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Phytoplankton community structure and physico-chemical characteristics of streams flowing through an agro- plantation complex in Tiko, Cameroon

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Large scale rubber, oil palm and banana plantations have replaced pristine coastal ecosystems in Tiko, Cameroon, through which freshwater flows. Agrochemical inputs into aquatic systems have the potential to influence phytoplankton community structure through adjustment of physico-chemical characteristics of water. Since plantation establishment in Tiko, Cameroon, no studies on the impacts of the agro-chemicals used on the aquatic ecosystems have been carried out. Phytoplankton community structure was assessed to evaluate current status and existing physico-chemical conditions. Three streams flowing through the Tiko plantations were selected to evaluate these effects. Two sets of water samples were collected (10 cm below the surface) at each sampling point in triplicates for nutrient and phytoplankton analyses. Nitrate, bicarbonate, zinc, iron and turbidity were found to exceed the WHO and EPA water quality standards. Eighty (80) species of phytoplankton belonging to 10 divisions were recorded during the study. The division with the highest species abundance was Bacillariophyta (31 species) followed by Chlorophyta (21 species) and the most abundant species recorded was *Microcystisaeruginosa* followed by *Chlorella* sp.Phytoplankton richness and abundance were higher in streams that had higher concentrations of nitrates and phosphates. These happened to be flowing through plantations in which agrochemicals use and human activities were highest. Of the 80 species recorded, 27 were indicators of eutrophication. The saprobic index ranged from 0.19 - 1.00 indicating that the streams were eutrophic. The results are significant for better management and monitoring of these ecosystems.

Key words: Phytoplankton, community structure, nutrients, eutrophication, Tiko.

INTRODUCTION

Phytoplankton is an important primary producer and the base of the food chain in aquatic ecosystems. It is highly sensitive to even slight fluctuations in water quality. Maximum phytoplankton abundance is obtained when the physico-chemical factors are at optimum level; even slight disruptions result in disequilibrium of community structure and absence of some species from the system (Fonge et al., 2012). As a result, species composition of phytoplankton community is an efficient bio-indicator for water quality (Celekli and Kulkoyluoglu, 2006). The

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monitoring of phytoplankton is of great importance in the aquatic ecosystems because monitoring the ecosystem based solely on physico-chemical analysis is sometimes insufficient, while the phytoplankton composition of a water system reflects both the current and previous conditions of the water (Gharib et al., 2011). In the tropics, a potential source of inputs to aquatic ecosystems that can alter biodiversity and environmental quality is plantation agriculture (Hartemink, 2005; Brockerhoff et al., 2008); it increases soil erosion, decreases fertility and plays a major role in environmental pollution including water pollution. Plantation crops are grown with intensive use of fertilizers which when leached or drifted into water systems favour algal- and especially phytoplankton growth (Astorga, 1996; Calderon and Rola, 2003; Atanga, 2006). Depending on the quantity of inputs and the climate, this enhanced phytoplankton growth could attain bloom concentrations with significant implications on the water quality.

In Cameroon, since the establishment of plantations that were subsequently transferred to the Cameroon Development Corporation (CDC), very little research (Atanga, 2006; Maimo and Woaupi, 2007) has been done on the possible threats posed by these schemes to the environment. In addition, the Cameroon coastline is rich in biodiversity, and inland waterways contribute significantly to riparian productivity as well as breeding grounds for most marine fish. Phytoplankton constitutes major feed for breeding fish and fry. The Bacillariophyta (diatoms), Chlorophyta (green algae) and Cyanophyta (blue green algae) are three major groups of algae in these freshwater ecosystems. Water quality or nutrient changes will affect the ecological distribution of these algae (Fonge et al., 2012), and this in turn can be used as an indication of the water quality of the streams. The present study thus assesses the phytoplankton community structure and physico-chemical characteristics of water in streams flowing through plantations that make use of large quantities of agrochemicals in Tiko, Cameroon.

MATERIALS AND METHODS

Description of study site

The research was carried out in Tiko, Fako Division of the Mount Cameroon Region, South-western Cameroon. Fako Division is located between latitude 4°28´30″N and 3°54´26″N, and longitude 8°57´10″E and 9°30´49″E (Egbe et al., 2012). The Tiko municipality is a cosmopolitan town with a population of over 80,000 and covers a surface area of 48, 400 km^2 (Vincent, 2005). The climate is typically equatorial. There is a short dry season from December to February and a rainy season from March to November. The rainfall pattern varies throughout the region (Egbe et al., 2012). The relative humidity ranges between 75 to 87% with a mean temperature range of 17 to 35°C at sea level (Egbe et al., 2012).It is an agro-industrial area mostly occupied by plantations of the Cameroon Development Corporation. Subsistence farming is also practiced by the natives and some plantation workers (Vincent, 2005).

