	2.363	2.404	2.278 P	2.159	1.96	2.055	1.781 F	1.99	1.958	2.04	2.141	2.214
S2	2.057	1.965	1.862	1.883	2.06	1.944	1.951	1.958	1.822 F	2.12	2.205 P	2.08
S3	2.264 P	2.13	2.027	2.046	2.081	2.253	1.945	1.72 F	2.129	1.729	1.831	2.034
S4	2.272	2.229	2.178	1.98	2.346 P	2.177	1.979	1.947 F	2.006	2.195	2.149	2.278

P = PEAK, F = FALL

Table 4. Average dissimilarity of periphyton during 2015

2015	AD = 20.39					
	Contribution	**Cumulative %**	**Mean abund. 1**	**Mean abund. 2**	**Mean abund. 3**	**Mean abund. 4**
J	3.57	17.51	448	1.09E+03	1.05E+03	403
F	2.498	29.75	623	1.04E+03	833	488
M	2.409	41.57	480	823	808	348
A	2.388	53.28	473	1.00E+03	750	488
M	2.137	63.76	293	635	703	283
J	1.945	73.3	380	753	635	348
J	1.513	80.72	255	550	530	293
A	1.133	86.27	160	428	258	173
S	1.078	91.56	233	320	373	143
O	1.028	96.6	585	810	720	613
N	0.5254	99.18	683	688	813	678
D	0.1679	100	125	110	90	128

Table 5. Average dissimilarity of periphyton during 2016

2016						
Average dissimilarity=14.13%						
	Contribution	**Cumulative %**	**Mean abund. 1**	**Mean abund. 2**	**Mean abund. 3**	**Mean abund. 4**
J	2.263	16.02	515	818	505	935
F	2.207	31.64	270	543	295	708
M	1.595	42.93	495	729	555	808
A	1.562	53.99	495	725	443	723
M	1.426	64.08	388	620	355	580
J	1.292	73.23	150	273	77.5	335
J	1.011	80.39	505	703	590	685
A	0.7722	85.85	343	403	303	463
S	0.7221	90.96	660	603	753	705
O	0.638	95.48	735	623	630	730
N	0.5202	99.16	205	313	233	270
D	0.1181	100	100	108	82.5	95

Table 6. Analysis of variance (ANOVA) between the four sampling stations in Western Nayar River during 2015

ANOVA 2015						
Source of variation	**SS**	**Df**	**MS**	**F**	**P-value**	**F crit (F0.05)**
Between Groups	753107.1	3	251035.7	5.096	0.004096	2.816466
Within Groups	2167498	44	49261.33			
Total	2920605	47				

Remarks: poorly significant

Table 7. Analysis of variance (ANOVA) between the four sampling stations in Western Nayar River during 2016

ANOVA 2016						
Source of variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit (F0.05)**
Between Groups	382761.4	3	127587.1	2.18648	0.103072	2.816466
Within Groups	2567521	44	58352.76			
Total	2950283	47				

Remarks: Insignificant

The total Mean density was recorded minimum at S-4 for 2015 and S-3 for 2016 while it was computed to be maximum at S-2 during 2015 as well as in 2016. Mean density showed increasing trend from S-1 to S-2 then decreased gradually up to S-4 during 2015 while it increased from S-1 to S-3 then declined at S-4 during 2016.

Monthly values for Shannon Wiener diversity (H') index ranged from 1.879 (July) to 2.46 (November) at S-1, 1.803 (July) to 2.341 (January) at S-2, 1.8 (July) to 2.34 (December) at S-3 and 1.838 (September) to 2.394 (March) at S-4 during 2015. While it ranged from 1.78 (July) to 2.404 (February) at S-1, 1.822 (September) to 2.205 (November) at S-2, 1.72 (August) to 2.264 (January) at S-3 and 1.947 (August) to 2.346 (March) at S-4 during 2016 (Table 3).

Bray Curtis clustering classified the station to two clusters for the both years. S-2 and S-3 were grouped in one cluster while S-1 and S-4 in other at distance between 0.9 to 0.93 during 2015. During 2016 two clusters were produced having S-2 and S-4 in one and S-1 and S-3 in other at a distance of 0.94.

Coefficient of similarity between taxa during different months of 2015 and 2016 of all the four-sampling station was observed that there was close similarity between winters and lowest in the monsoon in all the station studied. SIMPER results revealed 20.39% and 14.13% average dissimilarity between the four stations during 2015 and 2016 respectively (Tables 4 and 5).

