

RESEARCH ARTICLE

Influence of Stream Characteristics on Diversity and Distribution of Benthic Algae in Gongawwa Ela in Kottawa Rain forest, Galle, Sri Lanka

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Abstract Influence of stream characteristics on diversity and distribution of benthic algae were studied at Gongawwa Ela during the period of September to November in 2016. Four sampling sites were selected and the distance between two sampling sites was 1.5km. Substrate types were categorized by sieve analysis and grain size distribution curves. Principle Component Analysis (PCA) was performed to identify the most important stream characteristics that could potentially influence on the growth of benthic algae. Physicochemical characteristics of water (nitrate, Total Dissolved Solids, temperature, pH, and Dissolved Oxygen) and substrates (pH, phosphate and nitrate) showed significant temporal variations. Conductivity and water velocity levels of the substrate varied significantly among the sampling sites. Species richness of benthic algae (29 genera) showed significantly negative correlations with the level of phosphate content ($R^2=0.9592$, $P<0.05$) and pH levels ($R^2=0.999$, $P<0.05$) of the substrate. Well graded substrate was observed only at the most downstream site (site 3) while other sites showed poorly graded substratum consisting over 90% of sand. The most abundant algal division was *Bacillariophyta* and the abundance of *Flagilaria* sp., *Pinnularia* sp., *Stigeoclonium* sp., and *Pediastrum* sp. showed significant temporal variation. *Pinnularia* sp., *Synedra* sp., *Anabaena* sp. and *Navicula* sp. were possible indicators of the upstream characteristics. Meanwhile, *Cosmarium* sp., *Pinnularia* sp., *Surirella* sp., *Tabellaria* sp., *Synedra* sp., *Closterium* sp. and *Navicula* sp. were possible indicators of the downstream characteristics. The PCA showed that the most important stream characteristics were DO, conductivity, Total Suspended Solids, water pH, nitrate in water and water discharge, while conductivity, nitrate, phosphate, % organic matter, pH, and % canopy cover were the types of substrate characteristics.

Keywords: Rainforest, stream characteristics, benthic algae, water quality, water discharge

Introduction

Streams in head waters are important to feed rivers due to its flow characteristics. Stream water flow depends on the incline and smoothness of the substrate, and cross sectional area of the stream. Streams are very sensitive ecosystems and the variation of stream characteristics and their impacts on biological composition is explained based on different ecological principles such as the river continuum concept (Vannote et al., 1980). The water flow is a major factor for determining the physical habitats such as cascades, riffles and pools in a

stream. Also, the stability of the substrate of the stream and the interactions between the water flow and the local geology are important to explain how habitat influences on the distribution and abundance of algae (Bunn & Arthington, 2002). The variations of streams morphology, biology and ecology from upper part of the stream to downstream also depend on the land use of streams catchment.

The benthic algae in streams occur as epiphytic or periphytic types and their diversity and distribution change with the nutrients, organic matter levels and the intensity of light. When the light intensity and nutrients are higher filamentous algae may grow enormously as periphyton communities. Some

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attached algae such as Pennate diatoms which are loosely retained with gelatinous bio films or are held within the tangled filamentous threads of such mature periphyton communities (Bellinger & Sige, 2010). When the temperature and light levels are higher, the blue green algae that grow attaching to the bottom sediment, rocks or submerged plants are become dominant in calm areas of the streams (Oram, 2014).

The distribution of benthic algae in streams can be influenced by the size, surface structure and chemistry of the substratum (Whitton, 1975). The alkalinity or acidity of water highly effects on the growth and reproduction of algae and therefore any deviation of water chemistry; water temperature and pH variations may cause problems in reproduction, ion exchange and viability of the aquatic organisms (Stoyan & Hristov, 2011). Total Dissolved Solids (TDS) provide nutrients or contaminants such as organic pollutants and toxic metals for the algal growth (Weber-Scannell & Duffy, 2007). However, the amount of Total Suspended Solids (TSS) attenuates light and reduces the transparency of water which is a negative factor for algal growth. According to Dodds & Welch (2000), factors such as the geological variation, addition of toxic compounds, global changes, introduced species, watershed development and functions of other biotic and abiotic factors affect the variation of algal biomass.