Site selection and observations at the sites selected

Three main streams flowing through the plantations were chosen and sampling was done based on accessibility (Figure 1). Stream 1 (Site 1) flows through the rubber plantation established in 2004 located at Small Ikange (SR4). Subsistent cropping in the plantation gaps and stream banks is a common practice at this site. Other possible activities that could result in nutrient inputs include laundry, sewage and refuse disposal by the inhabitants around the plantation. Stream 2 (Site 2) flows through the rubber plantation that was established in 1991 located at Camp 6 (SR2). This stream is bounded by a nursery for rubber, and the main plantation, both of which had recently been treated with fertilizers and could be sources of inputs into the stream. There is also a resident community within the plantation, but refuse disposal was not observed, and the residents make direct use of water from the stream. However, subsistent farming was very high due to numerous and larger gaps in the plantation. This stream was generally fast-flowing. Stream 3 (Site 3) flows through the banana plantation established in 1999 and located at Mafanja I (SB4). There was a banana processing factory and other banana plantations beside this relatively stagnant stream but no subsistent agriculture; however there was more intensive fertilizer use in this site.

Sample collection and handling

At each sampling point, two sets of water samples were collected 10 cm below the water surface in 350 ml and 50 ml bottles in triplicates for nutrient and phytoplankton analyses respectively. These samples were collected at 50 m intervals for each waterway. Samples from each waterway were then bulked to make one representative sample from each site. These samples were bulked because the streams are shallow and perennial, and so no stratification was expected. Two sub samples were collected in triplicates for analyses. Three drops of 10 % Lugol's iodine was added to each of the samples for phytoplankton analyses to fix the phytoplankton. These samples were then transported in a cooler box below 0°C to the University of Dschang Soil and Plant Science Laboratory and the University of Buea Life Science Laboratory for analyses.

Water analyses

Nutrient analyses were done at the University of Dschang Soil and Plant Science Laboratory. The parameters analysed were pH, HCO_3^-, electrical conductivity, turbidity, SO_4^{2-}, zinc (Zn), calcium (Ca), magnesium (Mg), NO_3^-, iron (Fe), potassium (K), sodium (Na), and phosphorus (P) as described by APHA (2005). These parameters were measured because they have been shown to influence phytoplankton distribution and the water quality in previous studies. In measuring conductivity, there Hanna Conductivity meter used simultaneously measures temperature and so conductivity measures are accordingly stabilized. Salinity was calculated from conductivity using the conversion factor described by Dohrman (2011).

Phytoplankton assessment

Phytoplankton assessment was carried out at the Life Science Laboratory of the University of Buea. A drop of each centrifuged water sample was mounted on a clean slide. Counting and identification of species were done using an Olympus BH – 2 light microscope equipped with Normaski optics at a magnification of 1000 X. Slides for quantitative and qualitative analyses were