3.2 Environmental Parameters and Their Effect on the Periphyton Community

Analysis of ten physico-chemical parameters in the Western Nayar river at all the four sampling sites (S1, S2, S3 and S4) was done monthly for two years from

2015-2016. Concerning the riverbed composition, coarse sand was dominated while silty/clayely material and emergent macro-phytes were minimally represented.

River stations varied in climate, size, habitat water quality, hydro-morphology, geology and land use characteristics. Analysis of ten physico-chemical parameters in the Western Nayar river at all the four sampling sites (S1, S2, S3 and S4) was done monthly for two years from 2015-2016. Concerning the riverbed composition, coarse sand was dominated while silty/clayely material and emergent macro-phytes were minimally represented. River stations varied in climate, size, habitat water quality, hydro-morphology, geology and land use characteristics. BIOENV Correlation analysis showed significant correlations of nitrate, phosphate, dissolve oxygen and water temperature with insect density at both the years. Canonical correspondence analysis revealed the relation between environmental variables and the periphyton taxa. During 2015, the eigen values for the three axes were 0.079832, 0.03484, 0.0088 showed 64.65%, 28.28%, 7.13% of variance respectively. S1 and S4 were located in the positive quadrant while S2 and S3 in negative quadrant of the two axes. *Oedogonium* and *Navicula* were the taxa associated with S1, *Spirogyra, Stigeoclonium, Amphora* and *Nitzschia* were associated with S3, *Synedra* with S2 and *Cosmarium* with S4. The environmental variables Current Velocity, Total Hardness, Total Alkalinity, Turbidity, pH and Dissolve Oxygen were present in Negative quadrant while Conductivity and Water temperature in the positive quadrant. During 2016, the eigenvalue of 0.059129, 0.041614 and 0.01394 showed 51.56%, 36.29% and 12.15% variance in the three axes. The stations S2 and S4 along with environmental variables Nitrate, Phosphate, Current Velocity and Total Alkalinity are located in the negative quadrant of the first axis, the associated taxa in this region are *Spirogyra, Phormidium, Stigeoclonium and Ulothrix,* While S1 and S2 are located in the positive quadrant of the first axis and negative quadrant of the second axis respectively. The former was associated *Anabaena, Cosmarium* and *Achnanthidium* while later with *Fragilaria, Gomphonema, Nitzschia* and *Diatoma.* Water Temperature, DO and Turbidity were the environmental variables along with this axis (Figs. 2 and 3).

4. DISCUSSION

The importance of periphyton in aquatic productivity is well accepted by the limnologists all over the world as it provides community structure and primary productivity that support a wide range of aquatic organism. They are easily grazed upon by invertebrate and fish hence contribute greatly to overall productivity**.** The periphyton are huge essential primary makers in the Western Nayar River of Garhwal Himalaya. Periphytic algal networks in the crisp water biological communities are getting more consideration in light of environmental change.

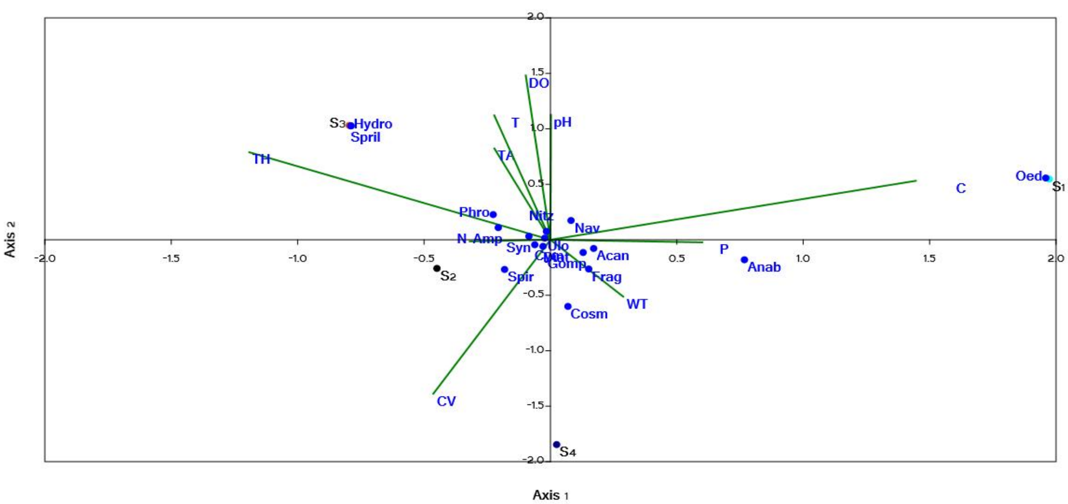


Fig. 2. Canonical Correspondence Analysis (CCA) plot showing the effect of physico-chemical parameters on the abundance of periphyton in the Western Nayar River during 2015

