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Water Quality, Biodiversity and Abundance of Blue-Green Algae in Nyong and Kienké River Mouths (South-Cameroon)

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Abstract: A survey was undertaken from March to June 2014 on the water quality and the occurrence of Cyanobacteria bio-indicator species in Nyong and Kienké warm river mouths. Physico-chemical parameters were measured *in-situ.* Species were identified and counted in laboratory. The pH varied from slightly acidic to slightly basic. Temperature, pH and transparency were within the tolerable limits for drinking water or fish farming. NO_3^-, Chlorophyll a and biomass were lower than standards. DO and FC were higher than upper limits, except DO in Kienké. NO_2^- was higher in Nyong than the upper limit. It was within the recommended range in Kienké. TSS was within acceptable standards for fish farming but above the upper limit for drinking water. NO_2^-, NH_4^+ and PO_4^{3-} proved good conditions for bio-fertilizers or toxin-producers. Chlorophyll a and biomass contains were low but FC and TSS exceeded standards for drinking water, and were within standards for fish farming. Thirty-seven species belonging to 28 genera, 15 families and four orders, were divided into 25 freshwater species and 12 tolerant species. Sixteen toxigenic species, 15 useful species and six species of unknown status were identified. The species diversity was low and Microcystaceae (Chroococales) was the most species-rich family (eight species i.e. 21.6%) and was the most abundant (34.7%), followed by Rivulariaceae (Nostocales) (five species i.e. 13.5% and 12.4% of abundance), Aphanizomenonaceae (Nostocales) (four species i.e 10.8% and 20.8% of abundance), Hapalosiphonaceae (Nostocales) (two species i.e.5.4% and 0.8% of abundance), Microcoleaceae (Oscillatoriales) (two species i.e. 5.4% and 2.1% of abundance), Nodulariaceae (Nostocales) (three species i.e. 8.1% and 7.9% of abundance), Nostocaceae (Nostocales) (two species i.e. 5.4% and 1.9% of abundance), and Oscillatoriaceae (Oscillatoriales) (three species i.e. 8.1% and 0.8% of abundance). Eight families [Chroococcaceae (Chroococales), Coelosphaeriaceae (Synechococcales), Cyanothecaceae (Gomontiellales), Cymatolegaceae (Nodosilineales), Cyanothrichaceae (Chroococales), Gomphosphaeriaceae (Chroococales), Pseudanabaenaceae (Pseudanabaenales), and Tolypothrichaceae (Nostocales)] presented each one rare species (2.7%). According to abundances, species classification in descending order is *Raphidiopsis mediterranea* (14.3%), *Synechocystis aquatilis* (11.9%), *Aphanothece elabens* (7.3%), *Microcystis aeruginosa* (5.1%). Other species were rare. Twenty-three co-dominants (62.2%) were identified. Globally, a positive association was noted between species in each river. The pooled assemblage at low tide fitted the log-linear niche partitioning model with a high environmental constant while other assemblages fitted the lognormal model with in each case a

low environmental constant. Although these two river mouths were suitable for fish farming, direct consumption of raw water is detrimental to human health.

Keywords: Physicochemical Parameters, Cyanobacteria, Useful Species, Toxigenic Species, Community Structure

1. Introduction

Cyanobacteria Stanier ex Cavalier-Smith, 2002 or Cyanobacteriota Oren, Mareš & Rippka, 2022 or 'blue-green algae', or Myxophyta, or Cyanobacterium, Cyanophyta or Cyanophyte, is a heterogeneous group of prokaryotic kingdoms whose cells are devoid of membrane-enclosed chloroplasts, distinguishing them from other algae which are all eukaryotic [1, 2]. Principally photosynthetic organisms, Cyanobacteria resemble the eukaryotic algae in many ways, including morphological characteristics and ecological niches, and they are at one time treated as algae, hence the common name of blue-green algae [2]. Chemical, genetic, and physiological characteristics are used to classify the group within the kingdom. Cyanobacteria may be unicellular or filamentous. Many have sheaths to bind other cells or filaments into colonies [2]. Cyanobacteria contain chlorophyll *a* as green pigment, various yellowish carotenoids as blue pigment phycobilin, and some species present the red pigment phycoerythrin [1, 2]. The combination of phycobilin and chlorophyll produces the characteristic blue-green colour from which these organisms derive their popular name and because of the other pigments, many species are green, brown, yellow, black, or red [1, 2].

Blue-green algae represent one of the seven-kingdom classifications of life [3-5]. It has since been reclassified as protists, and the prokaryotic nature of cells has caused them to be classified with bacteria in the prokaryotic kingdom Monera. Il comprises one class (Cyanophyceae Schaffner 1909), five orders [(1) Chamaesiphonales or Synechococcales L. Hoffm., Komárek & Kaštovský, 2005 (2 families, 3 genera, 16 species, and 2 subspecies); (2) Chroococcales J. H. Schaffn., 1922 (4 families, 28 genera, 160 species, and 42 subspecies); (3) Nostocales Cavalier-Smith, 2002 (5 families, 46 genera, 412 species, and 35 subspecies); (4) Pleurocapsales Geitler, 1925 (2 families, 4 genera, and 7 species); and (5) Stigonematales Geitler, 1925 (4 families, 10 genera, 36 species, and 6 subspecies], to which is added a form of uncertain classification in terms of genus and species; thus making a total of 17 families, 92 genera, 632 species, and 85 subspecies [6]. But these numbers are clearly below reality because several forms are undetermined and until today around 5,843 species and infraspecific names are listed in the world [7]. Cyanobacteria include marine, brackish water, freshwater and terrestrial algae, making this kingdom very important for ocean and freshwater ecology [7, 8]. Photosynthetic species are essential primary producers of the aquatic food webs, and also have an economic importance [9-14]. In addition to being photosynthetic, many species of Cyanobacteria can also "fix" atmospheric nitrogen, transforming the gaseous nitrogen of the air into compounds that can be used by living cells [2]. Particularly efficient nitrogen fixers are found among the filamentous species that have specialized cells called heterocysts. In Southeast Asia, nitrogen-fixing cyanobacteria often are grown in rice paddies, thereby eliminating the need to apply nitrogen fertilizers [15-17].

Several species have a detrimental impact as producers of cyanotoxins harmful to aquatic living organisms, thus altering the quality of water essential for the health of humans and living aquatic organisms [10-14, 18]. Cyanobacteria reproduce asexually, either by means of binary or multiple fission in unicellular and colonial forms or by fragmentation and spore formation in filamentous species [2]. Thus under favorable conditions, blue-green algae can reproduce at explosive rates, forming dense concentrations called blooms [2, 19]. Cyanobacteria blooms are especially common in waters that have been polluted by nitrogen wastes; in such cases, the overgrowths of Cyanobacteria can consume so much of the water's dissolved oxygen [19-21]. These potentialities make Cyanobacteria good bio-indicators of the water quality of life.