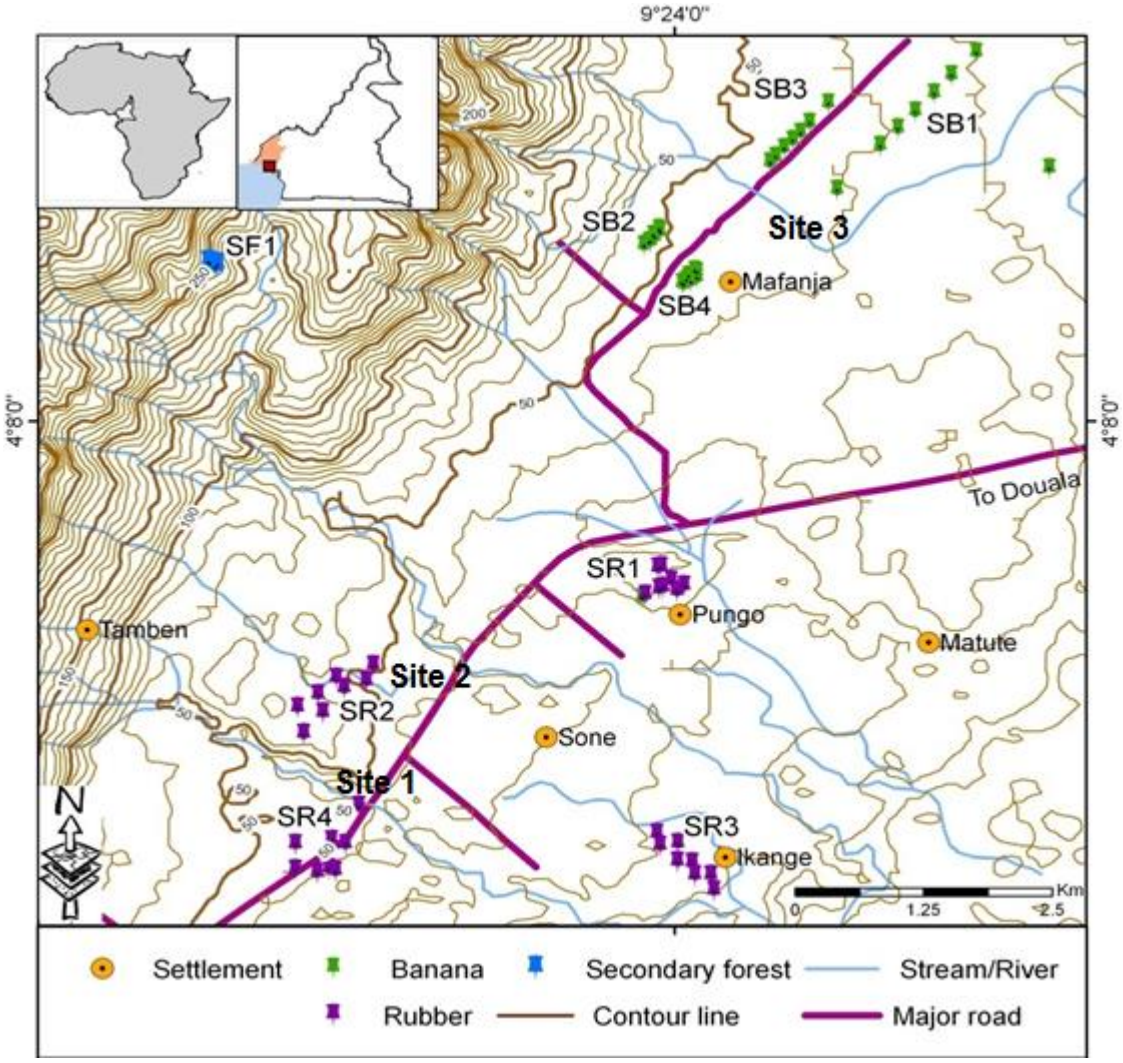

Figure 1. Map showing the study sites. SR1, SR2, SR3, SR4, SB1, SB2, SB3 and SB4 are Sites for a terrestrial survey (manuscript in preparation). Sites used in the current study = Site 1, Site 2 and Site 3.

prepared in triplicates, each replicate from a 50 ml bottle, and whole count method was employed. Following counting, extrapolation was done by multiplying the count from three drops (3 ml) by a factor of 333.33 to get the number of cells per litre. The Sedgwick Rafter counting chamber was used to determine phytoplankton density (Fonge et al., 2012). Identification of phytoplankton followed relevant text books and publications, including Compère (1977), Lltis (1980), Gasse (1986), Krammer and Lange-Bertalot (1986, 1988,1991, 2002), Catherine et al. (2003), Nwankwo and Onyema (2003), Nwankwo et al. (2003),Nguetsop et al. (2007), Belinger and Sigee (2010) and Guiry (2013).

Saprobic index

The saprobic index was used to determine trophic status and calculated according to Belinger and Sigee (2010):

$$Saprobic\ index = \frac{Number\ of\ Euglenophyta}{Number\ of\ Cyanophyta + Chlorophyta}$$

The saprobic index numerically shows whether a system is eutrophic, oligotrophic and so on. If the saprobic index is < 1 the system is eutrophic, and if > 1 the system is oligotrophic.

Shannon-Weaver diversity (H)

Shannon Weaver diversity index of phytoplankton species within the different sites was determined using:

$$ShannonH' = \sum_{i}^{i=1} pilnpi$$

Where, H' = Index of species diversity, *Pi* = Proportion of total sample belonging to *i*th species, *n* = number of species, ln = natural log.

Evenness of phytoplankton communities was calculated following that of Shannon Index as follows:

Table 1. Physico-chemical characteristics of water samples across sites.

Parameter	Site 1 (Rubber 2004)	Site 2 (Rubber 1991)	Site 3 (Banana 1999)	EPA/WHO standard
P^H	7.5	7.5	7.2	6.5 – 8.5
HCO^-(mg/l)	117.12	251.32	131.76	8.5 mg/l
Turbidity (NT)	7.9	7.3	6.2	5 NT
SO_4^{2-} (mg/l)	1.81	1.81	1.65	250 ppm
Zn (mg/l)	6	5	3	5/2 mg/l
Ca (g/l)	0.78	0.74	0.34	0.7 g/l
Mg (g/l)	0.58	0.46	0.70	-
$N\text{-}NO_3^-$ (g/l)	64.40	67.20	67.20	0.045 g/l
Fe (mg/l)	6.39	6.00	5.21	0.3/5 mg/l
K (mg/l)	0.15	0.20	0.15	10 mg/l
Na (mg/l)	0.99	0.37	0.37	20ppm/400 ppm
P Soluble (mg/l)	2.76	4.17	1.05	0.1 mg/l
Salinity	0.05	0.02	0.03	<1.5

For parameters with two values, upper value = drinking water standards while lower values = irrigation water standards.

$$Evenness = \frac{Shannon\ H'}{\ln S}$$

Where, S is the total number of species, ln = natural log.

$$Sorenson\ index, Cn = \frac{2C}{A+B}$$

Where, C_n = Sorensen's similarity coefficient, A and B are the number of individuals per site, C = number of species common to both sites

Patterns of species distribution across sites, as well as association of different physico-chemical parameters with the different sites were analysed using Simple Correspondence Analyses. Pearson's correlation was used to determine relationships between nutrient and phytoplankton parameters and species abundance across the different sites. These analyses were done using the Minitab version 16 statistical package (2010) (Minitab Inc., USA).