Acronyms: Nitz - Nitzschia, Nav - Navicula, CYM - Cymbella, AMP - Amphora, SYN - Synedra, Acan - Achnanthidium, FRAG - Fragilaria, DIAT - Diatoma, GOMP - Gomphonema, ULO - Ulothrix, STEGO - Stigeoclonium, HYDRO - Hydrodictyon, SPI - Spirogyra, COSM - Cosmarium, PHRO - Phormidium, ANAB - Anabaena, SPRIL - Spirulina

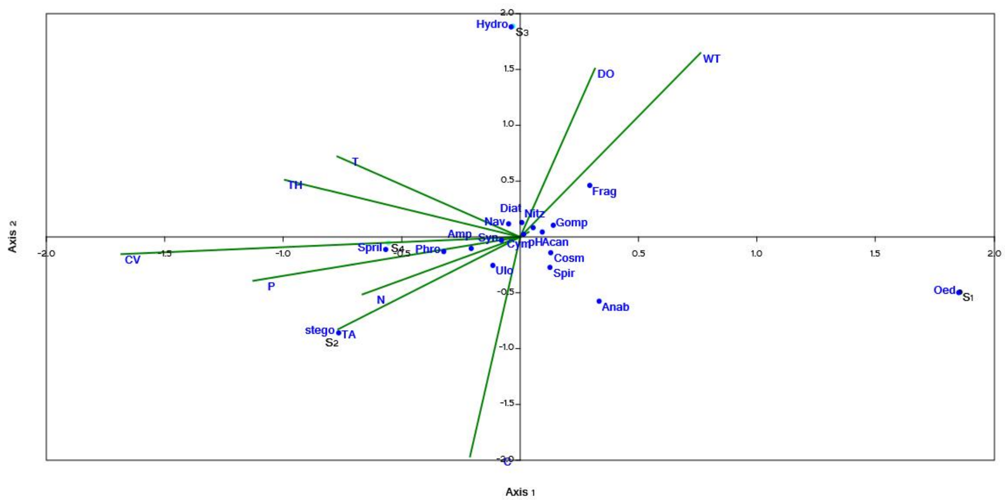


Fig. 3. Canonical Correspondence Analysis (CCA) plot showing the effect of physico-chemical parameters on the abundance of Periphyton in the Western Nayar River during 2016

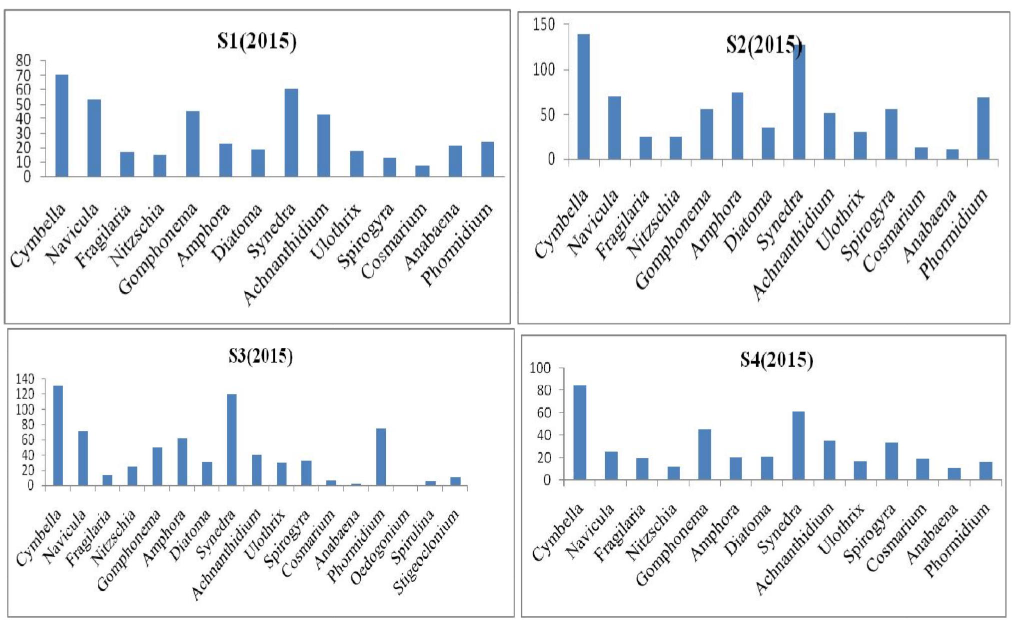
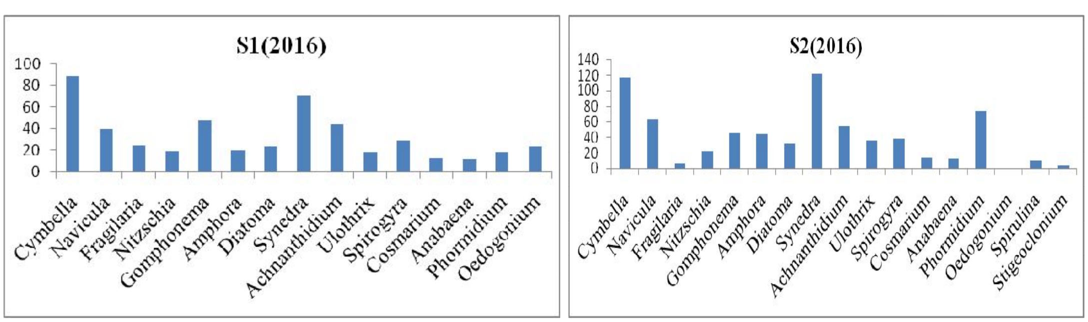