In a stream, the abundance, biomass and the growth of particular benthic algae are considered as bio-indicators (Dokulil, 2003). A good indicator species has a narrow ecological range, rapid response to environmental change, well defined taxonomy, reliable identification and a wide geographic distribution (Bellinger & Sige, 2010). The response

to the natural or anthropogenic impacts can be early observed as specific stress symptoms in algae and therefore those are bio-sensors for environmental changes. Therefore, the land use of the catchment is predictable using benthic algal indicators of a stream which is important for the protection of sensitive ecosystems (Bellinger et al., 2010). Such types of studies are scanty in Sri Lanka and hence the knowledge is limited which would be important for the conservation and management aspects of stream ecosystems of Sri Lanka. The present study was focused to investigate the influence of variations of stream characteristics on the distribution of benthic algae at selected sites from upstream to downstream of the Gongawwa Ela in Kottawa Rainforest.

Methodology

Site description

Kottawa forest reserve (6° 5'40.54"N and 80°19'26.75"E) is an isolated patch of low country rainforest located at Yakkalamulla divisional secretariat in Galle, Sri Lanka. Gongawwa Ela (tributary of Polathumodara River) which is located inside the Kottawa rainforest was selected for the current study (Figure 01). Two sites from the upper most part of the stream (site1, site 2) and two sites (site 3, site 4) from the downstream were studied on monthly basis during the period of September to November 2016. Stream bank morphology and riparian vegetation were observed and were mapped using GPS (etrex 20X GARMIN) readings. The catchment of the selected part of the stream was delineated on the site and it was used to identify the major land use types in the area.

