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Algal community structure and primary productivity of stream ecosystem of west Garo hills, Meghalaya, India

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Abstract
The present study was carried out in Waribok stream of West Garo Hills, Meghalaya. The algal flora of this region is unexplored. The stream ecosystem harbors a diverse group of algae. Maximum numbers of species were recorded from downstream (121 species) as compared to upstream (78 species). In both the study sites species richness was high in Bacillariophyceae and Zygnematophyceae member during spring and winter seasons. Primary Productivity and phytoplankton chlorophyll a content were maximum in downstream during winter season with 1.09 $gC/m^3/h$ and 0.35 mg/l respectively and showed strong positive correlation with cell abundance and N:P ratio and negative correlation with water current.

Keywords: stream**,** algae, primary productivity, chlorophyll a and correlation

Introduction

Composition of an algal community structure and their seasonal changes in freshwater body depends on many environmental and chemical factors like water velocity, depth, transparency, water temperature, pH, nutrients content, dissolved oxygen and grazing by higher organims (Kohler, 1993; Ebigwai *et al*., 2014; Srinivas *et al*., 2017; Halder *et al*., 2019) [12, 18, 24, 40]. The algal assemblages mainly depend upon the quality of water and its morphology. Standing water bodies (lentic) can harbour diverse groups of algae because of its longer retention time where single cell algae can survive and grow. Whereas in flowing water system (lotic system) algae cannot assemblage due to very short retention time which make them unable to survive and grow within the flowing zone (within the geographical area). Algae are very sensitive to pollution and are used as indicator of water quality (Yang *et al*., 2009) [47]. It is very necessary to assess the fresh water bodies because they receive different type of wastes from different sources which remain unchecked. The best way to assess the quality of freshwater bodies is by studying the algal community structure. Many authors have used species diversity which combine species richness as qualitative and abundance of species as quantitative measure of different groups of algae to determine the trophic status of many water bodies (Siangbood and Ramanujam, 2014; Gopinath and Kumar, 2015 and Belokda *et al*., 2019) [7, 16, 35,].

Primary production is the functional characteristic of aquatic ecosystem. Phytoplankton is the main primary producer in surface water. It forms the back bone of aquatic food chain (Ahmed and Singh, 1989) [1] and prime producer of dissolved oxygen in aquatic system (Reynolds, 1987) [33]. Primary productivity is governed by cell abundance and diversity which are in turn controlled by light penetration on surface water, temperature, transparency and chemical parameters (Wyatt *et al*., 2010; Knight *et al*., 2015) [45, 21]. Fluctuation in primary productivity depends mainly upon algal variability, their growth rate. Thus, any change in water quality gets reflected in structural pattern of primary producers and ultimately affect the primary productivity. The seasonal dynamic and succession of phytoplankton community have been known to be associated with water transparency, temperature, light incident and nutrients which are the important factors controlling algal biomass. Chlorophyll a concentration reflects the phytoplankton biomass in aquatic system (Onyema, 2008) [28]. It is the measurable unit of productivity. Chlorophyll a distribution is intrinsically limited to the uppermost water layer. The pattern of vertical distribution of phytoplankton determined the potential of primary productivity and pattern of light penetration within the water column (Behrenfeld and Falkowski, 1997; Yacobi, 2006) [6, 46]. In most cases, Chlorophyll a concentration in the algal biomass varied with algal diversity (Lepisto, 1999; Sontakke and Mokashe, 2014) [24, 39]. According to many studies, nutrients, transparency, temperature, dissolved oxygen and land use systems were the prime factors that regulated the chlorophyll a concentration (Borges *et al*., 2015; Miranda *et al*., 2014; Baliarsingh *et al*., 2015) [8, 27].

Material and Methods

Study sites

Meghalaya one of the states in India, with geographical area of 22,429 sq. km is situated in North East India with geographical coordination of 20.1^0 to 26.5^0 N latitudes and 85.49^0 to 92.52^0 E longitudes. It has 11 districts; the study was conducted in one of the district, West Garo Hills. It has an area of 3,714 km^2. The region is mostly hilly with plains fringing the northern, western and the southwestern borders. South-West monsoon and seasonal wind largely control the climate of the district. To assess the trend of primary productivity and chlorophyll a in lotic ecosystem, a stream was selected. The stream is situated in Waribok hence it is known as Waribok stream. Two sites had been selected

upstream and downstream based on the use and its surroundings. Upstream is situated at an altitude of 648m asl, with the geographical coordinates at latitude 25°36'67" N and longitude 90°18'64" E. The depth of this site is 25cm to 60cm. Downstream is located at an altitude of 627m asl, with the geographical coordinates at latitude 25°36'77" N and longitude 90°19'14" E. The depth of this site is 10 cm to 44 cm. This site of the water is used for domestic purposed.