Fig. 4. Density of Periphyton (units x 10^3) on four stations during 2015 in Western Nayar River



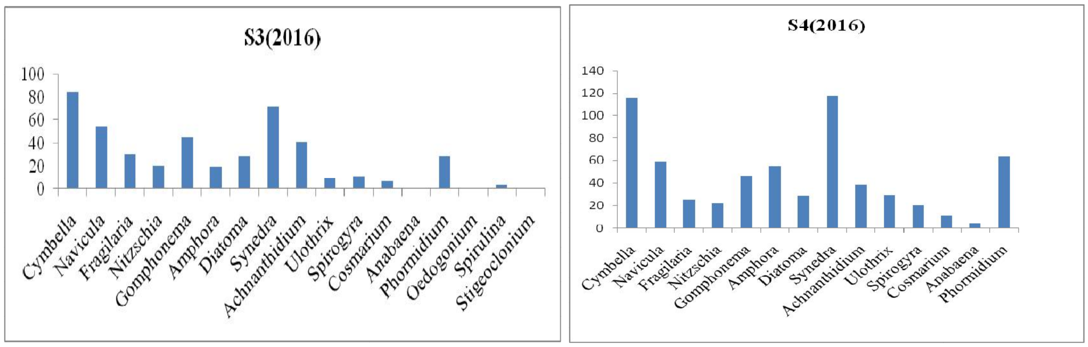


Fig. 5. Density of Periphyton (Units x 10³) on four stations during 2016 in Western Nayar River

The high biodiversity inside the restricted space, fast development rate and short life cycle propel them to rapidly react to ecological changes (Pfeiffer et al., 2015). In present investigation, five classes of Periphyton were watched, viz, Bacillariophyceae, Chlorophyceae, Ulvophyceae, Zygnematophyceae and Cyanophyceae at all the four inspecting sites in the Western Nayar River. Absolute 17 periphyton taxa having a place with five classes specifically Bacillariophyceae (9 genera), Chlorophyceae (2 genera) Ulvophyceae (1), Zygnematophyceae (2) and Cyanophyceae (3 genera) were found.

Seasonal study indicated that the highest density of periphyton was found amid winter (January) and lowest amid monsoon (July). Maximum density of periphyton in winter season may be due to low water velocity, high transparency, low water temperature, stable substrate heterogeneity and other suitable factors. Similar findings have also been found in Bhagirathi River of Garhwal Himalaya (Sharma *et al.*, 2008), River Ravi [66] and Danubian Floodplain Lake (Pfeiffer *et al.*, 2015). The minimum periphyton density during rainy season was also observed in Bhilangana River by Gusain [65] and in the rivers of Manipur by Gurumayum and Goswami (2013). According to Nautiyal [58], the variations in Periphyton density amid monsoon season may be attributed to ecological changes like water velocity, substratum, turbidity and transparency.