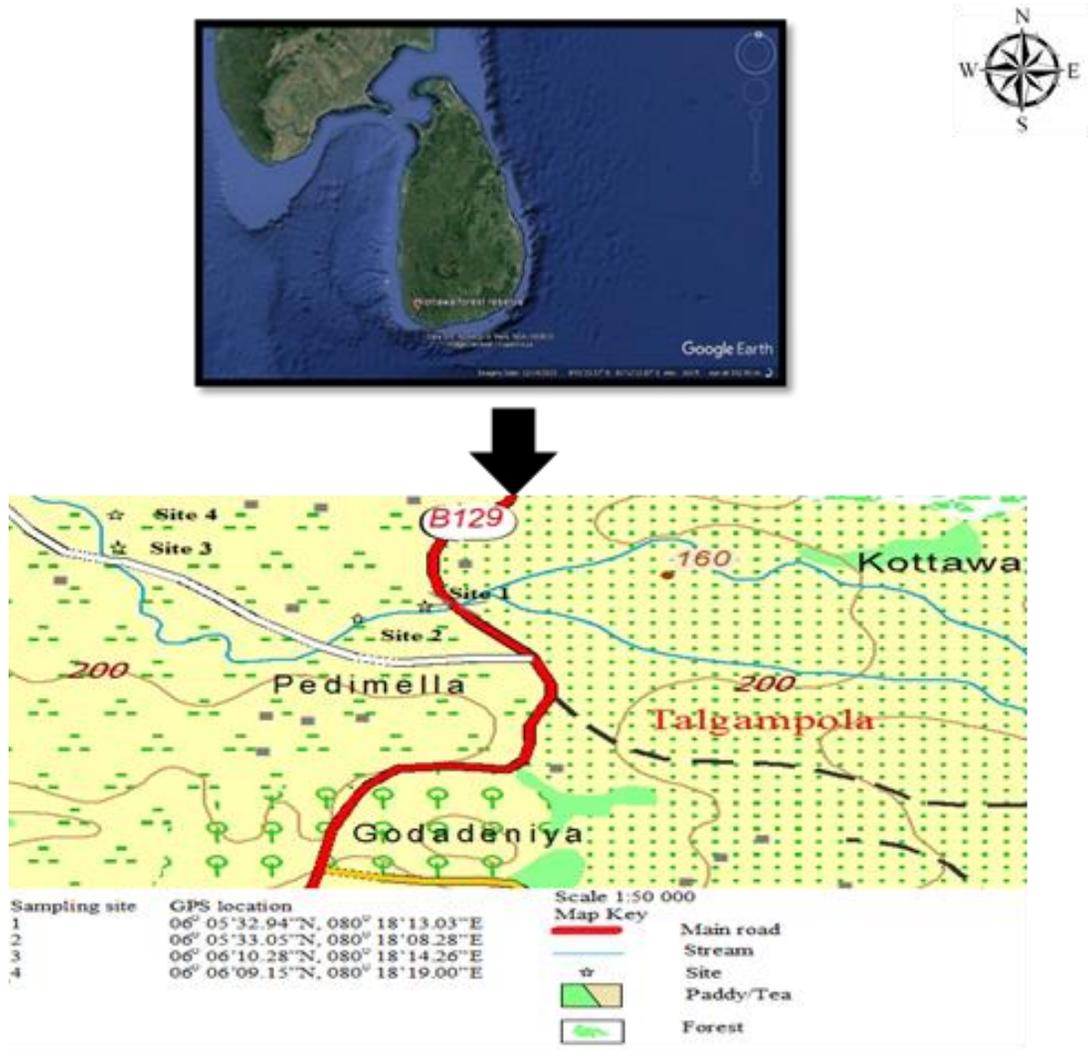


Figure 01: Locations of the four sampling sites

Analysis of water quality

Water quality parameters (water temperature, pH, conductivity, surface light intensity, turbidity, nitrate and phosphate) were analyzed in three replicates of water samples at each site using standard instruments (Table 01) and following the standard methods (APHA, 1999). Sodium salicylate method was used

to determine the nitrate levels both in water and the substrate as described by (Merck, 1974) and the absorbance was measured at 440nm (HACH, DR3900). Ammonium molybdate method was used to determine the dissolved phosphorous levels both in water and the substrate (APHA, 1999).

Table 01: Instruments used for water quality analysis

Parameter	Units	Instrument
Temperature	°C	Water Quality Meter(YSI Model 85)
Conductivity	μS/cm	Water Quality Meter(YSI Model 85)
pH		pH meter (EUTECH instrument)
GPS Location		GPS (etrex 20 X GARMIN)
Light intensity	Lux	Lux meter (LX-101)
Velocity	m/s	Velocity meter (KENEK VP 1000)

Determination of stream characteristics

The following method was performed to determine the percentage of different grain sizes recorded in the substrate samples. Following the substrate classification method (ASTM D422- Standard Test Method for Particle-Size Analysis of Substrate) the

mechanical sieve set with different pore sizes was used to determine the distribution of coarser, larger-sized particles and finer particles of the substrate samples. The % value of a given particle type (Table 02) was calculated using the following equation.

$$\% \text{ value of a given particle type} = \frac{\text{weight of the given particle}}{\text{Total weight of the sample}} * 100\%$$

Table 02: Classification of the particle sizes of substrate

Particle size	Class	Texture
< 63 μm	Mud	Smooth & sticky
63 μm - 0.25 mm	Fine sand	Smooth with some roughness & not sticky
0.25 mm - 0.5 mm	Sand	Rough grainy texture
0.5 mm-1 mm	Coarse sand	Coarse, particles loose
1mm <	Gravel	Very coarse , Small stones

The particle size distribution curves presented by semi-logarithmic graphs were plotted using the percentage of passing via each sieve of the mechanical sieve set. Three basic parameters of

Effective Size (D10), Uniformity Coefficient (Cu), and Coefficient of Gradation (Cc) were determined using the particle size distribution curves (Fig 02).

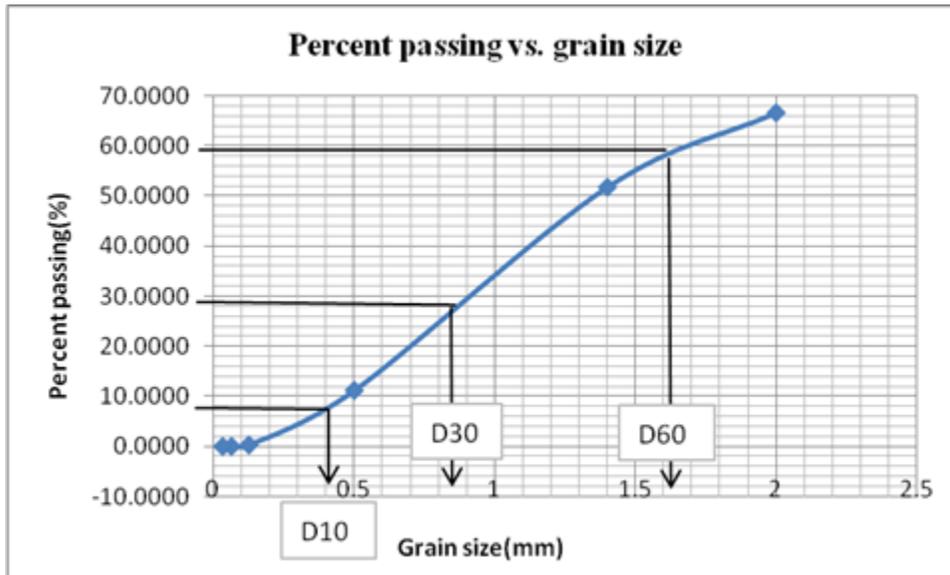


Figure02: Particle size distribution curve

$$Cu = D60/D10$$

$$Cc = D20 / (D60 \times D10)$$

Criteria for grading substrate (Holtz & Kovacs, 1981)

for gravel to be well graded as,

$$Cu > 4 \& 1 < Cc < 3$$

For sand to be well graded,

$$Cu >= 6 \& 1 < Cc < 3$$

Water velocity and total water discharge

In order to determine the stream discharge, the mid-section method was used (Huber & Bedient, 2002). Similar length portions were marked on a transect which was laid across the stream and the flow velocity was measured using velocity meter at half of