Samples collection

Collection of Water and algal samples from upstream and downstream of Waribok of West Garo Hills, Meghalaya were carried out every month from September 2015 to August 2017 by following the method given in APHA, (2012) [2]. The collected data were grouped into four seasons.

Assessment of physico-chemical parameters and algal species

Water samples were collected from both the sites in 500ml of polyethylene bottles (4 replicates) and were brought to the laboratory for water analysis. Temperature, pH, water current and turbidity were measured in situ by using thermometer, digital pH testr 20, a float method and turbidity meter (TU-2016) respectively. Estimation of nitrate (NO_3), phosphate (PO_4) and silica (SiO_2) were analyzed in the laboratory following standard methods (APHA, 2012) [2].

The phytoplankton was collected from the surface water by a plankton net having mesh size of 45 µm. Periphytic algae were collected from different substrata like stones, rocks, pebbles, dead leaves and sediments with the help of scalpel and tooth brush. The algal samples were preserved in 4% formaldehyde and brought into the laboratory for qualitative and quantitative analysis. Taxonomic identification up to species level was mainly carried out with the help of Floras and Monographs (Tiffani and Britton, 1952; Presscott, 1982; Desikachary, 1985; Gandhi, 1998 and John *et al.*, 2002) [10, 14, 20, 44] and taxonomy was updated using the online database Algae Base (Guiry and Guiry, 2018) [17]. Species richness was calculated as the total number of species present in a given sample.

Primary Productivity and Chlorophyll a measurement

Primary productivity of water body was measured by Light and Dark bottle method (Winkler's method).The BOD bottles with 300 ml were filled with water samples from the selected water bodies, avoiding any air bubble. 1 ml of manganous sulphate and 1 ml of alkaline potassium iodide were added in one of the light bottles to fix the initial dissolved oxygen according to Winkler's method. While the other light bottles were suspended in a vertical position under water in the euphotic zone of the sampling station for three hours. After incubation time, the bottles were taken out and fixed prior to dissolve oxygen determination in the laboratory. Then the bottles were brought to the laboratory and 2 ml of sulphuric acid was added and were mixed thoroughly to dissolve the precipitation completely. 50 ml of the sample was taken from each bottle in a 100 ml conical flask and a few drops of starch indicator were added. Blue colour appeared, it was further titrated against Sodium thiosulphate solution till the end point (blue colour turned colourless).

The net primary productivity (NPP) is calculated as follows
NPP = (Final dissolved oxygen in light bottle – Initial dissolved oxygen in light bottle)* 0.375/T

For chlorophyll a measurement from phytoplankton biomass, initial volume of water sample was recorded and the phytoplankton cells were separated by filtration. The filter papers were placed in a tissue-grinder and 2-3 ml of 90% acetone was added and ground until the filter fibers were separated. The acetone along with ground filters were transferred into a centrifuge tube, the tube was rinsed with another 2 ml of 90% acetone and added to centrifuge tube. The total volume was made to 10 ml with 90% acetone. The samples were stored in darkness at 4ºC for 10-12 hours. The absorbance of supernatant was measured at 664 nm, 647 nm and 630 nm. Chlorophyll a was calculated by following the method given by Strickland and Parsons (1972).

$$\text{Chlorophyll a (mg/l)} = 11.85\,(OD_{664}) - 1.54\,(OD_{647}) - 0.08\,(OD_{630})$$

The chlorophyll a concentrations in given water sample was calculated by the following formula.

$$\text{Chlorophyll a (mg/l)} = \frac{\textbf{Chlorophyll a(mg/l) X extract (l)}}{\textbf{Volume of sample (l)}}$$

For chlorophyll a measurement from periphytonic biomass, periphytonic algae were collected from a known area ($1cm^2$) of natural substrate for estimation of algal productivity. Samples were transferred to centrifuge tube and kept in ice box under complete darkness, transported to laboratory and stored till chlorophyll a estimation was carried out. Algal samples were washed several times with distilled water by centrifugation each time. Chlorophyll a was extracted in 90% acetone and kept overnight at 4°C to allow complete extraction of the pigments. The absorbance of supernatant was measured at different wavelengths using Agilent Technology model no Carry 60 UV-Vis. The amount of chlorophyll a was calculated following the above equation. This equation gave chlorophyll a concentration in extract on a volume basis. Hence, the data were converted on area basis, i.e., mg/cm^2 of substrate. Correlation between chlorophyll a content in periphytonic algal biomass and different important water parameters like water current, cell abundance and nitrogen to phosphorus ratio were examined by linear regression analysis using SPSS 16.0.