Nyong and Kienké river mouths (South Cameroon region) are source of drinking water and fishing activities [22]. Residents depend on artisanal small-scaled fishing using canoes, for household consumption [23, 24] and to supply the neighboring urban areas [24]. Nevertheless, the demand is growing and fishermen complain about the deterioration of the fish resources for many reasons including irresponsible fishing practices (use of pesticides) and the poor land use management [22]. In this region, the community structure of aquatic micro algae is little known, except works concerning the tidal variation impact on the abundance of phytoplankton in the Nyong estuary [25], seasonal variation of the water quality and the composition of the phytoplankton communities in lower Nyong estuary [26], influence of physico-chemical parameters on the zooplankton dynamics in Kienké estuary [27]. But nothing is known concerning the zoonotic algae, the toxigenic species and those useful for the nutrition of fish. The present study aimed to establish a baseline of information on the distribution of algae, as a first step in evaluating the status and the occurrence of species known as bio-indicators of the aquatic life quality (useful species or producers of toxins).

2. Materials and Methods

2.1. Study Sites

Studies took place in 2014 at the mouth of two rivers (Southern coastal zone of Cameroon): Nyong river mouth: 03°16'40.71"N, 09°53'27.21"E and 03°14'58.41"N,

09°56'41.07"E; Kienké river mouth: 02°22'4.06"N, 09°48'32.20"E and 02°17'56.31"N, 09°50'55.94"E) (Figure 1A). These two river mouths are separated by a distance of 111.1 km. The prevailing climate is tropical with rainfall even during the driest months (December and January: 54.2 mm and 33.8 mm respectively) [28]. The average air temperature ranges from 24.4°C (August) to 26.7°C (Marsh) and the average rain fall ranges from 116 mm (January) to 340 mm (September). The average air humidity ranges from 84.0% (January to March) to 87.0% (September and October) [28]. Four seasons are defined: a long dry season (late November-February), a short rainy season (March-June), a short dry season (July-August) and a long rainy season (early September-early November) [23]. Soils are acidic, yellow ferralitic types, poor in minerals and organic matters and soils on gneiss outcrop cover the bulk between Campo and Kribi [23]. Many streams crossing the region are influenced by the equatorial climate [23]. The main rivers (Nyong, Lokoundjé, Kienké, Lobé and Ntem) flow into the Atlantic Ocean and the watercourses are used by the residents for traditional fishing or as waterways using canoes or other navigation fleet [23].

2.2. Sampling Design

Samplings were set up from March to June 2014 in the lower course of Nyong and Kinké River mouths. Four sites were selected 300 m from the shore of Nyong and 30 m from the shore for Kienké. In each river sampling sites were accessed using a wooden canoe [Nyong River mouth: site 1 at the beginning of the estuary (3°16'1.79"N, 9°56'25.72"E), site 2 at the middle of the estuary: (3°15'57.58"N, 9°55'31.13"E; 1.71 km from site 1), site 3 at the transition with ocean water (3°15'38.99"N, 9°54'16.28"E; 4.11 km and 2.47 km from site 1 and site 2 respectively) and site 4 located in the coastal area of the ocean (3°16'3.85"N, 9°53'45.64"E; 5.15 km, 3.4 km and 1.3 km from site 1, site 2 and site 3 respectively) (Figure 1B); Kienké River mouth: site 1 near a residential camp (2°19'20.40"N, 9°50'17.78"E), site 2 near a marshy area (2°20'14.06"N, 9°50'1.07"E; 1.9 km from site 1), site 3 at the transition with the ocean (2°20'55.01"N, 9°49'22.47"E; 1.8 km and 3.5 km from site 2 and site 1 respectively) and site 4 located in the coastal area of the ocean (2°21'17.29"N, 9°48'57.40"E; 4.8 km, 2.8 km and 1.1 km from site 1, site 2 and site 3 respectively)] (Figure 1C). In each river, site 4 was situated 10 km from the coast and an outboard boat permitted us to reach it. Samsung 14.2 Mega Pixels and Kodak 9.2 Mega Pixels cameras were used for the field shots. Coordinates of the sites were taken using a Garmin GPS. Three sampling sessions were done at each site (one in March, June and August respectively). Raw water was sampled at one-meter depth using a Teflon ball and a two-litter Niskin messenger bottles and 150 ml transparent plastic polyethylene bottles for physico-chemical analyzes and transported to the laboratory using a 100 ml Coleman cooler containing pieces of ice for temperature maintenance.

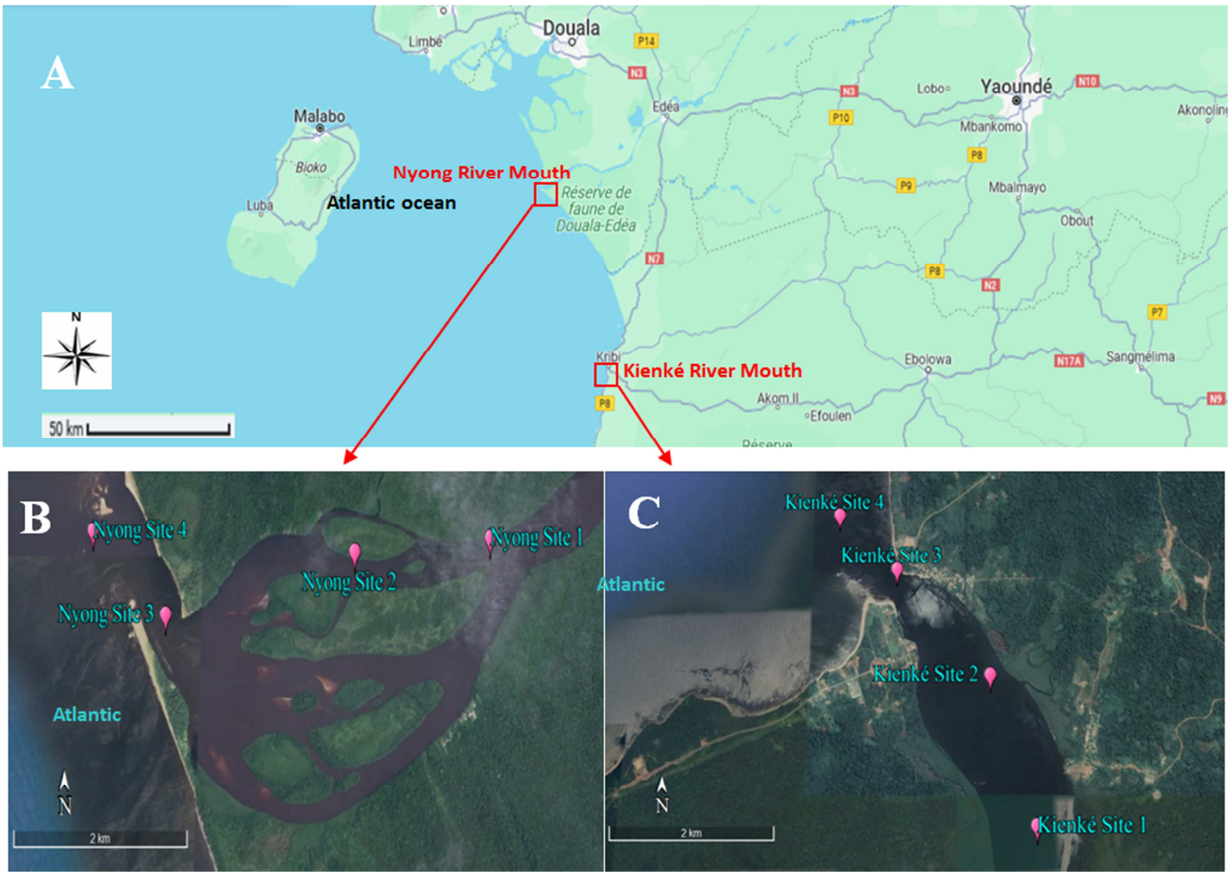

Figure 1. *Location of the study sites in Southern coastal zone of Cameroon (southern province, Ocean department). A: Location of the Nyong and Kienké River mouths; B: Location of the collection sites in the Nyong River mouth; C: Location of the collection sites in the Kienké River mouth.*