Discharge per unit time (m³/S) = $W1 \times D1 \times V$

Benthic algae sampling and analysis

A transect was plotted across the two banks and the algae sampling was done by using a quadrat (0.25 m²) (TCEQ, 2014). Benthic algae were sampled carefully from hard substrates using a scraper and from soft substrates using a smooth brush and the samples were preserved in Lugol’s iodine (1-2 %) (Hötzel & Croome, 1999) and were transported to the

$$N = \frac{n \times f}{A}$$

Where,

N = Abundance of each species

The diversity of algae was calculated using different indices; Shannon-Weiner diversity, Pielou’s evenness

$$H' = - \sum Pi \ln Pi$$

H’: Shannon index

Pi: Relative abundance of ith species

$$J' = \frac{H'}{H'_{max}}$$

Determination of canopy cover

Light intensity of 25 points of each site was measured by Lux meter (LX-101). Then highest lux meter readings were removed and the mean value of light readings (I_{mean}) was obtained. Then the values that are higher than $I_{mean} \times 3$ were excluded. This procedure was repeated until getting no more values for $I_{mean} \times 3$.

Canopy cover(n)

$$= \frac{\text{Remaining number of readings} \times 100\%}{\text{Total number of readings}}$$

Forest canopy cover was estimated by,

the total depth and total water discharge at each site was determined using a transect method at different depth of 1m distance on the transect. Water discharge was calculated according to the following equation at each portions on the transect (1m) and the total discharge was calculated using those values.

W1: length of the portion
 D1: depth at the portion
 V: water velocity at the portion

laboratory. The samples were identified using identification keys (Bellinger & Sigee, 2010; Lund & Lund, 1995; Presscott, 1954; Vuuren et al., 2005; Entwisle et al., 1997), enumerated using sedgewick rafter cell and the abundance was presented as number of cells or colonies per unit area. The abundance of each species was calculated using the equation given below.

n = Average number of algal cells counted in 1mL of sample
 f = Field conversion factor
 A = Area of the quadrat (m²)

index and Menhinicks’ species richness index (Shannon, 1948).

J’: Pielou’s evenness index
 H’max: minimum value of H’ (lnS)

$$D = S\sqrt{N}$$

D: Menhnick’s richness index
 S: Number of species present in sample
 N: Total number of individual organisms in the sample

Statistical Analysis

Spatial variation of different parameters were analyzed by using one way ANOVA tests and the correlations were analyzed between the biotic (species diversity, species richness) and the environmental factors. Principle Component Analysis was done to determine the most important factors which can be used for explaining the site specific characteristics of the stream.

Results and Discussion

Water and substrate quality

Table 03 and 04 give the mean values of water quality parameters and substrate quality at each site respectively. The highest values of conductivity, phosphate concentration, and TSS were observed at the most downstream site. One way ANOVA showed that there was no significant spatial variation of the water quality parameters except for conductivity which also showed spatial variations in the substrate. However, there were significant temporal variations of water temperature, pH, nitrate, DO, TDS, substrate temperature, substrate pH, phosphate, nitrate and organic matter in the substrate during the study period. The pH level of water was ranged from 6 to 7 which is favorable for algal growth. According to Alexander, (1997), green algae were dominated in acidic substrate while the diatoms and the blue green algae were less frequent in acidic substrate. The observed water pH range is suitable for the growth of oligotrophic algal species because the eutrophic species are growing at water pH above 9 (Moss, 1973). Lund & Lund (1995) reported that nitrate and phosphate are the two most important elements which can effect on the growth of benthic algae. In the

present study, highest abundance of algae (57330 ± 11934 individuals/m²) was observed with the highest concentration of nitrate in the substrate (2.60 ± 0.7 mg/L). Carrick & Lowe, (1989) also reported that high biomass of green algae and diatoms at the water enriched with nitrate. However, the relationship between the algal species richness and phosphate levels in substrates was significantly negative ($R^2=0.9592$, $P<0.05$) (Figure 03). After heavy rainfall in November, a comparative decline of substrate nitrate ($P<0.05$: One way ANOVA) and substrate phosphate were observed at each site except at the site 3 that located at downstream. Tea estates and home gardens were located at some places of the stream catchment and the agricultural runoff in the area may have enriched the phosphate and nitrate levels in the substrate. Oram, (2014) reported that phosphate in water can precipitate as iron phosphate or can be stored in partially decomposed organic matter in substrate and the latter process is more efficient at the neutral water pH (Busman et al., 2009). The phosphate and nitrate concentrations in substrate were statistically identified in PCA as important parameters for the changes of density and diversity of benthic algae in the stream.