RESULTS

Physico-chemical characteristics of water

Results of water analyses are presented in Table 1. The systems are freshwater ecosystems (salinity 0.02 - 0.05). The pH of water ranged from 7.2- 7.5 with the highest pH in sites 1 and 2 and lowest in site 3. Bicarbonate (HCO^-) concentration ranged from 117.17 - 251.32 mgl^{-1}, with highest concentration in site 2 and lowest in site 1. Turbidity was highest (7.9 NT) in Site 1 and lowest (6.2 NT) in site 3 while sulphate (SO_4^{2-}) ranged from 1.65 - 1.81 mgl^{-1} with highest SO_4^{2-} concentration in Sites 1 and 2 and lowest in site 3. Calcium (Ca) content was highest in site 1 (0.78 gl^{-1}) and lowest in site 3 (0.34 gl^{-1}) while zinc (Zn) ranged from 3 - 6 mgl^{-1} with highest concentration in Site 1 and lowest in Site 3. Magnesium concentration was highest in Site 3 (0.70 gl^{-1}) and lowest in site 2 (0.46 gl^{-1}). Nitrogen-nitrate ($N\text{-}NO_3^-$) ranged from 64.4 - 67.2 gl^{-1} with highest value in site 2 and 3 and lowest in Site 1.

Iron (Fe) content ranged from 5.21 - 6.39 mgl^{-1} with highest concentration in site 1 and lowest in site 3. Potassium (K) concentration was highest in Sites 1 and 3 (0.23 mgl^{-1}) and lowest in Site 2(0.15 mgl^{-1}). Sodium (Na) concentration at all sites was below 1.0 mgl^{-1} while the concentration of soluble phosphorus (P) was highest in Site 2 (4.17 mgl^{-1}) and lowest in Site 3(1.05 mgl^{-1}) (Table 1). When water quality of the streams in the agro-plantation complex in Tiko and the USEPA (1986)/WHO (2008) standards were compared, concentrations of Nitrogen-nitrate, bicarbonate, zinc, iron and turbidity recorded in this study exceeded the WHO (2008) and USEPA (1986) water quality standards for a healthy freshwater ecosystem (Table 1).

Phytoplankton community structure

A total of 80 species belonging to 63 genera and 10 divisions were identified in all three sites. The division with the highest species abundance was the Bacillariophyta (31 species) followed by Chlorophyta (21 species), Cyanophyta and Dinophyta (eight species each), and Euglenophyta (seven species). The divisions with the least abundance were Charophyta, Chrysophyta, Cryptophyta, Haptophyta and Rhodophyta which had one species each (Table 2). The most abundant species was *Chlorella* sp. followed by *Microcystis aeruginosa*. When

Table 2. Phytoplankton abundance across the different sites.