Results

Physico-chemical parameters of Waribok stream

Seasonal fluctuation was recorded in water temperature in both upstream and downstream during the study period. Water temperature was high in downstream with 26^O C in monsoon. The water was slightly acidic to alkaline in nature in both upstream and downstream. Maximum pH was reported from downstream during monsoon with 8.1. Water current and dissolved oxygen was maximum in upstream with 0.21 m/sec (during monsoon) and 7.70 mg/l (during winter) respectively. Turbidity, nitrate and phosphate were maximum in downstream with 5.85 NTU (during monsoon), 0.30 mg/l and 0.19 mg/l (during autumn) respectively. Silica content was maximum in upstream with 4.26 mg/l (during spring) Table 1

Table 1: Seasonal variation with range in physico-chemical parameters in upstream and downstream of Waribok (Mean values with standard error are given in parenthesis).

Parameters	Autumn		Winter		Spring		Monsoon	
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
Temperature (^{O}C)	18-23 (21±2.64)	21-23 (22±1.2)	15-17 (16±0.57)	15-17 (17±0.95)	20-24 (20±1.42)	18-22 (21±1.35)	23-25 (24±0.01)	24-26 (25±0.57)
pH	6.8-7.7 (7.6±0.5)	7.2-7.8 (7.8±0.79)	6.9-7.5 (7.1±0.25)	7.20-7.9 (7.26±0.8)	6.7-7.4 (7.25±0.66)	6.9-7.6 (7.41±0.1)	7.3-7.8 (7.56±0.3)	7.7-8.1 (7.80±0.4)
Water current (m/sec)	0.05-0.16 (0.08±0.04)	0.04-0.05 (0.04±0.006)	0.04-0.09 (0.07±0.03)	0.02-0.04 (0.03±0.01)	0.16-0.19 (0.18±0.01)	0.15-0.17 (0.16±0.005)	0.2-0.21 (0.20±0.006)	0.15-0.19 (0.18±0.04)
Turbidity (NTU)	1.17-2.71 (1.82±0.1)	1.45-2.65 (2.04±0.06)	1.0-2.1 (1.21±0.2)	1.26-2.68 (1.91±0.41)	2.22-4.21 (2.68±0.23)	2.57-4.86 (3.21±0.03)	1.24-4.5 (4.51±0.19)	2.72-5.85 (5.65±0.42)
Dissolved oxygen (mg/l)	6.10-7.4 (7.2±0.31)	5.80-6.50 (6.0±0.15)	6.90-7.70 (7.6±0.21)	5.66-7.25 (6.55±1.31)	6.80-7.60 (7.5±0.65)	6.80-7.20 (7.1±0.3)	5.60-7.30 (6.6±1.35)	5.40-6.20 (5.78±1.05)
Nitrate (mg/l)	0.22-0.27 (0.24±0.05)	0.24-0.30 (0.26±0.02)	0.06-0.16 (0.11±0.03)	0.08-0.17 (0.12±0.02)	0.07-0.17 (0.12±0.03)	0.09-0.19 (0.15±0.05)	0.1-0.25 (0.21±0.01)	0.22-0.25 (0.23±0.07)
Phosphate (mg/l)	0.07-0.15 (0.13±0.01)	0.13-0.19 (0.16±0.03)	0.03-0.10 (0.10±0.005)	0.09-0.14 (0.11±0.02)	0.08-0.14 (0.11±0.01)	0.11-0.13 (0.12±0.01)	0.1-0.18 (0.14±0.02)	0.13-0.17 (0.15±0.02)
Silica (mg/l)	1.20-1.82 (1.54±0.1)	1.50-2.05 (1.65±0.55)	2.12-4.12 (3.16±0.04)	1.84-2.74 (2.34±0.1)	1.97-4.26 (3.01±0.01)	2.46-3.38 (3.28±0.11)	1.78-2.75 (2.26±0.05)	2.87-3.35 (3.18±0.12)

Algal community structure of Waribok stream

Waribok stream is a comparatively clean water body and a picnic spot, located at the outskirts of Tura town. A Total of 78 algal species spreading over 8 classes were recorded from upstream. The upstream was dominated by Bacillariophyceae with 42 species followed by Zygnematophyceae with 17 species, Chlorophyceae with 10 species, Cyanobacteria with 4 species, Euglenophyceae with 2 species and Trebouxiophyceae, Ulvophyceae and Chrysophyceae with 1 species each were recorded. In downstream, a total of 121 algal species spreading over 8 classes were recorded. The downstream was dominated by Bacillariophyceae with 64 species, followed by Zygnematophyceae with 25 species, Chlorophyceae with 17 species, Cyanobacteria with 7 species, Euglenophyceae with 4 species, Trebouxiophyceae with 2 species, Chrysophyceae and Ulvophyceae with 1 species each were recorded (Table 2).