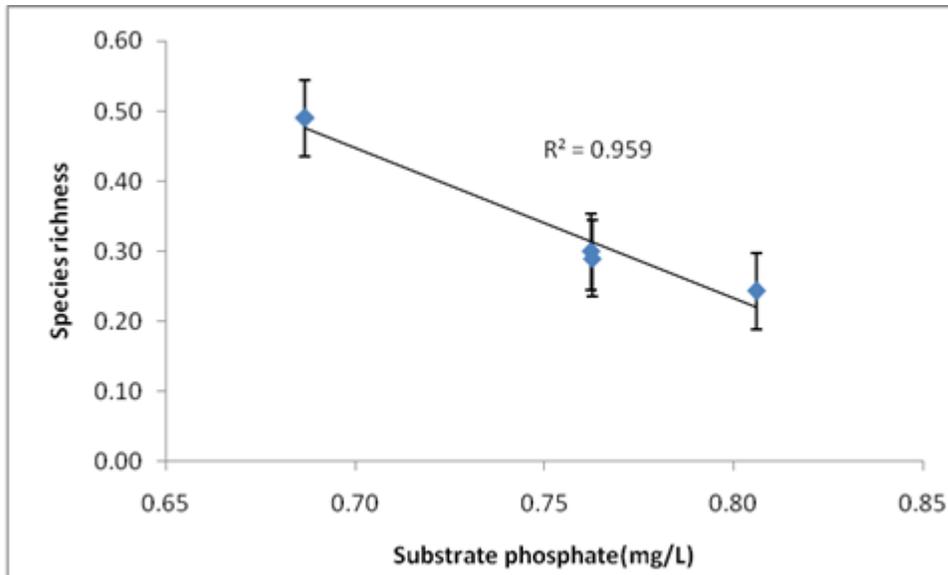


Figure 03: Correlation between substrate phosphate and species richness

Stream characteristics

Table 05 gives the percentage of retained on the mechanical sieve set at the four sites. The Figure 04 shows grain size distribution curves for the sites and the Table 06 gives the coefficient values at the sites.

The values for D60, D30 and D10 are shown in the Figure 04 for the sampling sites. The substrate consisted mostly with sand at all sites (>98%) and well graded substrate was observed ($C_c=1.2$, $C_u=6.67$) only at the site 3 which can be the reason for the highest species diversity and species richness

observed especially at the rainy month. The organic matter content in the substrate did not vary significantly between the sampling sites ($P>0.05$: one way ANOVA) however; it was statistically identified as an important parameter in the stream characteristics (PCA). McIntire, (1968) explained a relationship between the algal communities and the organic matter content where the diatoms were dominated at low organic matter levels while blue green algae, chlorophyte and xanthophytes were abundant at high organic matter contents. The dominant algal group in the present study was diatoms while the chlorophytes were dominant with high organic matter content in the substrate. Moonsin et al. (2013) have observed high abundance of

benthic algae in the period of late rainy season to early dry season in Mekong River passing through Ubon Ratchathani Province, Thailand. However, in the present study, benthic diatoms were abundant in early rainy season (October) and in the dry season (September) nevertheless the Shannon wiener index (1.92 ± 0.49) and species richness (25) were highest in the rainy period. Even though, the substrate conductivity varied significantly among the sites in the stream ($P<0.05$, one way ANOVA) the substrate conductivity at the sites were relatively lower due to the high composition of sand in the substrate. Grisso et al. (2009) suggested that, conductivity correlates strongly with the particle size and the texture of substrate.

Table 03: Mean values of water quality parameters of the three months (Mean±SD).

Parameter	Site 1	Site 2	Site 3	Site 4
pH	7.07±0.57	7.2±0.35	7.58±0.43	7.29±0.29
Conductivity(µS)	247.76±78.7	254.03±86.3	213.66±46.0	327.46±106.6
Temperature(°C)	28.6±0.85	28.8±1.2	28.2±1.1	28.8±1.2
Nitrate (mg/L)	0.687±0.37	0.806±0.34	0.882±0.42	0.763±0.33
Phosphate (mg/L)	0.036±0.667	0.04±0.149	0.029±0.112	0.073±0.133
DO(mg/L)	5.85±3.08	6.05±2.56	8.4±2.63	7.66±2.12
TSS(mg/L)	0.014±0.003	0.016±0.004	0.015±0.004	0.023±0.012
TDS(mg/L)	1.007±0.97	0.658±0.57	1.029±0.93	1.008±0.96

Table 04: Mean values of substrate quality parameters at the sites (Mean±SD).