Species name	Phylum	Abundance (cells/L)			Trophic status
		Site 1	Site 2	Site 3	
Fragilaria virescens†	Bacillariophyta	2333	0	0	Eutro*
Cyclotella sp. †	Bacillariophyta	2000	0	0	Oligo
Pinnularia major†	Bacillariophyta	333	0	0	Oligo
Frustulia sp. †	Bacillariophyta	667	0	0	Eutro
Gomphonema sp.1†	Bacillariophyta	333	0	0	NC
Liemophora sp. †	Bacillariophyta	1000	333	0	NC
Pleurosigma sp. †	Bacillariophyta	333	0	0	NC
Asterionella sp. †	Bacillariophyta	1333	0	0	Eutro
Achnanthes sp. †	Bacillariophyta	333	0	0	NC
Nitzschia closterium†	Bacillariophyta	333	0	0	Eutro
Frustularia sp. †	Bacillariophyta	333	0	0	NC
Diatomella balfouriana†	Bacillariophyta	1667	0	0	NC
Gomphonema sp.2†	Bacillariophyta	333	0	0	Eutro
Eunotia curvata†	Bacillariophyta	333	0	333	Eutro
Diatoma vulgaris‡	Bacillariophyta	0	333	0	Eutro
Diatoma sp. ‡	Bacillariophyta	0	333	0	Eutro
Achnanthes aonvergens‡	Bacillariophyta	0	667	0	Eutro
Navicula sp.1‡	Bacillariophyta	0	333	0	Eutro
Pinnularia largerstedtii‡	Bacillariophyta	0	2333	0	NC
Gyrosigma sp. ‡	Bacillariophyta	0	667	0	Oligo
Rhoicosphenia sp. ‡	Bacillariophyta	0	333	0	NC
Nitzschia linearis‡	Bacillariophyta	0	667	0	Oligo
Mastogloia baltica‡	Bacillariophyta	0	667	0	NC
Navicula atomus‡	Bacillariophyta	0	333	0	NC
Fragilaria heidenii‡	Bacillariophyta	0	333	0	NC
*Nitzschia latens***	Bacillariophyta	0	0	333	NC
*Cocconeis pedicula***	Bacillariophyta	0	0	1333	Eutro
Nitzschia dissipata‡	Bacillariophyta	0	333	0	Eutro
Synedra ulna‡	Bacillariophyta	0	2000	0	Eutro
Phaeodactylum tricornutum‡	Bacillariophyta	0	333	0	NC
Navicular sp.2‡	Bacillariophyta	0	333	0	Eutro
Desmidium sp. †	Charophyta	1667	0	0	Oligo
Tetraedron trigonium	Chlorophyta	333	667	0	NC
Scenedesmus sp.	Chlorophyta	1000	667	3333	Eutro
Ankistrodesmus sp.	Chlorophyta	667	1000	0	Oligo
Oedogonium sp. †	Chlorophyta	333	0	0	NC
Monostroma sp. †	Chlorophyta	333	0	0	NC
Cosmarium sp.	Chlorophyta	1667	333	0	Eutro/odour
Rhizoclonium sp. †	Chlorophyta	5333	0	0	Eutro
Micrasterias radiata†	Chlorophyta	1000	0	0	NC
Oocystis sp. †	Chlorophyta	1000	0	0	Oligo
Haematococcus sp.	Chlorophyta	667	333	0	Eutro
Pleurococcus sp. †	Chlorophyta	333	0	0	NC
Tetraplektron tribulus†	Chlorophyta	333	0	0	NC
Scenedesmus obliquus†	Chlorophyta	333	0	0	Meso
Chlamydomonas sp. †	Chlorophyta	333	0	0	Oligo
Gloeocystis plantonica†	Chlorophyta	333	0	0	Oligo
Staurastrum sp. ‡	Chlorophyta	0	1000	0	Oligo
Chlorella sp.	Chlorophyta	10333	667	667	Eutro
Thalassionema nitzschioides†	Chlorophyta	333	0	0	NC

Table 2. Contd.

Species name	Phylum	Abundance (cells/L)			Trophic status
		Site 1	Site 2	Site 3	
Klebsormidium sp. ‡	Chlorophyta	0	333	0	NC
Oocystis solitarta‡	Chlorophyta	0	333	0	NC
Draparnaldia sp. †	Chlorophyta	333	0	0	Oligo
Chromulinaconica‡	Chrysophyta	0	333	0	NC
Cryptomonas sp.	Cryptophyta	333	333	0	Eutro/odour
Oscillatoria sp. †	Cyanophyta	1000	0	0	Eutro
Microcystis aeruginosa	Cyanophyta	10000	13333	10000	Eutro
Microcoleus sp. †	Cyanophyta	333	0	0	Oligo
Phormidium sp. †	Cyanophyta	333	0	0	Eutro
Aphanocapsa sp. ‡	Cyanophyta	0	333	0	Eutro
Stenopterobia sp. ‡	Cyanophyta	0	2000	0	NC
Anabaena spiroides	Cyanophyta	0	333	0	Meso
Calothrixfusa	Cyanophyta	333	333	0	NC
Peridinium umbonatum	Dinophyta	1667	333	333	Oligo
Peridinium sp.	Dinophyta	333	0	333	Meso-Eutro
Peridinium gatunense†	Dinophyta	333	0	0	Oligo
Dinophysis acuminata†	Dinophyta	333	0	0	Eutro
*Oodimium poucheti***	Dinophyta	0	0	333	NC
*Amphisolenia inflate***	Dinophyta	0	0	333	NC
*Ceratium hirundinella***	Dinophyta	0	0	333	Meso-Eutro
Phalacroma sp.**	Dinophyta	0	0	333	NC
Euglena sp.	Euglenophyta	3333	333	1000	Eutro
Phacus tortus	Euglenophyta	333	667	333	NC
Vaucheria dichotoma†	Euglenophyta	333	0	0	Oligo-Meso
Trachelomonas volvocina†	Euglenophyta	333	0	0	Eutro
Trachelomonas sp. ‡	Euglenophyta	0	667	0	Eutro
Phacus sp. ‡	Euglenophyta	0	667	0	NC
Euglena minuta	Euglenophyta	0	2000	333	Eutro
Homozygosphaera sp. †	Haptophyta	2	0	0	NC
Batrachospermum sp.	Rhodophyta	5	3	2	Oligo

*Eutro = Eutrophic; Oligo = oligotrophic; Meso = Mesotrophic; NC = not counted; † = species unique to site 1; ‡ = species unique to site 2;** = species unique to site 3.

all species are considered, overall, the mean abundance of phytoplankton cellsacross the different sites ranged from 254 ± 132 to 750 ± 193 cells/L.Site 1 had the highest mean abundance while Site 3 had the least. Kruskal-Wallis test showed significant differences in abundance ($H = 27.83$, $DF = 2$ and $p < 0.001$) between Site1 and Site 3 ($p < 0.001$) and between Site 2 and Site 3 ($p = 0.004$) (Figure 2).