Table 2: List of algal species recorded from upstream and downstream of Waribok

Chlorophyceae	Upstream	Downstream
Ankistrodesmus fusiformis Corda	+	+
Coelastrum astroideum De Notaris	+	+
Gloeocystis major Gerneck ex Lemmermann	-	+
Gloeocystis vesiculosa Nageli	-	+
Golenkinia radiata Chodat	+	+
Microspora crassior (Hansgirg) Hazan	+	+
Microspora tumidula Hazen	-	+
Oedogonium capillare Kutzing ex Hirn	+	-
Oedogonium globosum Nordstedt ex Hirn	+	-
Oedogonium pisanum Wittrock ex Hirn	-	+
Oedogonium sp	-	+
Pediastrum duplex Meyen	+	+
Pediastrum integrum Nageli	-	+
Pediastrum simplex Meyen	-	+
Scenedesmus obliquus (Turpin) Kutzing	+	+
Scenedesmus denticulatus Lagerheim	+	+
Scenedesmus opoliensis P.G. Richter	-	+
Scenedesmus quadricauda (Turpin) Brebisson	+	+
Scenedesmus serratus (Corda) Bohlin	-	+
Zygnematophyceae		
*Actinotaenium curtum*var. Obtusum (West andG.S.West) Teiling ex Croasdale	+	-
Arthrodesmus octocornis Ehrenberg ex Ralfs	+	+
Closterium acutum Brebisson	-	+
Closterium dianae Ehrenberg ex Ralfs	+	+
Closterium gracile Brebisson ex Ralfs	-	+
Closterium idiosporum West and G.S. West	+	-

Cosmarium contractum O. Kirchner	+	+
Cosmarium pygmaeum W.Archer	-	+
Cosmarium angulosum Brebisson	-	+
Cosmarium connatum Brebisson ex Ralfs	+	+
Cosmarium debaryi W.Archer	+	-
Cosmarium galeritum var. subtumidum Borge	+	+
Cosmarium pachydermum P. Lundell	-	+
Cosmarium quadrum P. Lundell	-	+
Cosmarium Speciosum P. Lundell	+	-
Cosmarium subalatum var. Noncrenatum Kant and P.Gupta	+	+
Cosmarium subcirculare W.B. Turner	-	+
Cosmarium subspeciosum Nordstedt	+	+
Euastrum gayanum De Toni	+	+
Hyalotheca dissiliens Brebisson ex Ralfs	+	+
Mougeotia sp 1	+	+
Mougeotia sp 2	-	+
Pleurotaenium ehrenbergii (Ralfs) De Bary	+	-
Spirogyra crassa (Kutzing) Kutzing	+	+
Spirogyra *elliptica* C.C. Jao	-	+
Spirogyra porticalis (Mueller) Cleve	-	+
Spirogyra pratensis Transeau	-	+
Spirogyra punctiformis Transeau	+	+
Staurastrum anatinum Cooke and Wills	-	+
Staurastrum punctulatum Brebisson	-	+
Bacillariophyceae		
Achnanthes brevipes C. Agardh	+	-
Achnanthes conspicua Ant. Mayer	+	+
Achnanthes exilis Kutzing	-	+
Achnanthes inflata (Kutzing) Grunow	-	+
Achnanthes lanceolata Brebisson ex Ralfs	+	+
Achnanthes minuscule Hust	+	-
Achnanthes minutissimum (Kutzing)	-	+
Achnanthes sp	+	-
Achnanthidium deflexum C.W.Reimer	+	+
Amphora coffeaeformis C. Agardh	+	-
Caloneis bacillum (Grunow) Cleve	-	+
Caloneis silicula Ehrenberg	-	+
Cocconeis placentula Ehrenberg	-	+
Cymbella affinis Kutzing	+	-
Cymbella amphicephala Naegeli	+	-
Cymbella cistula (Ehrenberg) Kirchner	+	-
Cymbella cornuta (Ehrenberg) R.Ross	-	+
Cymbella excisa kutzing	-	+
Cymbella minuta Hilse in Rabenhorst	-	+
Cymbella proxima Reimer	+	+
Cymbella tumida (Brebisson) Van Heurck	+	-
Cymbella turgidula Grunow	-	+
Cymbella ventricosa C.Agardh	-	+
Discostella sp	+	-
Diploneis sp	+	-
Encyonema sp	-	+
Epithemia turgid Ehrenberg Kutzing	+	-
Epithemia sp	+	-
Eunotia major (W.Smith) Rabenhorst	-	+
Eunotia minor (Kutzing) Grunow	+	+
Eunotia sp	-	+