Parameters	Site 1	Site 2	Site 3	Site 4
pH	6.82±0.42	1.135±1.05	1.107±1.11	1.199±1.13
Conductivity(µS)	19.33±1.15	18.00±2.00	8.33±3.06	15.67±5.86
Phosphate (mg/L)	0.968±1.06	1.135±1.05	1.107±1.11	1.199±1.13
Nitrate (mg/L)	1.602±1.01	1.681±1.33	0.947±0.62	1.63±1.53
Organic matter (%)	1.88±0.266	2.68±0.078	2.97±0.355	2.92±0.655

Table 05: The sieve size and percentage passing of the substrate

Sieve size(mm)	Site 1(%)	Site 2(%)	Site 3(%)	Site 4(%)
2	77.52	68.05	59.33	61.85
1.4	63.24	50.38	47.69	44.79
0.5	17.45	12.65	17.65	9.46
0.125	0.58	0.41	1.64	0.28
0.063	0.09	0.05	1.12	0.09
0.032	0.00	0.00	0.64	0.00

Table 06: Coefficient values and the classification of the substrate

Site	C _U	C _C	Grading of sand
1	3.71	1.24	Poorly graded
2	3.4	0.95	Poorly graded
3	6.67	1.20	Well graded
4	3.9	1.03	Poorly graded

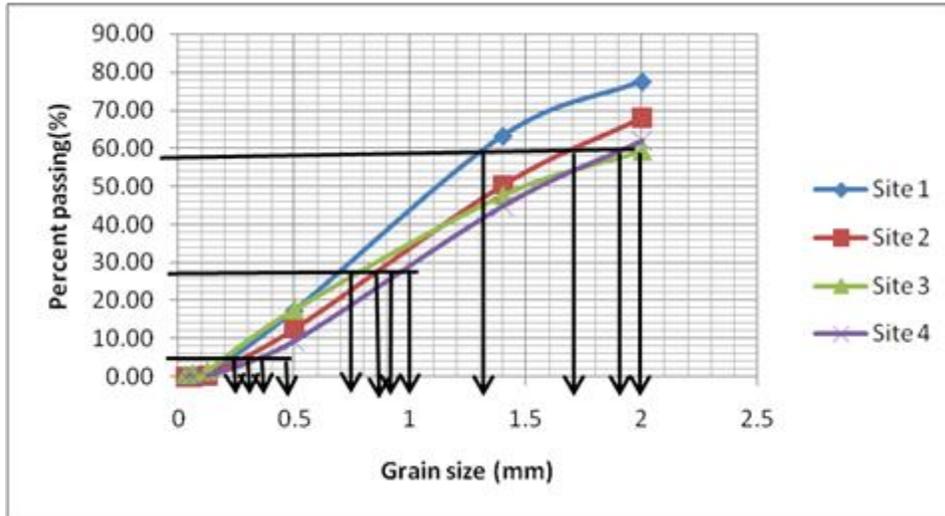


Figure 04: The semi logarithmic graph for percentage of passing vs. grain size at the sites

Water velocity and discharge

The monthly data for water velocity and discharge at the sites are given in the Table 07. The highest stream velocity and water discharge were observed at the site 3 (downstream). The oneway ANOVA explained significant difference ($P < 0.05$) of water velocity among sites. The water velocity was high at the most down part of the stream due to the elevation difference of the area and it was one of the

statistically important parameters in the stream. Therefore, relatively low abundance and high species diversity of benthic algae was observed at the downstream sites 3 and 4. The lowest velocity of the stream was recorded in October which caused low removal of attached diatoms. Allan & Castill, (1999) suggested that the flood condition is creating unstable nutrient supply resulting favorable conditions for the diatoms.