In terms of diversity, Site 1 had the highest diversity of phytoplankton ($H' = 3.15$), with the most even distribution of species. It had more species (49), which on average occurred in higher numbers than at other sites. Site 3 was the least diverse ($H' = 1.87$), with the least even distribution of species; it was species-poor (16) and had the least species abundance on average (Table 3).

Of all species recorded, 29 were indicators of eutrophication (*Microcystis aeruginosa, Chlorella* sp., *Euglena minuta, Trachelomonas volvocina, Calothrixfusa, Rhizocloniumsp*), 14 species were indicators of oligotrophic conditions (*Batrachospermum* sp., *Cyclotella* sp., *Thalassionema nitzschoides)*, one species was an oligo – mesotrophic indicator, one species was an indicator of mesotrophic conditions and 2 species were meso-eutrophic indicators (Table 2) (Makarewicz, 1993; Wang et al., 2013). However, the Euglenophycean index for the trophic status of the water system ranged from 0.19 in Site 1 to 1.00 in site 3 showing that sites 1 and 2 are eutrophic. Sites 1 and 2 were most similar, with a Sorensen index of 0.32, compared to indices of 0.28 between sites 1 and 3 and 0.29 between sites 2 and 3.On a scale of 0 - 1, these similarities cannot be considered significant. The different sites were unique in terms of resident phytoplankton. These unique species were present in only one of the three sites. Site 1 had more

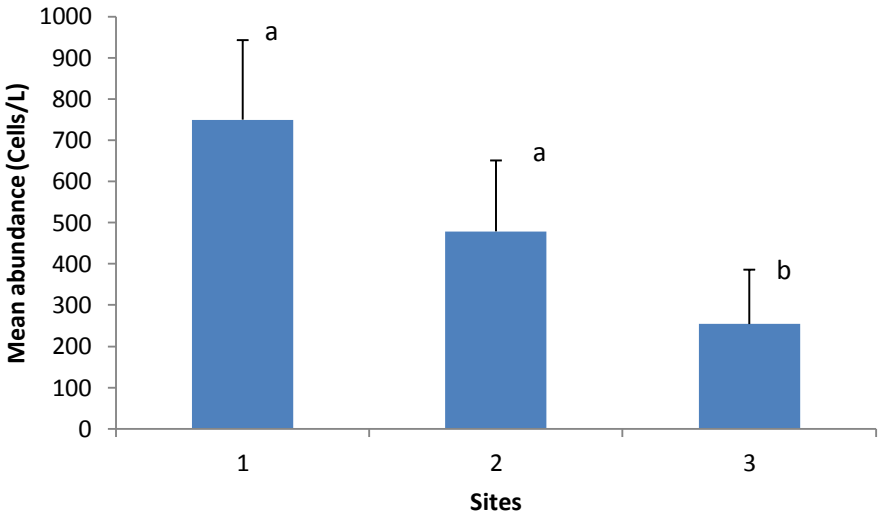

Figure 2. Mean abundance of phytoplankton species across the different sites. H = 27.83, DF = 2, P < 0.001. Bars represent mean ± SE, means separated through Kruskal- Wallis multiple comparison test at α = 0.05. Bars with the same letter are not significantly different.

Table 3. Diversity, mean abundance, species richness of phytoplankton and saprobic level status.

Site	Diversity (H')	Evenness	Mean abundance of species	Species richness	Saprobic index
Site 1	3.1482	0.8089	750	49	0.36
Site 2	2.8564	0.7797	479	39	0.19
Site 3	1.8703	0.6746	254	16	1.00

H' = Shannon index, Saprobic index< 1 = eutrophic, > 1 = oligotrophic.

unique species compared to Sites 2 and 3. Species that are unique to site 1 include *Fragilaria virescens, Oscillatoria* sp*., Frustulia* sp*., Gomphonema* sp*. 1, Asterionella* sp*., Achnanthes* sp*., Nitzschia closterium, Scenedesmus obliquus, Trachelomonas volvocina, Gomphonema* sp*.* 2, all of which are indicators of eutrophication. *Aphanocapsa* sp*., Diatoma vulgaris, Diatoma* sp*.,* and *Achnanthes aonvergens* were found only in site 2 and are also indicators of eutrophication while *Cocconeis pedicula* was the only indicator of eutrophication identified in site 3. *Cryptomonas* sp. and *Cosmarium* sp. are indicators of eutrophic conditions and are odoriferous. These were found in sites 1 and 2 (Table 2).