2.3. Physico-Chemical Parameters of the Water

Six physico-chemical parameters were measured *in situ*: (1) Salinity ($\mu S.cm^{-1}$) using a Salinometer, (2) water temperature (°C), (3) the potential of hydrogen (pH) using the thermo-pH meter Hanna model HI 98130, (4) conductivity ($S.m^{-1}$) using a brand conductivity meter WTW series 3310 set2, (5) dissolved oxygen (DO) (%) using an oximeter Extech model Exstik II DO 600, and (6) transparency (cm deep) using a Secchi disk. Seven additive parameters were measured in the Laboratory of Biotechnology and Environment of the University of Yaoundé 1 using a Hach DR390 spectrophotometer at program 630 and wavelength 810 nm and a Carberg Brand BOD incubator: (1) Biochemical Oxygen Demand for five days (BOD_5) ($mg.l^{-1}$), (2) Ammoniacal nitrogen (NH_4^+) ($mg.l^{-1}$), (3) Nitrates (NO_3^-) ($mg.l^{-1}$), (4) Nitrites (NO_2^-) ($mg.l^{-1}$), (5) Orthophosphate (PO_4^{3-}) ($mg.l^{-1}$), (6) total suspended solids (TSS) ($mg.l^{-1}$) (inorganic materials such as clay, gravel, sand and silt, algae and bacteria) and (7) faecal coliforms (FC). NH_4^+ was measured using the Nessler reagent calorimetric method: three drops of the mineral stabilizer of polyvinyl alcohol and one milliliter of Nessler's reagent were added to 25 ml of the raw water; after 10 minutes the solution was placed in the spectrophotometer and the coloration of the complex formed was read at 425 nm wavelength by reference to a control consisting of distilled water. NO_3^- was determined by the cadmium reduction method: one sachet of nitraVer® 5 nitrate reagent [mixture of phosphoric acid potassium salt KH_2PO_4 (1:1, 30-40%), benzensulfonic acid 4-amino- $C_6H_7NO_3S$ (20-30%), benzoic acid 2,5-dihydroxy- $C_7H_6O_4$ (20-30%), cadmium (3-7%), copper [propandioato(2-)-O, O]- $C_3H_2O_4Cu$ (0.1-1%) and 2-propenamide homopolymer $(C_3H_5NO)x$ (<0.1%)] was introduced in 10 ml of the raw water; after 5 minutes, the reagent reduces the available nitrate ions into NO_2^- which, in the presence of sulphanilic acid, reacts to form a diazonium salt which, in turn, fixed gentisic acid to form an amber color compound, the color intensity being read at a 500 nm wavelength by reference to 25 ml of a control liquid of distilled water. NO_2^- was measured using nitraVer® 3 reagent [mixture of phosphoric acid potassium salt (1:1, 50-100%), potassium pyrosulfate (5-10%), benzensulfonic acid, 4-amino-, monosodium salt (5-10%), 2,7-naphthalenedisulfonic acid, 4,5-dihydroxy-disodium salt (1-5%) and Glycin N, N-1,2-cyclohexandiylbis[N-(carboxymethyl)-trisodium salt (1-5%)] during 10 minutes. PO_4^{3-} was determined by the colorimetric method using phosVer® 3 phosphate reagent [mixture of potassium pyrosulfate $K_2S_2O_7$ (70-80%), sodium molybdate Na_2MoO_4 $2H_2O$ (1-3%), potassium antimonyl tartrate $C_8H_4K_2O_{12}Sb_2$ $3H_2O$ (<0.5%), EDTA tetrasodium salt $C_{10}H_{12}N_2Na_4O_8$ $2H_2O$ (<0.5) and ascorbic acid $C_6H_8O_6$ (15-25%)]. Phosphate reagent was added to 10 ml of raw water and homogenized during 2 minutes and the result was read at 890 nm wavelength. Ten milliliter of raw water and distilled water as reference were separately placed in the spectrophotometer in order to determine TSS and the result was read at 810 nm wavelength. FC was determined and counted using the membrane filtration technique: the culture medium (tergitol 7-lactose TTC agar: 200 g lactose, 10 g peptone, 6 g yeast extract, 5 g meat extract, 0.05 g bromothymol blue, 70.1 g tergitol, 7.12 g Agar-Agar, 0.025 g TTC additive) was used; for the preparation, 53.9 g of the culture medium was dissolved in one litter of deionized water and placed in the autoclave for 15 minutes at 121°C; the nutrient medium was cooled in a water bath between 45-50°C; then 5 ml of the sterile aqueous solution at 0.05% of TTC was added to 100 ml of the nutrient medium and homogenized; the culture was placed in Petri dishes during 4 mm and the dilution of the percolate samples was done using the sterile diluted water; a volume (v) of each sample was filtered using a vacuum pump; each filtration membrane was placed in the culture and the solution was incubated at 44.5°C during 24 hours; the number of bacteria colonies (n) was determined and counted and the initial density was estimated as (n/v)*100.

2.4. Species Identification and Counting

Biological parameters (bacteria composition, identification and counting) were carried out at the micro algae laboratory of the Specialized Center for Research on Marine Ecosystems at Kribi (AquaSol service). Blue-green algae species identification was made using a Zeiss NR183268 series microscope and by referring to the descriptions, drawings, dimensions and photographs in available dichotomous keys and illustrated documents [29]. Update name of species and their natural environment were obtained by referring to catalogs and websites available online [8, 30]. The cells concentration in each sample of water was determined using the Malassez cells. In case of insufficient homogeneity, the assembly was resumed using a new Malassez cell and the rehomogenized raw water. Bacteria cells were identified and for each species, we counted the number of cells in ten randomly selected squared grid areas and the average number (n_i) of 10 Malassez's squared grids and the final concentration were recorded as $c_i = n_i x 10^5$ cells ml^{-1}. The total number of cells in volume "v" was estimated as $n_i = c_i v$ and data were compiled in a species matrix database.