Fragilaria biceps Ehrenberg	+	-
Fragilaria capucina Desmazieres	+	+
Fragilaria crotonensis kitton	-	+
Fragilaria virescens Ralfs	-	+
Frustulia rhomboids (Ehrenberg) De Toni	-	+
Gomphonema gracile Ehrenberg	+	-
Gomphonema lanceolatum Kutzing	+	-
Gomphonema olivaceum(Hornemann)	+	-
Gomphonema parvulum(Kutzing) Kutzing	+	+
Gomphonema sp	-	+
*Gomphonema sphaerophorum*Ehrenberg	+	-
Gomphonema vibrio Ehrenberg	-	+
Gyrosigma acuminatum (Kutzing) Rabenhorst	+	-
Gyrosigma exilis(Grunow) C.W.Reimer	-	+
Gyrosigma scalproides(Rabenhorst) Cleve	-	+
Hantzschia amphioxys(Ehrenberg) Grunow	+	-
Melosira sp	+	-
Melosira varians C.Agardh	-	+
Meridion circulare (Greville) C.Agardh	-	+
Navicula cryptocephala Kuetzing	+	-
Navicula cuspidata (Kutzing) Kutzing	+	-
*Navicula lanceolata*Ehrenberg	-	+
Navicula viridula(Kutzing) Ehrenberg	+	+
*Navicula bacillum*Ehrenberg	+	-
Navicula confervacea(Kutzing) Grunow	+	+
*Navicula gracilis*Ehrenberg	+	+
Navicula oblonga (Kutzing) Kutzing	-	+
*Navicula radiosa*Kutzing	-	+
*Navicula rhyncocephala*Kutzing	+	+
Navicula vulpine Kutzing	-	+
*Nitzschia linearis*W. Smith	+	+
Nitzschia commutata Grunow	-	+
Nitzschia dissipata(Kutzing) Rabenhorst	-	+
Nitzschia intermedia Hantzsch	+	-
Nitzschia palea (Kutzing) W.Smith	-	+
Nitzschia reversa W.Smith	+	-
Pinnularia appendiculata (C.Agard) Schaarchmidt	-	+
Pinnularia mesolepta (Ehrenberg) W.Smith	+	+
Pinnularia cardinalis f. hankensis skvortzov	-	+
Pinnularia divergens W.Smith	-	+
Pinnularia gibba (Ehrenberg) Ehrenberg	-	+
Pinnularia interupta W.Smith	-	+
Pinnularia lata (Brebisson) W.Smith	-	+
*Pinnularia*sp	+	-
Pinnularia viridis(Nitzsch)Ehrenberg	-	+
Planothidium rostratum(ostrup) Lange-Bertalot	-	+
Sellaphora bacillum (Ehrenberg) D.G. Mann	-	+
Stauroneis anceps Ehrenberg	-	+
Stauroneis smithii (Grunow)	-	+
Surirella angusto (Kutzing)	+	-
Surirella apiculata (Wm. Smith)	+	+
Surirella brebissonii Krammer and Lange-Bert	+	+
Surirella elegans Ehrenberg	-	+
Surirella robusta Ehrenberg	-	+
Surirella splendid (Ehrenberg) Kutzing	-	+
Surirella stalagma M.H.Hohn and J Hellerman	-	+

Synedra ulna (Nitzsch) Ehrenberg	-	+
Tabellaria fenestrata (Lyngbye) Kutzing	-	+
Thalassiosira bramaputrae (Ehrenberg) Hakansson and Locker	-	+
Tryblionella sp	-	+
Trebouxiophyceae		
Actinastrum hantzschii Lagerheim	-	+
Chlorella vulgaris Beyerinck (Beijerinck)	+	+
Ulvophyceae		
Ulothrix cylindricum Prescott	+	+
Chrysophyceae		
Mallomonas acaroides Perty, nom.inval.	+	+
Cyanobacteria		
Anabeana constrica (Szafer) Geitler	+	-
Arthrospira sp	+	-
Hapalosiphon sp	-	+
Leptolyngbya boryana (Gomont) Anagnostidis and Komarek	-	+
Lyngbya sp	+	-
Merismopedia punctata Meyer, nom.illeg	-	+
Microcystis sp	-	+
Nostoc sp	-	+
Oscillatoria limosa C.Agardh ex Gomont	+	-
Oscillatoria prince Vaucher ex Gomont	-	+
Oscillatoria sp	-	+
Euglenophyceae		
Euglena sp	-	+
Phacus hamelii Allorge and Lefevre	+	+
Trachelomonas sp	+	+
Trachelomonas volvocina (Ehrenberg) Ehrenberg	-	+

(+) indicate present; (-) indicate absent

Seasonal variations in species richness of different algal groups were observed in both upstream and downstream. In upstream, species richness was high in Bacillariophyceae (35 species) during spring season followed by Zygnematophyceae (15 species) and Chlorophyceae (7 species) during winter season, Cyanobacteria (4 species) during monsoon, Euglenophyceae (2 species) during autumn and monsoon. In downstream, same trend was observed in species richness in major groups. Species richness was high in Bacillariophyceae (38 species) during spring followed by Zygnematophyceae (18 species) and Chlorophyceae (14 species) during winter, Cyanobacteria (5species) and Euglenophyceae (4 species) during monsoon, 2 species of Trebouxiophyceae, 1 species of Ulvophyceae both in winter and spring seasons and 1 species of Chrysophyceae in spring (Figure 1).