Ordination of physico-chemical parameters of water samples and phytoplankton community parameters

The relationship between phytoplankton diversity, richness, evenness and abundance, and water chemistry assessed using correspondence analysis are presented in Figure 3. The ordination shows that Components 1 and 2 contributed 60.7% and 39.3% respectively of the total inertia. Site 2 is highly associated with phytoplankton diversity, probably a result of the high nutrient levels especially phosphorus at this site (Table 1); Site 1 is closely associated with HCO^- concentration. This figure also shows that the distribution of phytoplankton (evenness) is associated with pH, SO_4^{2-}, Fe and turbidity of the sites.

Correlation of water parameters and phytoplankton diversity across sites

Correlation between physico-chemical parameters of water and phytoplankton community parameters across sites showed relationships between the following: turbidity and Fe (r = 1.00, p= 0.016), Zn and Fe (r = 1.00, p= 0.002), Mg and Soluble P (r = 0.998, p = 0.035), Mg and mean phytoplankton abundance (r = 1.00, p = 0.034), phytoplankton diversity and evenness (r = 1.00, p= 0.007), phytoplankton diversity and richness (r = 1.00,

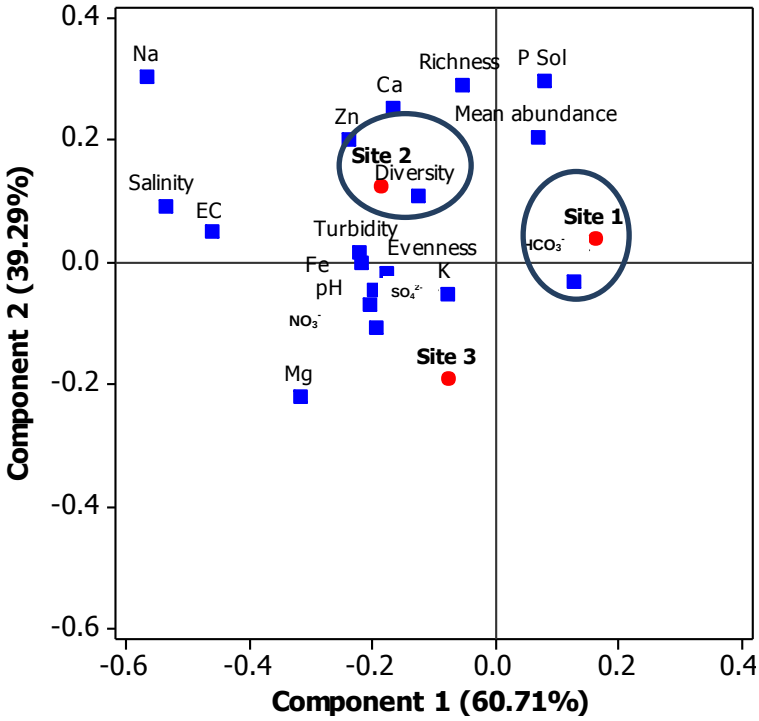

Figure 3. Plot showing the association chemical parameters and phytoplankton parameters between the different sites. Red dots = sites, Blue squares = water chemistry and phytoplankton parameters. Circles group sites with the parameter that has a disproportionately higher concentration at that site. SO42- = SO_4^{2-}, HCO3- = HCO_3^-, NO3- = NO_3^-.

p = 0.006) and phytoplankton evenness and richness (r = 1.00, p = 0.001). There were no significant correlations between any macronutrient and phytoplankton community descriptors.

DISCUSSION

The physico-chemical and biotic characteristics of water are interrelated and often driven by the surrounding land uses that determine the quality of water at point sources that enter the freshwater streams. The current study in three streams flowing through an agro industrial zone in Tiko, Cameroon, show different patterns for each system, but overall convey the picture of a eutrophic system.

The water quality characteristics are overall not ideal for a healthy freshwater ecosystem but influence growth and abundance of phytoplankton species at the different sites. In the current study, some chemical parameters were found to exceed the WHO and USEPA water quality standards. Concentrations of NO_3^- ranged from 64.4 - 67.20 gl^{-1}, exceeding at all sites, the WHO (2008) limit of 45 mg/l (Tening et al., 2013). Potential nitrate sources in this system include decaying organic matter, sewage, fertilizer inputs and manures. High inputs from these sources increase nutrient concentration and influence abundance of species. It has been shown that for phytoplankton blooms and hence eutrophication to occur, high levels of nitrogen- and phosphorus-based nutrients is necessary. The resulting algal blooms cause anoxia and hypoxia, odour, taste and toxicity problems, destroying the aesthetic and recreational values of water and resulting in a structural shift in communities in some locations (Camargo and Alonso, 2006; Tening et al., 2013). The levels of NO_3 recorded during this study were beyond thresholds and the Saprobic Index indicated that the water was eutrophic at the time of sampling. Therefore although chlorophyll *a* biomass was not determined, micro algae blooms were evidenced by odour, with the phytoplankton community structure reflecting a dominance of the Baccilliarophyta and Chlorophyta, and having many species present indicative of eutrophication. This Bacillariophyta dominance is consistent with earlier studies done in a variety of habitats in the tropics (Celekli and Kulkoyluoglu, 2006; Gharib et al., 2011). The dominance of the Bacillariophyta could be a result of their high tolerance to chemicals and nutrients (Celekli and Kulkoyluoglu, 2006); nitrates, phosphates, and other metals were high in the different study sites.