Present study affirms that the members of Bacillariophyceae were dominant followed by Cyanophyceae and Chlorophyceae. The Bacillariophyceae (diatoms) were higher in number during winter and lower during monsoon season. Dominance of *Cymbella* and *Fragilaria* among diatoms may be attributed to good concentration of nutrient in the streams which make them fit to withstand along the altering environment conditions in monsoon season. Dominance of diatoms (Bacillariophyceae) among periphyton was also found by some other researchers [47-53]. The diatoms are considered as fast and efficient colonizers and have specialized fixation structures to attach to the substratum [54]. The green algae form a carpet as periphyton in which diatom and blue green algae are trapped. The diatoms repulse and rapidly recoup aggravation like insecure substratum, flood, and dry spell. The behaviour of the other periphyton taxa follows the trend exhibited by the diatoms which constitute the bulk of its members. Low temperature and reduced turbidity and current velocity were observed during the winter maxima which suggested an inverse relationship between these physical factors and the periphyton populations in both the years.

Very little contribution of Cyanophyceae (blue green growth) among periphyton were found at all the four stations in the present investigation. Less measure of nutrients in the river might be resulted in lower contribution of Cyanophyceae [55]. High water speeds, substratum insecurity and related scraped area result in to loss of filamentous periphyton [56].

Most extreme and least number of Cyanophyceae and Chlorophyceae were seen in monsoon season. The greatest density of blue green algae and green algae in winter season might be ascribed to low turbidity, high transparency, low water speed, low water temperature, high dissolve oxygen, and nearly low supplement level (Nitrate and phosphate). Canonical Correspondence analysis (CCA) clarified that the decent variety and wealth of periphyton are constrained by numerous ecological variables and their versatile capacity in the investigation zone as opined by Aberle and Wiltshire [57] and Nautiyal [33] in Nayar River. The most predominant periphytic genera in the Western Nayar stream amid the investigation were *Synedra, Amphora, Cymbella, Gomphonema, Nitzschia, Navicula* and *Achnanthidium* (diatoms), *Phormidium* (Cyanobacteria), *Cladophora, Ulothrix* (Ulvophyceae) and *Spirogyra* (Zygnematophyceae).

Overall the diatoms constituted an average of 49% and 69% of all organisms recorded from the Alaknanda and the Nayar rivers respectively [58,59]. It has been reported by Pearsall [60,61] that waters having large amount of silica and nitrate exhibit high diatoms density, and that flood enhance their growth.

In River Western Nayar though different form of periphyton are available (epipsamic, epipelic, epilithic) but for present study only epiplithic periphyton were sampled from pebbles and stones. Substratum heterogeneity may have greater effect on quality of periphyton. This idea may be investigated in separate study.

The aggregate density of periphyton at each investigation sites during the first year of study was found to be in the order S-2> S-1 >S-4 >S-3 in 2015, and the order remained the same during 2016 also due to same substrate compositions. The general maximum density and assorted variety of periphyton was seen to be most elevated at S-2 and least at S3.

Different specialists like Howkins [62] and Angradi [63] additionally opined that the physical edifices in substrate types (rock stone, sand, stones and cobbles) by and large support more biodiversity than basic substratum, for example, sand and wood. However, the difference in periphyton communities among the four sampling sites was significant in 2015 ($p= 0.04$) and it was not significant during 2016 ($p=0.10$). Shannon-wiener diversity index of periphyton ranged from 1.72 to 2.46 during entire period of study. Monthly the value of Shannon-Wiener diversity index was calculated to be maximum at S1 in November and minimum at S2 in July during 2015. During 2016 maximum Shannon-Wiener diversity index maximum at S4 and minimum at S2.

Seasonal variation pattern of periphyton density showed it highest in winter followed by summer and lowest in monsoon. The winter season recorded highest diversity due to conducive environmental conditions like secure substrate smooth water flow and high transparency.

Extreme flow of water amid storm in Western Nayar River results into unstable substrate and altered water quality in this way influencing periphyton density and diversity. In any case, the periphyton is productive colonizers having short life cycle hence they are able to recover soon after beginning of conducive ecological condition in the water body.

Similarity index of periphyton communities between the entire four investigation site was observed to be most noteworthy somewhere in the site of S2 and S3 (91.9%) amid 2015 and 90.2% in 2016. Highest closeness somewhere in the site of S2 and S3 might be because of comparable ecological conditions at the two sampling spots in the Western Nayar River during the two year contemplates period.