Table 07: Mean velocity and discharge at the sites

Site	September		October		November	
	Velocity (m/s)	Discharge (m ³ /s)	Velocity (m/s)	Discharge (m ³ /s)	Velocity (m/s)	Discharge (m ³ /s)
1	0.068±0.06	0.0984	0.0295±0.04	0.0133	0.078±0.02	0.1654
2	0.055±0.01	0.0867	0.004±0.01	0.0022	0.2517±0.10	0.3995
3	0.3275±0.37	0.4975	0.294±0.04	0.0529	0.611±0.20	0.2475
4	0.1112±0.07	0.2829	0.0255±0.01	0.1031	0.3253±0.19	1.0801

Benthic algae diversity and distribution

Twenty nine algal genera belonging to Divisions Bacillariophyta, Chlorophyta, Cyanophyta, Xanthophyta and Rhodophyta (Table 08) were identified. The most abundant benthic algal division was Bacillariophyta (18 diatom genera/species). Among those genera the common diatoms were *Flagilaria* sp., *Synedra* sp., *Aulacoseira* sp., *Gomphonema* sp., *Navicula* sp. and *Nitzchia* sp. Three blue green algae were recorded as *Anabaena* sp., *Oscillatoria* sp. and *Lyngbia* sp. Among them, *Anabaena* sp. and *Oscillatoria* sp. were highly abundant. Seven genera

of green algae were recorded as *Spyrogyra* sp., *Stigeoclonium* sp., *Chaetophora* sp., *Closterim* sp., *Cylindrocystis* sp., *Cosmarium* sp. and *Pediastrum* sp. where *Stigeoclonium* sp. and *Chaetophora* sp. were common. One genus from Rhodophyta as *Chroodactylon* sp. and one genus from Xanthophyta as *Vaucheria* sp. were recorded in the stream. *Flagilaria* sp., *Synedra* sp., *Aulacoseira* sp., *Gomphonema* sp., *Navicula* sp. and *Nitzchia* sp. were the most abundant diatoms at all the four sites in the stream which could be considered as possible bio-indicators in the Gongawwa Ela. The most upstream sites represented by *Pinnularia* sp., *Synedra* sp., *Anabaena* sp. and *Navicula* sp.. The species recorded

from the most downstream sites were *Cosmarium* sp., *Pinnularia* sp., *Surirella* sp., *Navicula* sp., *Tabellaria* sp., *Syendra* sp., *Closterium* sp., *Flagilaria* sp., *Nitzschia* sp., *Gomphonema* sp. and *Aulacoseira* sp.. Akinyemi et al. (2007) have recorded *Pinnularia* sp. as a good bio-indicator for water pollution and this alga was observed at site 1, 3 and 4 in the present study. *Cosmarium* sp. which was recorded from most downstream (site 3 and site 4) is resistant to the increasing of stream velocity and nutrient depletion. The highest diversity of desmids has been observed in summer months when pH, conductivity and total hardness were low (Stamenković & Cvijan, 2009). Also, desmids have been used for assessing the water quality of freshwater resources (Ngearnpat & Peerapornpisal, 2007). *Anabaena* sp. was recorded only from site 2 located in the upstream. According to Douterelo et al. (2004), the community composition of cyanobacteria changes with water quality and therefore they can be used for environmental studies in riverine ecosystems. *Surirella* sp. which is resistant to water flow and water pollution (Hill et al., 2001) was found only from the site 3 (downstream) in which the substratum was well graded. *Tabellaria* sp. and *Gomphonema* sp. have been assigned as indicators for moderate health in the Coopers Creek catchment of Australia and those algae were recorded during the current study only at the most downstream site. Some genera of benthic algae were found only in one sampling site and those could be considered as possible bio-indicators of the stream; *Vaucheria* sp. and *Chroodactylon* sp. were recorded only in dry period from the upstream site, *Cylindrocystis* sp. was

recorded only in September from the upstream site. The highest relative abundance of *Flagilaria* sp. was found from the sites 2, 3 and 4 ($P < 0.05$: One way ANOVA) at dry the month where the nutrient concentrations were increased. *Spirogyra* sp. was observed both in wet (September) and dry (November) months. According to Allan & Castill, (1999), the dry season with low velocities is more favorable for the colonization and growth of *Spirogyra* sp.. The maximum abundance of filamentous algae was recorded in November just after heavy rainfall and high discharge at the downstream (site 4).

Benthic algae abundance was not varied significantly among the four sampling sites ($P > 0.05$: one way ANOVA). However, the abundances of *Flagilaria* sp., *Pinnularia* sp., *Stigeoclonium* sp. and *Pediastrum* sp. showed significant monthly variations. Mean abundance (individuals/m²) of *Flagilaria* sp., *Pinnularia* sp. and *Pediastrum* sp. showed their highest values (5548±3487, 971±770 and 13±10 respectively) in October. The mean abundance of *Stigeoclonium* sp. was highest in November (43±22 individuals/m²). Shannon Weiner Diversity index value, evenness and dominance for each month at each site are given in the Table 09. The highest diversity index value of 2.45 was observed at a downstream site (site 03) with the most alkaline water pH (≥ 8.00) and on the well graded substrate during the rainy period in November and the lowest index value 1.23 was recorded at the upstream site (site 2) during the dry period in October.