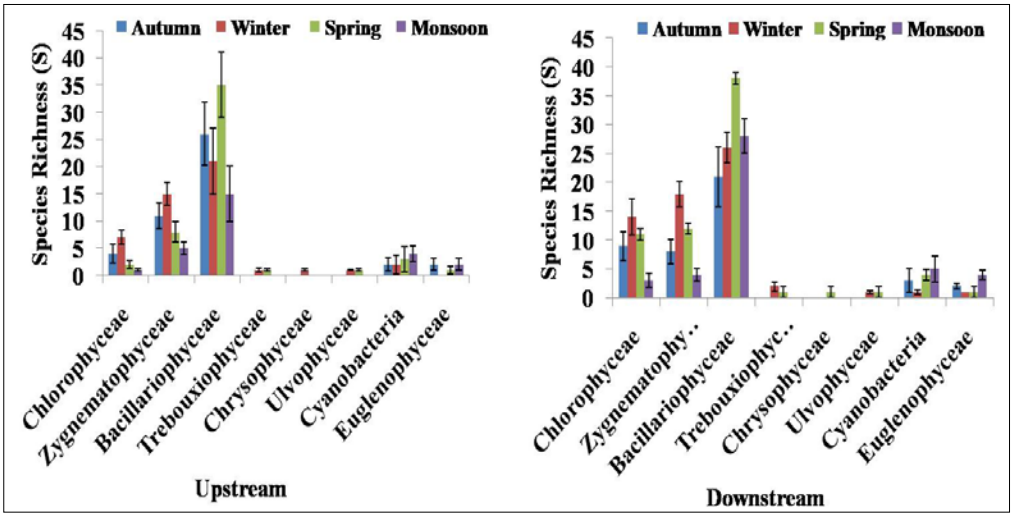


Fig 1: Seasonal variation in Species richness of different algal groups in upstream and downstream of Waribok. Standard deviation represented by Error bars.

Primary Productivity and Chlorophyll a content in phytoplankton

There was significant seasonal variation in the net primary productivity and phytoplankton chlorophyll a content in both the study sites. The maximum primary productivity and phytoplankton chlorophyll a content were observed in downstream during winter season with 1.09 gC/m^3/h and 0.35 mg/l respectively and minimum in upstream with 0.04 gC/m^3/h and 0.018 mg/l respectively during monsoon (Figure. 2).