2.5. Statistical Analysis

Data matrixes were constructed using Excel version 2003 spreadsheet. Data of qualitative variables are given in terms of absolute or relative frequencies while that of quantitative variables (abundance counts) was given in terms of mean ± standard error (se). Two independents percentages were compared using the Fisher exact test while two mean values were compared using the Student t-test when the conditions of normality and equality variance passed. Otherwise we used the nonparametric Mann-Whitney rang sum test. Simultaneous comparison of several quantitative series was set up using the one-way ANOVA procedure when the conditions of normality and equal variance passed. Otherwise we used Kruskall-Wallis

test from SigmaStat software 2.03 (SPSS, Inc., Chicago, IL) and pairwise comparisons were set up when relevant using Dunn's procedure. For the simultaneous comparison of several percentages, the asymptotic p-value or the exact p-value was determined using the independent chi-square test or the Fisher-Freeman-Halton test from StatXact software version 3.1. When the difference was globally significant, the pairwise comparison was conducted and the significance level corrected using the Bonferroni procedure. Regression equation was set up when necessary and tested using ANOVA test. Analysis of the species abundances allowed the determination of 15 indexes using PAST 3.05 software: (1) absolute abundance of the i^{th} species n_i, (2) observed sample size n, (3) relative abundance of the i^{th} species $p_i=(n_i/n)*100$, (4) species richness S, (5) maximum abundance n_1 or n_{max}, (6) Margalef's index $Mg=(S-1)/\ln(n)$, (7) richness ratio d=S/n with 0 (low-rich communities)≤d≤+1 (very species-rich communities), (8) Shannon-Weaver diversity index H' with 0 (for a single-species community)≤H'≤H'_{max}=ln(S) (for perfect species regularity of abundances), (10) Simpson diversity index D with 0 (for high diversities)≤D≤+1 (for low diversity), (11) Hill's first-order diversity number $N_1=e^{H'}$ for the estimated number of abundant species, (12) Hill's second-order diversity number $N_2=1/D$ (estimated number of co-dominant species), (13) Hill's ratio $Hill=N_2/N_1$ with 0≤Hill≤+1, (14) Pielou's evenness index J=H'/ln(S) with 0 (perfect heterogeneity of the assemblage)≤J≤+1 (perfect balance of abundances), and (15) Berger-parker dominance index $I_{BP}=n_{max}/n$ (low value reflects a high diversity). The Pielou's index varies from 0 (complete heterogeneity) to 1 (perfect homogeneity of the community). Comparison of the species richness was performed using the individual rarefaction procedure. The non-parametric estimator Chao1 was used to estimate the theoretical species richness T and the sampling effort was estimated as (S/T)*100. The overall species covariance was evaluated using Schluter's procedure [31]. Between species correlation was evaluated using Kendall's correlation. The dissimilarity between sites, mouths and rivers was evaluated using Bray-Cutis index. The correlation between the presence of each species and the physicochemical parameters of water was tested using the point-bisserial correlation. The rank abundance plotting was used to illustrate the shape of the species abundance distribution (SAD). We used five theoretical models to fit the curves: broken-stick (BS), log-linear (LL), lognormal (LN), Zipf (Z) and Zipf-Mandelbrot (ZM). The best model was selected using Akaike Information Criteria (AIC) or Bayesian Information Criteria (BIC) (the best model presented the lowest AIC or BIC). The estimated sample size n* was adjusted to the observed size n using the correction factor n/n*. The package vegan of R 3.4.1 software helped us to adjust the SADs.

3. Results

3.1. Physico-Chemical Parameters and the Water Quality

Nyong and Kienké River mouths belonged to the warm river category (Table 1). During the two seasons, the average temperature, transparency and pH were within the tolerable limit standards for drinking water or for fish farming (Table 1). On the other hand, the average NO_3^-, Chlorophyll a and biomass were lower than the standard limits (Table 1). The average of DO and FC were higher than the upper limit standard, except the DO in the Kienké River mouth (Table 1). NO_2^- was during the dry season, on average lower than the recommended lower standard (Table 1). However, in Nyong River mouth, the average value of NO_2^- was higher during the rainy season than the upper limit standard while in the Kienké River mouth; it was within the recommended range (Table 1). TSS averages in the Nyong River mouth were within acceptable standards for fish farming but above the upper limit standard for drinking water. On the other hand, in the Kienké River mouth, values were on average within the standard range during the dry season but in the rainy season, they were lower than the lower limit of the standard range (Table 1). The BOD_5, conductivity, NH_4^+ and PO_4^{3-} had no standard limits. Between seasons the difference in water temperature was significantly high during the rainy season than the dry season, while it was the opposite for DO which was rather high during the dry season than the rainy season in both river mouths (Table 1). The mean difference in transparency, water conductivity and PO_4^{3-} was not significant in the Nyong River mouth, however in the Kienké River mouth, it was significantly lower during the dry season than the rainy season. The difference in BOD_5 and NO_3^- was not significant in the Kienké River while in the Nyong River it was significantly low during the dry season than the rainy season (Table 1). In the Nyong River mouth, a negative correlation was noted between temperature and DO (r=-0.735, $p=3.8x10^{-6}$), DO and NO_3^- (r=-0.581, p=0.001), transparency and NO_3^- (r=-0.485, p=0.007), NO_2^- and BOD_5 (r=-0.404, p=0.027). A positive correlation was noted between pH and salinity (r=0.675, $p=4.3x10^{-5}$), pH and BOD_5 (r=0.442, p=0.015), pH and chlorophyll a or biomass (r=0.452, p=0.012 respectively), DO and transparency (r = 0.386, p=0.035), DO and BOD_5 (r=0.433, p=0.0.017), salinity and NH_4^+ (r=0.491, p=0.006), salinity and BOD_5 (r=0.612, $p=3.3x10^{-4}$), salinity and chlorophyll a or biomass (r=0.531, p=0.003 respectively), transparency and PO_4^{3-} (r=0.510, p=0.004), transparency and FC (r=0.557, p=0.001), salinity and chlorophyll a or biomass (r=0.426, p=0.019 respectively), NH_4^+ and BOD_5 (r=0.479, p=0.007), NH_4^+ and chlorophyll a or biomass (r=0.394, p = 0.031 respectively), BOD_5 and chlorophyll a or biomass (r=0.401, p=0.028 respectively), chlorophyll a and biomass (r=1.00, $p=2.4x10^{-137}$). Between TSS, PO_4^{3-}, NO_3^-, chlorophyll a and other parameters, correlations were not significant.

In the Kienké River mouth, correlation was positive between temperature and salinity (r=0.537, p=0.007), temperature and PO_4^{3-} (r=0.614, p=0.001), DO and NH_4^+ (r=0.425, p=0.039), salinity and PO_4^{3-} (r=0.504, p=0.012), salinity and NO_2^- (r=0.420, p=0.041), TSS and BOD_5 (r=0.555, p=0.005), TSS and chlorophyll a or biomass (r=0.564, p=0.004 respectively), NO_3^- and NO_2^- (r=0.429, p=0.037), NO_3^- and FC (r=0.707, $p=1.1x10^{-4}$), NO_2^- and FC

(r=0.482, p=0.017), chlorophyll a and biomass (r=1.00, $p=3.4x10^{-108}$). On the other hand, the correlation was negative between water temperature and transparency (r=-0.481, p=0.017), temperature and DO (r=-0.593, p=0.002), temperature and PO_4^{3-} (r=-0.611, p=0.002). Correlations between pH, BOD_5, CF, transparency, NH_4^+ or PO_4^{3-} and other parameters were not significant.