Principal Component Analysis (PCA) has been appeared to be useful strategy in the examination of site shrewd strength of periphyton genera. The predominant genera of periphyton were *Navicula, Gomphonema Amphora, Phormidium, Synedra, Cymbella, Achnanthidium and Nitzschia* among diatoms, *Spirogyra* (Zygnematophyceae) and *Ulothrix* among Ulvophyceae during two years of study period. Periphyton genera like *Oedogonium* (chlorophyceae) *and Anabaena* (Cyanophyceae) prevail at S-1 and *Navicula, Phormidium and Stigeoclonium* prevail at S-3. Anyway genera like *Cymbella*, *Amphora, Synedra, Spirogyra, Gomphonema, Fragilaria* and *Ulothrix* at S-2 in the Western Nayar during 2015. In the year 2016 *Oedogonium* dominated at S-1 and genera like *Spirogyra, Anabaena, Achnanthidium, Ulothrix* and *Spirulina* prevailed at S-2. *Stigeoclonium* and *Fragilaria* dominant at S-3 and *Nitzschia, Diatoma, Navicula, Amphora, Phormidium* and *Synedra* were the characteristics genera of S-4 stations.

Canonical Correspondence Analysis (CCA) was made in use to explain the effect of physico-chemical parameters on the periphyton abundance in the Western Nayar River of Garhwal Himalaya. Coesel [64] described the relation of periphyton growth and habitat environment. CCA indicated that total alkalinity, DO, water turbidity, nitrate, Current velocity, pH and total hardness were of primary importance and favored the growth and abundance of *Spirogyra*, S*ynedra, Phormidium*, *Spirulina*, *Stigeoclonium, Amphora* and *Nitzchia.* While water temperature, phosphate and conductivity negatively correlated with these genera and were favorable for *Anabaena*, *Achnanthidium, Fragilaria, Gomphonema, Cosmarium, Oedogonium, Ulothrix* and *Navicula.* (S-1 and S-4). But in 2016 the dissolved Oxygen, water temperature and pH, positively regulated the growth of *Anabaena, Spirulina, Cosmarium, Achnanthidium, Gomphonema, Fragilaria,* and *Nitzschia* (S-1) and total hardness, turbidity, current velocity, nitrate, phosphate and total alkalinity, negatively correlate with these taxa but positively regulated the abundance and growth of *Diatoma, Amphora, Navicula, Phormidium, Stigeoclonium, Synedra* and *Ulothrix* at S-2, S-3 and S-4 Stations. Current velocity, nitrate and phosphate to be most influential limiting factors for growth and abundance of maximum periphyton taxa were also observed by Ahn et al. [56]. During 2015 Cluster Analysis showed that the station S-1 and

S-4 having almost similar species composition so they clustered closely and S-2 and S-3 clustered in another group due to their similarity in species composition but in 2016 S-1 and S-3 showed more similarity in species composition so they clustered closely and S-2 and S-4 grouped into another cluster. The different clustered in both the years were due to different environmental conditions of the river. This might be affect the species composition of the particular site.

5. CONCLUSION

Two years study on the status of biodiversity of the Western Nayar river of Garhwal Himalaya revealed that the four different spots, having different Periphyton community a. The density and diversity of start increasing during autumn after flash floods in monsoon and reach its maximum in winter due to most stable substratum and onset of most favorable environmental conditions like accumulation of enormous detritus which act as a food as well as habitat for benthic biota during the period. A total of 19 periphytic genera belonging to 3 classes, were found in the Western Nayar river of Uttarakhand during 2015 and 2016 study. The density of periphyton was more at spot no 2, Inkleswar during spring month April which was followed in decreasing order by Spot no. 4 (Chippalghat), 3 (Sankarsain) and least at Spot no. 1 Seoli. Velocity of water current is less at Inkleswar which may be taken as a positive factor for periphytic growth along with pebbly bottom. Spot no. 4 has more detritus and consequently moderate periphytic growth. The environmental variables Current Velocity, Total Hardness ,Total Alkalinity, Turbidity, pH and Dissolved Oxygen were present in Negative quadrant while Conductivity and Water temperature in the positive quadrant. While inter-relating all the observed parameters, it was observed that the periphyton had a negative relationship with the physical parameters (water temperature and current velocity) and a positive relationship with the chemical parameters (dissolved oxygen and pH) in all the spots under investigation.

ACKNOWLEDGEMENT

Both authors thankful to Head department of zoology campus Pauri HNB, Garhwal University, Srinagar Uttarakhand & CSIR for their encouragement and the facilities provided.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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