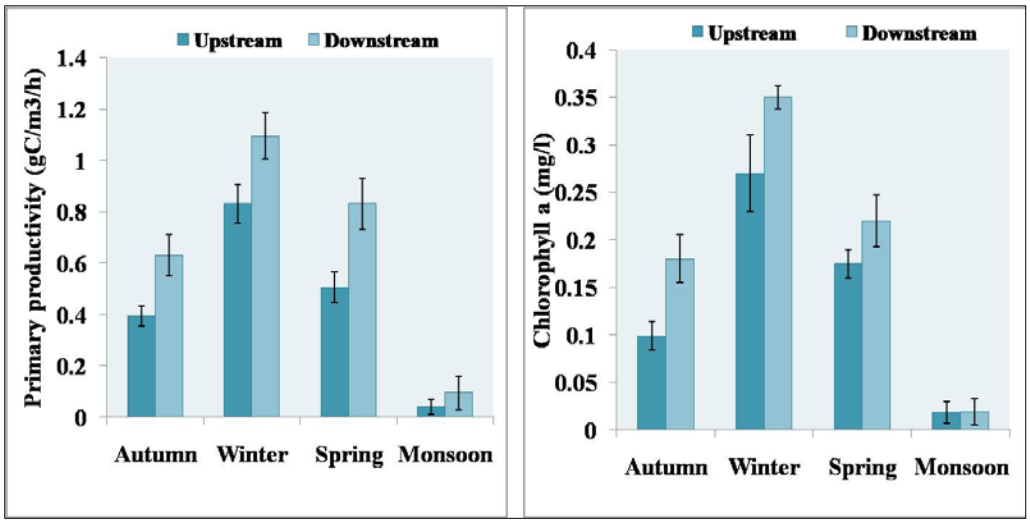
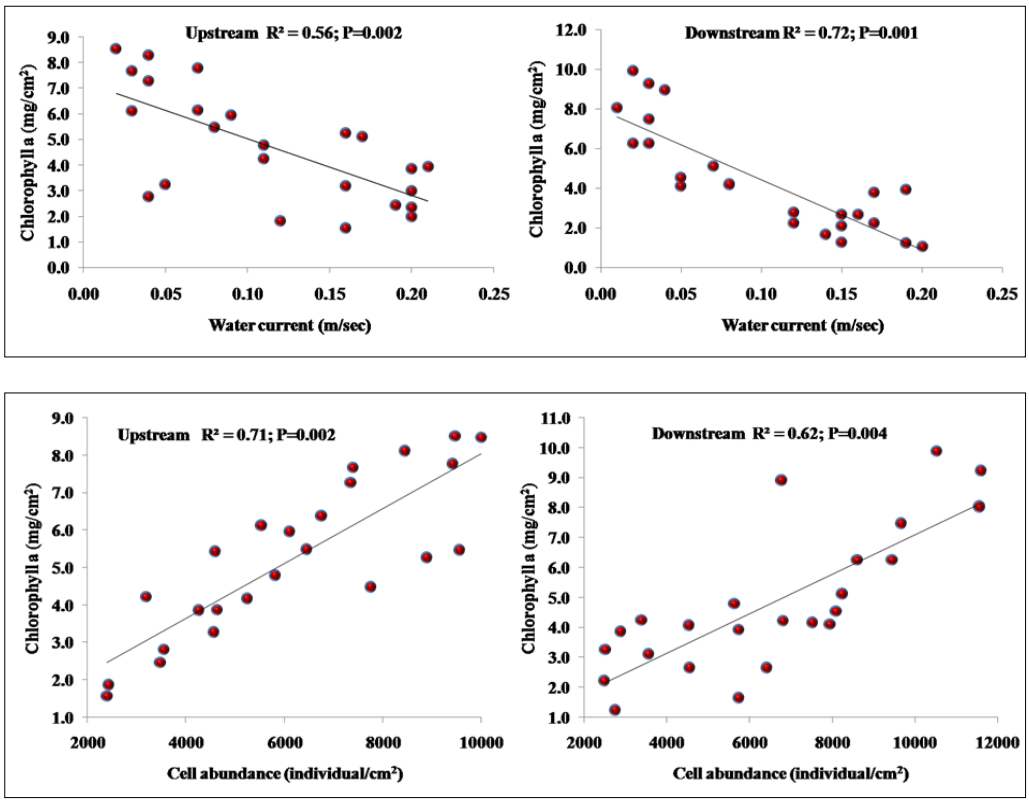


Fig 2: Primary productivity and chlorophyll a content from upstream and downstream of Waribok stream, West Garo Hills (Error bars represent standard deviation).

Linear regression analysis were applied between chlorophyll a content in periphytonic algal biomass with water current, cell abundance and nitrogen to phosphorus ratio (N:P) at 0.5 level, which are known as influential factors controlling productivity. A strong negative correlation was established between chlorophyll a concentration and water current by linear regression in both upstream and downstream (upstream:R^2=0.56; P=0.002; downstream:R^2=0.72; P=0.001). Whereas chlorophyll a concentration were positively correlated with cell abundance in both upstream (R^2= 0.71; P= 0.002) and downstream (R^2=0.62; P=0.004). A positive correlation was established between chlorophyll a concentration with N:P ratio in upstream and downstream (upstream:R^2= 0.51; P=0.03 and downstream R^2=0.64; P=0.006) Figure 3.



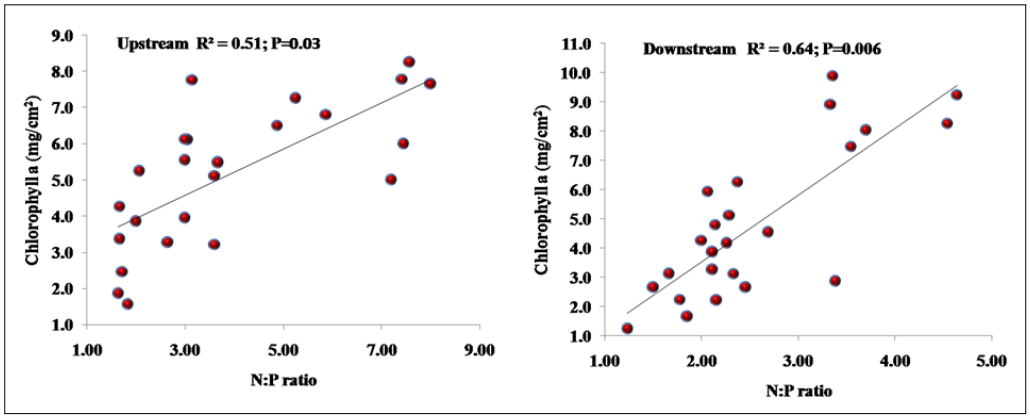


Fig 3: Linear regression of periphytonic chlorophyll a with water current, cell abundance and N:P ratio in upstream and downstream of Waribok, West Garo Hills Meghalaya.