Based on the pooled data, a positive correlation was noted between temperature and NO_3^- (r=0.336, p=0.013), pH and salinity (r=0.478, $p=2.6x10^{-4}$), pH and NH_4^+ (r=0.373, p=0.005), pH and chlorophyll a or biomass (r=0.351, p=0.009 respectively), salinity and NH_4^+ (r=0.297, p=0.029). A positive correlation was also noted between temperature and salinity and BOD_5 (r=0.310, p=0.022), TSS and BOD_5 (r=0.391, p=0.003), TSS and chlorophyll a or biomass (r=0.442, p=0.001 respectively), NO_2^- and FC (r=0.314, p=0.021), BOD_5 and chlorophyll a or biomass (r=0.343, p=0.011 respectively), chlorophyll a and biomass (r=1.000, $p=7.4x10^{-254}$). On the other hand, the correlation was negative between transparency and NO_3^- (r=-0.361, p=0.007), temperature and DO (r=-0.569, $p=7.0x10^{-6}$), temperature and transparency (r=-0.378, p=0.005), pH and NO_3^- (r=-0.309, p=0.023) or NO_2^- (r=-0.351, p=0.009). Correlations between DO, PO_4^{3-}, NO_3^-, NH_4^+, FC and other parameters were not significant.

3.2. Biodiversity of Aquatic Green-Blue Algae

A total of $10802.1x10^5$ cells of Cyanophyceae Schaffner, 1909 were collected, corresponding to seven orders (Table 2) [(1) Chroococcales J. H. Schaffn., 1922; (2) Gomontiellales Strunecky & Mares, 2023; (3) Nodosilineales Strunecky & Mares, 2023; (4) Nostocales Cavalier-Smith, 2002; (5) Oscillatoriales Cavalier-Smith, 2002; (6) Pseudanabaenales L. Hoffmann, J. Komárek & J. Kaštovský, 2005; and (7) Synechococcales L. Hoffm., Komárek & Kaštovský, 2005]. Sixteen families were identified. Four families (25.0%) belonged to Chroococcales [(1) Chroococcaceae Rabenhorst, 1863, (2) Gomphosphaeriaceae Elenkin, 1933, (3) Cyanothrichaceae Elenkin corrig. Kiselev 1947, and (4) Microcystaceae Elenkin, 1933].

Table 1. *Minimum, maximum and mean values (± standard error) of the physico-chemical parameters of the water in the Nyong and Kienké River mouths.*

River Mouths/Physico-chemical parameters	References	Min.-Max. (Mean±se)	Min.-Max. (Mean±se)
A. Nyong River mouth		Dry season: n=10	Rainy season: n=20
Temp. (warm river: ≥20°C)	[32, 33]	26.0-26.4 (26.1±0.05)	27.2-32.4 (39.3±0.3)
Trans. (norm: 128 to 153 cm)	[34]	43.0-225.0 (142.9±17.6)	46.0-152.0 (95.2±6.7)
DO (norm: 5.8 to 7.0 $mg.l^{-1}$)	[34]	25.3-39.5 (30.3±1.3)	5.8-10.9 (8.1±0.3)
BOD_5 (mg.l-1) (no limits)	[32]	6.0-40.0 (24.7±3.8)	5.0-38.0)(15.7±2.0)
pH (norm: 6.5-8.5)	[32]	6.1-7.9 (6.8±0.2)	6.2-8.9 (7.0±0.2)
Conductivity ($\mu S.cm^{-1}$)		18.0-26150.0 (4175.1±2875.4)	22.1-35540.0 (5524.8±2787.8)
NO_2^- (norm: 3 $mg.l^{-1}$)	[32]	0-0.02 (0.004±0.002)	0.0-16.5 (3.4±1.2)
NO_3^- (norm: 50 $mg.l^{-1}$)	[32]	0-1.8 (0.4±0.2)	0.6-9.9 (2.9±0.5)
NH_4^+ (no limits)	[32]	0.2-14.1 (2.2±1.4)	0.2-3.7 (1.1±0.2)
PO_4^{3}- (no limits)	[32]	0.08-1.12 (0.49±0.13)	0.0-2.0 (0.5±0.1)
Chl. a (norm: 10 $\mu g.l^{-1}$)	[12, 35]	0.02-0.30 (0.11±0.03)	0.01-0.30 (0.07±0.01)
Biomass ($mg.c.l^{-1}$)		0.6-9.0 (3.2±1.0)	0.3-9.0 (2.1±0.6)
FC (drinking: 0 per 100 ml)	[36, 37]	87.0-500.0 (209.0±43.1)	75.0-432.0 (154.3±23.2)
TSS	[36-39]	3.0-24.0 (13.1±2.3)	0.0-24.0 (10.1±1.6)
B. Kienké River mouth		Dry season: n=8	Rainy season: n=16
Temp. (warm river: ≥20°C)	[32, 33]	25.9-27.2 (26.5±0.2)	27.1-29.7 (28.3±0.2)
Trans. (norm: 128 to 153 cm)	[34]	140.0-325.0 (214.6±22.1)	46.0-221.0 (126.5±12.7)
DO (norm: 5.8 to 7.0 $mg.l^{-1}$)	[34]	9.7-17.8 (13.3±1.2)	0.4-13.0 (4.4±0.9)
BOD_5 (mg.l-1) (no limits)	[32]	5.0-23.0 (13.5±2.2)	2.5-50.0 (19.0±3.0)
pH (norm: 6.5-8.5)	[32]	6.5-8.5 (7.5±0.2)	6.4-8.1 (7.5±0.2)
Conductivity ($\mu S.cm^{-1}$)		16.4-99.6 (40.3±8.8)	540.0-40600.0 (17065.3±3343.8)
NO_2^- (norm: 3 $mg.l^{-1}$)	[32]	0.0-0.007 (0.002±0.001)	(0.0-27.0)(3.0±1.7)
NO_3^- (norm: 50 $mg.l^{-1}$)	[32]	0.0-0.6 (0.2±0.1)	0.0-3.7 (0.7±0.2)
NH_4^+ (no limits)	[32]	1.2-9.8 (3.6±1.3)	0.2-9.8 (1.5±0.6)
PO_4^{3}- (no limits)	[32]	0.0-0.21 (0.06±0.03)	0.0-0.43 (0.18±0.03)
Chl. a (norm: 10 $\mu g.l^{-1}$)	[12, 35]	0.02-0.22 (0.10±0.03)	0.02-0.40 (0.09±0.03)
Biomass ($mg.c.l^{-1}$)		0.7-6.6 (3.1±0.9)	0.7-12.0 (2.8±1.0)
FC (drinking: 0 per 100 ml)	[36, 37]	133.0-671.0 (257.5±61.7)	84.0-1440.0 (368.2±92.6)
TSS	[36-39]	1.5-27.0 (10.8±2.9)	0.0-33.0 (9.8±2.1)
Temp. (warm river: ≥20°C)	[32, 33]	26.0-32.4 (28.3±0.4)	t=6.528, p<0.001 *
Trans. (norm: 128 to 153 cm)	[34]	43.0-225.0 (111.1±8.3)	t=0,582, p=0.565 ns
DO (norm: 5.8 to 7.0 mg.l-1)	[34]	5.8-39.5 (15.5±2.0)	t=-21.103, p<0.001 *
BOD_5 (mg.l-1) (no limits)	[32]	5.0-40.0 (18.7±2.0)	t=-2.306, p=0.029 *
A. Nyong River mouth		Pooled data: n=30	Student t-test (df = 28)
pH (norm: 6.5-8.5)	[32]	6.1-8.9 (7.0±0.1)	t=0.582, p=0.565 ns