Table 08: The mean abundance (number of individuals/m²) of algal groups at the sampling sites during the study period.

Month	Site	1	2	3	4
September	Division				
	Bacillariophyta	7536±1042	1648±157	1240±149	1504±241
	Chlorophyta	108±23	132±40	1676±625	8±2
	Cyanophyta	8±0	56±18	86±0	172±0
	Xanthophyta	28±0	0±0	0±0	0±0
October	Rhodophyta	4±0	0±0	0±0	0±0
	Bacillariophyta	680±45	7872±1232	25336±2634	22768±2305
	Chlorophyta	4±2	24±9	24±6	184±25
	Cyanophyta	38±18	76±26	88±30	236±98
	Xanthophyta	0±0	0±0	0±0	0±0
November	Bacillariophyta	300±21	1612±251	804±54	400±32
	Chlorophyta	64±18	328±97	72±25	1708±618
	Cyanophyta	4±2	56±32	780±350	80±46
	Xanthophyta	0±0	0±0	0±0	0±0

Table 9: Diversity index values at each site

Period	Site	Shannon diversity	Evenness	Dominance	Species richness
September	1	1.31	0.45	0.55	0.18
	2	2.04	0.69	0.31	0.35
	3	1.39	0.47	0.53	0.24
	4	1.41	0.48	0.52	0.41
October	1	2.21	0.7	0.3	0.51
	2	1.23	0.39	0.61	0.13
	3	1.79	0.57	0.43	0.11
	4	1.96	0.62	0.38	0.13
November	1	2.36	0.73	0.27	0.78
	2	1.55	0.48	0.52	0.25
	3	2.45	0.76	0.24	0.55
	4	1.45	0.45	0.55	0.33

Canopy cover

The canopy covers from upstream to downstream of the site 1, 2, 3, and 4 were 96±0.0%, 94±2.83%, 92±5.66% and 86±8.49% respectively. Canopy cover was relatively higher at the upstream sites and lowest at downstream sites.

Principle Component Analysis

The percentage variances represented by the component 1, 2 and 3 were 47% and 34% and 19% respectively. The factor values for different

parameters in the two components are tabulated (Table 10). Substrate conductivity, water pH, substrate nitrate, organic matter, nitrate in water and substrate pH highly contributed to the component 1 and those can be used to explain the stream characteristics on algae distribution. Similarly, the water discharge, water conductivity, substrate phosphate, TSS and canopy cover (%) highly contributed to the component 2 and those also can be used to explain the stream characteristics on algal growth.

Table 10: Factor values for different parameters at the two components

Parameter	Component1	Component 2
Discharge	0.148	0.975
Water conductivity	-0.366	0.892
Substrate conductivity	-0.979	-0.240
DO	0.891	0.398
Water pH	0.996	0.820
Substrate phosphate	0.449	0.843
Nitrate in water	0.936	0.029
TDS	0.232	0.088
Temperature	-0.522	-0.688
TSS	-0.026	0.996
Substrate pH	-0.328	0.652
Velocity	0.970	-0.56
Substrate nitrate	-0.879	0.295
Phosphate in water	-0.728	-0.558
BOD	0.310	-0.497
Organic matter	0.800	0.597
Canopy cover	-0.335	-0.953

Conclusions

Water pH, conductivity, concentrations of nitrate and phosphate were the parameters that mostly influenced on the stream characteristics of Gongawwa Ela. Discharge and the velocity of water and some of the substrate characteristics such as nitrate, phosphate and organic matter content were identified as important factors for the variation of diversity and distribution of benthic algae. Also, high diversity and species richness of algae was observed at the downstream sites having an alkaline water pH and well graded substrate. Diatoms (Bacillariophyta) were the most dominant benthic algae in the stream

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and they were mostly present at low organic matter content whilst Chlorophytes were dominant at high organic matter contents. High abundance of benthic algae was observed at high nitrate and phosphate in the substrate. *Aulacoseira* sp., *Flagilaria* sp., *Tabellaria* sp. and *Nitzschia* sp. were the most abundant algae in the stream and can be considered as possible bio-indicators when observed stream characteristics. However, identification of indicator benthic algae for different land use patterns in stream catchments is recommended to study lengthier as an important assessment tool of river systems in Sri Lanka.

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