Although we did not determine phytoplankton biomass as an index of eutrophication in this study, the presence

of large numbers of species that are indicators of eutrophication suggest some level of nutrient input at these sites, which render the water eutrophic. To clarify sources of inputs, it is essential to monitor point sources and episodic discharges into these streams.

Sites 1 and 2 are shown by the Saprobic index to be eutrophic, and by Sorensen index to be slightly more similar. This similarity is driven by similar physico-chemical characteristics, similar biota and possibly, similar land uses at these sites. Both sites had a disproportionately higher number of species that indicate eutrophication, compared to Site 3. All three sites are characterised by unique assemblages of phytoplankton. Of the 49 species found in Site 1, 33 species occurred only at this site. Similarly, at Site 2, 24 of the 39 species present occurred only at this site, while 6 of the 16 species at site 3 were unique to that site. These patterns can only be explained by the physico-chemical characteristics of the sites, and are consistent with the extremely high nutrient concentrations recorded. Such drastic differences in sites that are relatively close together suggest that anthropogenic influences affect the water chemistry and biota. Although all three sites are freshwater systems (salinity <1.5 mgl^{-1} ANZECC, 2000), surrounding land uses differ. Sites 1 and 2 flow through rubber plantations established in 2004 and 1991 respectively. These sites are characterised by subsistent cropping in the plantation gaps and stream banks, laundry, sewage and refuse disposal by the inhabitants around the plantation, and a nursery for rubber which had recently been treated with fertilizers. Site 3 is a relatively stagnant stream at the time of sampling that flows through the banana plantation established in 1999 characterised by a banana processing factory but no subsistent agriculture; however there was more intensive fertilizer use in this site. These activities have the potential to release nutrient and chemical inputs into the streams. These would alter the water characteristics and resulting biota. In freshwater environments, phosphorus and nitrogen concentrations are a limiting factor of algal growth (Camargo and Alonso, 2006). The USEPA (1986) acceptable limit of phosphates is 2.0×10^{-5} mgl^{-1} for aquatic systems. Phosphorus concentrations recorded during this study ranged from 1.05 - 4.17 mgl^{-1} which is much higher. It has been reported that concentrations of phosphorus greater than 0.1 mg^{-l} in still water may give rise to algal bloom (Provin and Pitt, 2002); in the current study high abundance of eutrophic and odoriferous species observed are consistent with the high P concentrations recorded.

The high turbidity observed in the streams can be explained by the presence of particulate matter, finely divided organic matter, other microscopic organism such as planktonic algae. This is consistent with findings by Nowrouzi and Valavi (2011).In the current study therefore, the levels of turbidity cannot be directly linked to algae blooms due to the multiple sources and low variation of recorded turbidity from the standards. The ecological survey showed that agrochemicals are used in these plantations and could be a likely source of chemical inputs to the system, strongly suggesting that agrochemical use is linked to high levels of the different physico-chemical parameters observed. These results provide a credible baseline for further monitoring.

In terms of diversity, Site 1 was the most diverse, most species rich, with species most evenly distributed. The reason for high species diversity and richness in Site 1 could be because this water course passes through rubber plantations that were fertilized few months before this study was carried out. This is evident in the high concentrations of nitrates, phosphorus and potassium (67.2 gl^{-1}, 4.17 mgl^{-1} and 0.20 mgl^{-1} respectively) at this site. However, concentrations of nitrates and phosphates were higher at site 2, hence other factors could be responsible for the observed trends in species richness. Site 1 is also bordered by the rubber nursery where fertilizer application rate is high. However, this association between diversity and nutrients is not evident from the correspondent analysis probably because nutrient levels are universally high across all three sites.
Correlation showed Fe and turbidity and Zn and Fe to be positively correlated. Magnesium, soluble P,Mg and mean phytoplankton abundance were also positively correlated. This shows that the occurrence, abundance and diversity of phytoplankton are influenced by ambient physic-chemical conditions, especially phosphorus concentrations, consistent with findings by Fonge et al. (2012).

The results of the current study suggest that phytoplankton community structure and diversity depend on the ambient physico-chemical characteristics of water. These characteristics could be influenced by anthropogenic activities in the catchment area especially plantation agriculture and its management practices, as well as effluent from human settlements. The current study shows that human activities influence the physico-chemical characteristics of water and hence the resident phytoplankton population. More regular monitoring of point sources that discharge water from anthropogenic sources into the streams is necessary, and the current study thus provides a substantial baseline for long term monitoring.

Conflict of interests

The authors did not declare any conflict of interest.

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