Table 1. *Continued.*

River Mouths/Physico-chemical parameters	References	Min.-Max. (Mean±se)	Dry season vs. Rainy season
Conductivity (µS.cm^{-1})		18.0-25540.0 (5074.9±2064.9)	t=0.303, p=0.764 ns
NO_2^- (norm: 3 mg.l^{-1})	[32]	0.0-16.5 (2.3±0.8)	t=2.022, p=0.053 ns
NO_3^- (norm: 50 mg.l^{-1})	[32]	0.0-0.9 (2.0±0.4)	t=3.751, p=8.2x10-4 *
NH_4^+ (no limits)	[32]	0.2-14.1 (1.5±0.5)	t=-1.101, p=0.280 ns
PO_4^{3-} (no limits)	[32]	0.0-2.0 (0.5±0.1)	t=0.272, p=0.787 ns
Chl. a (norm: 10 µg.l^{-1})	[12, 35]	0.01-0.30 (0.08±0.02)	t=-0.958, p=0.346 ns
Biomass (mg.c.l^{-1})		0.3-9.0 (2.5±0.5)	t=-0.958, p=0.346 ns
FC (drinking: 0 per 100 ml)	[36, 37]	75.0-500.0 (172.5±21.2)	t=-1.225, p=0.231 ns
TSS	[36-39]	0.0-24.0 (11.1±1.3)	t=-1,089, p=0.285 ns
B. Kienké River mouth		Pooled data: n=24	Student t-test (df = 22)
Temp. (warm river: ≥20°C)	[32, 33]	25.9-29.7 (27.7±0.2)	t=5.395, p=2.0x10-5 *
Trans. (norm: 128 to 153 cm)	[34]	46.0-325.0 (155.9±14.0)	t=-3.714, p=1.2x10-3 *
DO (norm: 5.8 to 7.0 mg.l^{-1})	[34]	0.4-17.8 (7.3±1.1)	t=-5.690, p=1.0x10-5 *
BOD_5 (mg.l-1) (no limits)	[32]	2.5-50.0 (17.2±2.1)	t=1.232, p=0.231 ns
pH (norm: 6.5-8.5)	[32]	6.4-8.5 (7.5±0.1)	t=-0.171, p=0.866 ns
Conductivity (µS.cm^{-1})		16.4-40600.0 (11390.3±2768.0)	t=3.560, p=1.8x10-3 *
NO_2^- (norm: 3 mg.l^{-1})	[32]	0.0-27.0 (2.0±1.2)	t=1.215, p=0.237 ns
NO_3^- (norm: 50 mg.l^{-1})	[32]	0.0-3.7 (0.5±0.2)	t=1.244, p=0.226 ns
NH_4^+ (no limits)	[32]	0.2-9.8 (2.2±0.6)	t=-1.676, p=0.108 ns
PO_4^{3-} (no limits)	[32]	0.0-0.43 (0.14±0.03)	t=2.460, p=0.022 *
Chl. a (norm: 10 µg.l^{-1})	[12, 35]	0.02-0.40 (0.10±0.02)	t=-0.171, p=0.866 ns
Biomass (mg.c.l^{-1})		0.7-12.0 (2.9±0.7)	t=-0.171, p=0.866 ns
FC (drinking: 0 per 100 ml)	[36, 37]	84.0-1440.0 (331.3±65.1)	t=0.796, p=0.435 ns
TSS		0.0-33.0 (10.1±1.7)	t=-0.278, p=0.784 ns

Temp: Temperature (°C), Trans: Transparency (cm) (norm: 128 to 153 cm), DO: Dissolved oxygen (mg.l-1), BOD_5: Biochemical Oxygen Demand for five days (mg.l-1), pH: the potential of hydrogen, NO_2^-: Nitrite (mg.l-1), NO_3^-: Nitrate (mg.l-1), NH_4^+: Ammoniacal nitrogen (mg.l-1), PO_4^{3-}: Orthophosphate (mg.l-1), Chl. a: Chlorophyll a (µg.l-1), FC: Faecal coliforms (CFU.(100 ml) -1), TSS: Total Suspended Solids (mg.l-1) (norm for drinking water: 0 per 100 ml and norms for fish farming: 10-20 mg.l^{-1};>25-40 mg.l^{-1} [36-39]), Min.: Minimum, Max.: Maximum, n: sample size; se: standard error, ns: not significant difference (p≥0.05), *: significant difference (p<0.05).

Table 2. *Absolute and relative abundance of the blue-green algae orders in Nyong and Kienké River mouths.*

Orders	A. Nyong River mouth				B. Kienké River mouth			
	S (%)	n x10^5 (%)	Min.-Max. x10^5	Mean±se x10^5	S (%)	n x10^5 (%)	Min.-Max. x10^5	Mean±se x10^5
Chroococcales	9 (24.3)	1833.3 (17.0)	20.8-712.8	203.7 ± 74.4	10 (27.0)	2458.3 (22.8)	41.7-562.5	245.8 ± 57.8
Gomontiellales	1 (2.7)	145.8 (1.4)	145.8	145.8	1 (2.7)	333.3 (3.1)	333.3	333.3
Nodosilineales	1 (2.7)	166.7 (1.5)	166.7	166.7	1 (2.7)	187.5 (1.7)	187.5	187.5
Nostocales	13 (35.1)	1989.6 (18.4)	20.8-375.0	153.0 ± 33.4	14 (37.8)	2937.5 (37.2)	20.8-1312.5	209.8 ± 89.6
Oscillatoriales	3 (8.1)	145.8 (1.4)	20.8-93.8	48.6 ± 22.8	3 (8.1)	166.7 (1.5)	20.8-114.6	55.6 ± 29.7
Pseudanabaenales	-	-	-	-	1 (2.7)	63.0 (0.6)	62.5	62.5
Synechococcales	1 (2.7)	156.8 (1.5)	156.8	156.8	1 (2.7)	218.3 (2.0)	218.3	218.3
Global	28 (75.7)	4438.0 (41.1)	20.8-718.8	158.5 ± 28.9	31 (83.8)	6364.1 (58.9)	20.8-1312.5	205.3 ± 45.1
Comparison	FFH: df=6 p=2.2x10^{-7}*	FFH: df=6 p<0.001*	-	$F_{(3; 21)}$=0.950, # p=0.434 ns	FFH: df=6 p=2.0x10^{-7}*	FFH: df=6 p<0.001*	-	$F_{(3; 23)}$=0.366, # p=0.778 ns

Orders	C. Global				D. Comparison of the mean values: A *vs.* B
	S (%)	n x10^5 (%)	Min.-Max. x10^5	Mean ± se x10^5	
Chroococcales	11 (29.7)	4291.7 (39.7)	62.5-1281.3	390.2 ± 112.5	Student test: t = -0.452, df = 17, p = 0.657 ns
Gomontiellales	1 (2.7)	479.2 (4.4)	479.2	479.2	-
Nodosilineales	1 (2.7)	354.2 (3.3)	354.2	354.2	
Nostocales	17 (45.9)	4927.1 (45.6)	20.8-1541.7	289.8 ± 86.1	Mann-Whitney test: T = 215.0, p = 0.844 ns
Oscillatoriales	5 (13.5)	312.5 (2.9)	20.8-208.3	62.5 ± 36.5	Student test: t = -0.281, df = 7, p = 0.787 ns
Pseudanabaenales	1 (2.7	63.0 (0.6)	62.5	62.5	-
Synechococcales	1 (2.7)	375.0 (3.5)	375.0	375.0	-
Global	37 (100.0)	10802.1 (100.0)	20.8-1541.7	291.9 ± 54.1	Student test: t = -0.855, df = 57, p = 0.396 ns
Comparison	FFH: df=6 p=1.7x10^{-9}*	FFH: df=6 p<0.001*	-	$F_{(3; 29)}$=1.125, # p=0.355 ns	