Discussion

The physico-chemical parameters of Waribok stream varied seasonally. Water temperature fluctuated throughout the seasons. Temperature is one of the prime factors that affect aquatic organisms as well as their functions. As expected, water temperature was minimum during winter season and maximum during monsoon season. Similar results were reported in by Manohar, 2018 and Rameshkumar *et al*., 2019 [26, 32]. In both the study sites, water was slightly acidic to alkaline in nature. The slightly alkaline condition during the monsoon could be due to runoff of rain water. Alkaline pH was reported due to eutrophication caused by different anthropogenic activities during monsoon season by many authors (Liu *et al*., 2010; Tian *et al*., 2012 and Zhao *et al*., 2017) [25, 48]. Water current fluctuates with change in the season, maximum water current was recorded during monsoon season in upstream and minimum was recorded during winter season in downstream. Siangbood and Ramanujam, (2014) [35] also reported increased in water current velocity during monsoon in Umtyngngar river. Higher turbidity and lower dissolved oxygen were observed during monsoon especially in downstream. Similar finding was reported by Behar, 1997 [5] where turbidity usually increased during rainfall and resulted in lower dissolved oxygen. Nitrate and phosphate content was maximum in downstream during autumn, the possible reason could be due to the anthropogenic activities in this site. Increased in nutrient (nitrate and phosphate) concentrations have been reported due to excessive pollution caused by anthropogenic activities (Srivastava *et al*., 2018; Halder *et al*.,2019) [41, 18]. Silica concentration was maximum in upstream during spring season, the increase in silica level in upstream could be due to increase in water fraction, rocky-sandy bed and good amount of dissolved oxygen. Silica showed positive correlation with water fractions and dissolved oxygen (Saravanakumar, 2008 and George *et al*., 2012) [34] and negative correlation with pH.

Maximum number of algal species was recorded from downstream of Waribok, the possible reason could be due to low water current and many microhabitats in this site which enable them to colonized and reproduced. The species richness was high in Bacillariophyceae group in both upstream and downstream during spring season, Bacillariophyceae are the element of shallow water bodies and they tend to colonized like brown patches on the sand particles whenever the water level is very low with high temperature before the onset of monsoon. The Zygnematophyceae and Chlorophyceae species richness were high during winter season in both the sites. Stream having low water current, optimum temperature, low turbidity and good transparency support the growth of Zygnematophyceae and Chlorophyceae members. Similar finding were reported by Silva *et al*., 2013; Hall and McCourt, 2015) [36, 19]. Low species richness during monsoon in both the sites could be due to high water current, high turbidity and low dissolved oxygen and high nutrient concentration (Shah *et al*., 2018; Prajapati and Patel, 2019) [38, 30].

In the present study, a distinct seasonal pattern in algal productivity has been observed in Stream (upstream and downstream). Net primary productivity and chlorophyll a were observed maximum in winter and minimum in monsoon. Maximum primary productivity and chlorophyll a in downstream during winter could be because of low water current which enables algae to colonized and reproduced. Similar trend have been reported by many workers (Siangbood and Ramanujam 2014; Knight *et al*., 2015; Singh *et al*., 2018) [35, 21,1]. The decline in productivity during monsoon could be due to dilution of water which adversely affected the phytoplankton assemblages (Kumar and Choudhary, 2007; Barupal and Gehlot, 2014) [4, 23]. Other factors controlling productivity were light, transparency, sediment suspension and nutrients and turbidity; those factors were again controlled by rainfall. Rainfall could accelerate high water current and reduce the algal standing crops. Several limnologists reported the effect of nutrients, light and water velocity as limiting factors for productivity (Miranda *et al*., 2014; Borges *et al*., 2015) [27,8].

The linear regression between periphytonic chlorophyll a concentration and water current velocity showed a negative correlation in both the study sites. Similar trend were also reported by many workers (Pan *et al*., 2009; Breuer *et al*., 2017) [9, 29]. Algal productivity declined drastically due to high water current which dislocated filamentous algae and did not allow phytoplankton to colonize (Breuer *et al*.,2017) [9]. Establishment of positive linear correlation between periphytonic chlorophyll a with cell abundance and N:P ratio in Waribok stream clearly indicated that cell abundance and N:P ratio available in the water bodies enhanced the productivity. Dunck *et al*., (2013) [11] reported positive correlation between chlorophyll a content and nitrogen to phosphorus ratio. Increase in chlorophyll a content indicated a proportional increase in algal density. The N:P ratio

was responsible for increase in biomass. Increase in phytoplankton biomass and chlorophyll a content with increase in total nitrogen to phosphorus ratio was also reported by Filstrup and Downing, (2017) [13] from lake in Midwestern, United state.

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