S: species richness, se: standard error, n: Global sample size, df: degree of freedom, Min.: Minimum abundance, Max.: Maximum abundance. FFH: Fisher-Freeman-Halton test, KW: Kruskall-Wallis multiple non-parametric rank-sum test, #: Fisher's one-way ANOVA, ns: not significant difference (p>0.05), *: significant difference (p<0.05)

One family (6.3%) of Gomontiellales (Cyanothecaceae J. Komárek, J. Kastovsky, J. Mares & J. R. Johansen, 2014) was recorded. One family (6.3%) of Nodosilineales (Cymatolegaceae Strunecky & Mares, 2023) was identified. six families (37.5%) of Nostocales were recorded: (1) Hapalosiphonaceae Elenkin, 1916, (2) Aphanizomenonaceae Elenkin, 1938, (3) Nodulariaceae Elenkin, 1916, (4) Nostocaceae Eichler, 1886, (5) Rivulariaceae Frank, 1886, and (6) Tolypothrichaceae Hauer, Bohunická, J. R. Johansen Mares & Berrendero-Gomez, 2014. Two families (12.5%) of Oscillatoriales were recorded: (1) Microcoleaceae O. Strunecky, J. R. Johansen & J. Komárek, 2013, and (2) Oscillatoriaceae Engler, 1898. One family (6.3%) of Pseudanabaenales (Pseudanabaenaceae K. Anagnostidis & J. Komárek, 1988) was identified. One family (6.3%) of Synechococcales (Coelosphaeriaceae Elenkin, 1933) was identified. Nostocales was the most species-rich (Nyong river mouth: 35.1% of the total richness; Kienké river mouth: 37.8%; pooled data: 45.9%) and the most abundant order (Nyong river mouth: 18.4% of the total collection; Kienké river mouth: 37.2%; pooled data: 45.6%) (Tables 2A, 2B, 2C). It was followed by Chroococcales for the species richness (Nyong river mouth: 24.3% of the total richness; Kienké river mouth: 27.0%; pooled data: 29.7%) and the abundance (Nyong river mouth: 17.0% of the total collection; Kienké river: 22.8%; pooled data: 39.7%) (Table 2A, 2B, 2C). Other orders were each represented by less than 3% of the total species richness and less than 5% of the total collection. For each order, the mean difference was not significant between the two river mouths and in each river mouth. Nostocales was the most species-rich order (17 species, 45.9% of the total species richness) and the most abundant (45.6%) followed by Synechococcales (nine species i.e. 24.3% and 26.7% of abundance), by Oscillatoriales (six species i.e. 16.2% and 7.3%).

Chroococcales was the least species-rich order (five species i.e. 13.5% of the total species richness and 20.3% of the total abundance) (see Table 2). For each order, comparison of abundances between the two mouths was not significant (see Tables 2). Sixteen families were identified (Table 3). The recorded families were divided into four families i.e. 25.0% of Chroococcales. These families were (1) Chroococcaceae Rabenh., 1863, (2) Cyanothrichaceae, (3) Gomphosphaeriaceae Elenkin, 1933, and (4) Microcystaceae Elenkin, 1933. Six families i.e. 37.5% of Nostocales were recorded: (1) Aphanizomenonaceae J. Komárek, J. Kaštovský, J. Mareš & J. R. Johansen, 2014, (2) Hapalosiphonaceae Elenkin, 1916, (3) Nodulariaceae, (4) Nostocaceae Eichler, 1886, (5) Rivulariaceae Frank, 1886, and (6) Tolypothrichaceae. Two families i.e. 12.5% of Oscillatoriales were recorded: (1) Microcoleaceae O. Strunecky, J. R. Johansen & J.Komárek, 2013, and (2) Oscillatoriaceae Engler, 1898. Four orders were represented respectively by only one family i.e. 6.3% [(1) Gomontiellales by Cyanothecaceae J. Komárek, J. Kaštovský, J. Mareš & J. R. Johansen, 2014, (2) Nodosilineales by Cymatolegaceae Strunecky & Mares, 2023, (3) Pseudanabaenales by Pseudanabaenaceae K. Anagnostidis & J. Komárek, 1988, and (4) Synechococcales by Coelosphaeriaceae Elenkin, 1933] (Table 3). Between families, the variation of the species richness and the mean abundance values were not significant in both river mouths and the pooled data (Table 3A, 3B, 3C). Based on the total abundances, Microcystaceae was the most recoded (14.6% in the Nyong River mouth, 20.2% in the Kienké River Mouth, and 34.7% in the pooled data). Il was followed by Aphanizomenonaceae (2.9% in the Nyong River mouth, 17.9% in the Kienké River mouth, and 20.8% in the pooled data), by Rivulariaceae (7.6% in the Nyong River mouth, 4.7% in the Kienké River mouth, and 12.3% in the pooled data), by Nodulariaceae (4.3% in the Nyong River mouth, 3.6% in the Kienké River mouth, and 7.9% in the pooled data). Other families were represented each by less the 5% of the total collection (Tables 3A, 3B, 3C).

Twenty-eight genera and 37 species were recorded (Table 4). Microcystaceae was the most species-rich family (seven species i.e. 18.9% of the total species richness in the Nyong River mouth, and eight species i.e. 21.6% in the Kienké River mouth and the pooled data respectively). It was the most abundant family (14.6% of the total collection in the Nyong River mouth, 20.2% in the Kienké River mouth, and 34.7% in the pooled data). These seven species were: (1) *Aphanocapsa delicatissima* West & G. S. West, 1912 (0.96%), (2) *Ap. elachista* West & G. S. West 1894 (0.77%), (3) *Aphanothece elabens* (Meneghini) Elenkin, 1936 (7.33%), (4) *Coelosphaerium confertum* West & G. S. West 1896 (3.09%), (5) *Ce. kuetzingianum* Nägeli 1849 (2.89%), (6) *Merismopedia elegans* A. Braun ex Kützing 1849 (2.70%), (7) *Microcystis aeruginosa* (Kützing) Kützing, 1846 (5.11%) and (8) *Synechocystis aquatilis* Sauvageau 1892 (11.86%) (Table 4). It was followed Rivulariaceae (four species i.e. 10.8% in the Nyong River mouth and Kienké River mouth respectively, and five species i.e. 13.5% in the pooled data). These five species were: (1) *Ca. brevissima* G. S. West 1907 (1.25%), (2) *Calothrix scytonemicola* Tilden 1910 (3.76%), (3) *Microchaete investiens* Frémy 1930 (0.87%), and (4) *Mi. uberrima* N. Carter 1926 (1.74%), and (5) *Rivularia aquatica* De Wildeman, 1897 (4.73%) (Table 4). Aphanizomenonaceae was represented by two species (5.4%) in the Nyong River mouth, four species (10.8%) in the Kienké River mouth, and four species (10.8%) in the pooled data. These four species were: (1) *Anabaena flos-aquae f. gracilis* (Klebahn) Elenkin 1938 (3.47%), (2) *An. sphaerica* Bornet & Flahault 1886 (1.74%), (3) *Raphidiopsis mediterranea* Skuja 1937 (14.27%), and (4) *Gloeotrichia natans* Rabenhorst ex Bornet & Flahault, 1886 (1.35%) (Table 4). Nodulariaceae was represented by three species (8.1%) in the Nyong River mouth, the Kienké River mouth and the pooled data respectively. These three species were: (1) *Anabaenopsis arnoldii* Aptekar, 1926 (3.47%), (2) *Aa. circularis* (G. S. West) Wołoszyńska & V. V. Miller, 1923 (3.86%) and (3) *Aa. tanganyikae* (G. S. West) Wołoszyńska & V. V. Miller, 1923 (0.58%) (Table 4).

Table 3. *Absolute and relative abundances of the blue-green algae families in Nyong and Kienké River mouths.*

Orders/families	A. Nyong River mouth				B. Kienké River mouth			
	S (%)	n x10^5 (%)	Min.-Max. x10^5	Mean±se x10^5	S (%)	n x10^5 (%)	Min-Max x10^5	Mean±se x10^5
Chroococcales								
Chroococcaceae	-	-	-	-	1 (2.7)	62.5 (0.6)	62.5	62.5 ± 0.0
Cyanothrichaceae	1 (2.7)	197.9 (1.8)	197.9	197.9 ± 0.0	1 (2.7)	218.8 (2.0)	218.8	218.8 ± 0.0
Gomphosphaeriaceae	1 (2.7)	62.5 (0.6)	62.5	62.5 ± 0.0	-	-	-	-
Microcystaceae	7 (18.9)	1572.9 (14.6)	20.8-718.8	224.7 ± 94.6	8 (21.6)	2177.1 (20.2)	41.7-562.5	272.1 ± 68.2
Gomontiellales								
Cyanothecaceae	1 (2.7)	145.8 (1.4)	145.8	145.8 ± 0.0	1 (2.7)	333.3 (3.1)	333.3	333.3 ± 0.0
Nodosilineales								
Cymatolegaceae	1 (2.7)	166.7 (1.5)	166.7	166.7 ± 0.0	1 (2.7)	187.5 (1.7)	187.5	187.5 ± 0.0
Nostocales								
Aphanizomenonaceae	2 (5.4)	312.5 (2.9)	83.3-229.2	156.3 ± 72.9	4 (10.8)	1937.5 (17.9)	62.5-1312.5	484.4 ± 283.4
Hapalosiphonaceae	2 (5.4)	72.9 (0.7)	20.8-52.1	36.5 ±15.6	1 (2.7)	20.8 (0.2)	20.8	20.8 ± 0.0
Nodulariaceae	3 (8.1)	468.8 (4.3)	31.3-375.0	156.3 ± 109.7	3 (8.1)	385.4 (3.6)	31.3-312.5	128.5 ± 92.1
Nostocaceae	1 (2.7)	125.0 (1.2)	125.0	125.0 ± 0.0	2 (5.4)	83.3 (0.8)	20.8-62.5	41.7 ± 20.8
Rivulariaceae	4 (10.8)	822.9 (7.6)	31.3-322.9	205.7 ± 64.7	4 (10.8)	510.4 (4.7)	93.8-187.5	127.6 ± 21.0
Tolypothrichaceae	1 (2.7)	187.5 (1.7)	187.5	187.5 ± 0.0	-	-	-	-
Oscillatoriales								
Microcoleaceae	1 (2.7)	93.8 (0.9)	93.8	93.8 ± 0.0	2 (5.4)	135.4 (1.3)	20.8-114.6	67.7 ± 46.9
Oscillatoriaceae	2 (5.4)	52.1 (0.5)	20.8-31.3	26.0 ± 5.2	1 (2.7)	31.3 (0.3)	31.3	31.3 ± 0.0
Pseudanabaenales								
Pseudanabaenaceae	-	-	-	-	1 (2.7)	62.5 (0.6)	62.5	62.5 ± 0.0
Synechococcales								
Coelosphaeriaceae	1 (2.7)	156.8 (1.5)	156.8	156.8 ± 0.0	1 (2.7)	218.3 (2.0)	218.3	218.3 ± 0.0
Global	28 (75.7)	4438.0 (41.1)	20.8-718.8	158.5 ± 28.9	31 (83.8)	6364.1 (58.9)	20.8-1312.5	205.3 ± 45.1
Comparison	FFH: df=15 p=0.090ns	FFH: df=15 p<0.001 *	-	KW: df=16 p=0.743 ns	FFH:df=15 p=0.184 ns	FFH: df=15 p<0.001 *	-	KW: df=19 p=0.499 ns

Orders/families	C. Global				E. Comparison of the mean values: A *vs.* B
	S (%)	n x10^5 (%)	[Min.-Max.] x10^5	(Mean ± se) x10^5	
Chroococcales					
Chroococcaceae	1 (2.7)	62.5 (0.6)	62.5	62.5 ± 0.0	-
Cyanothrichaceae	1 (2.7)	416.7 (3.9)	416.7	416.7 ± 0.0	-
Gomphosphaeriaceae	1 (2.7)	62.5 (0.6)	62.5	62.5 ± 0.0	-
Microcystaceae	8 (21.6)	375.0 (34.7)	83.3-1281.3	468.7 ± 141.9	Mann-Withney test: T = 66.0; p=0.597 ns
Gomontiellales					
Cyanothecaceae	1 (2.7)	479.2 (4.4)	479.2	479.2 ± 0.0	-
Nodosilineales					
Cymatolegaceae	1 (2.7)	354.2 (3.3)	354.2	354.2 ± 0.0	-
Nostocales					
Aphanizomenonaceae	4 (10.8)	2250.0 (20.8)	145.8-1541.7	562.5 ± 330.2	Mann-Withney test: T = 9.0; p=0.700 ns
Hapalosiphonaceae	2 (5.4)	93.8 (0.9)	20.8-72.9	46.9 ± 26.0	Mann-Withney test: T = 5.0; p=1.00 ns
Nodulariaceae	3 (8.1)	854.2 (7.9)	62.5-416.7	284.7 ± 111.8	Mann-Withney test: T = 7.0; p=0.333 ns
Nostocaceae	2 (5.4)	208.3 (1.9)	62.5-145.8	104.2 ± 41.7	Mann-Withney test: T = 3.0; p=0.667 ns
Rivulariaceae	5 (13.5)	1333.3 (12.3)	93.8-510.4	266.7 ± 81.3	Mann-Withney test: T = 8.5; p=0.400 ns
Tolypothrichaceae	1 (2.7)	187.5 (1.7)	187.5	187.5 ± 0.0	-
Oscillatoriales					
Microcoleaceae	2 (5.4)	229.2 (2.1)	20.8-208.3	114.6 ± 93.8	Mann-Withney test: T = 1.0; p=0.667 ns
Oscillatoriaceae	3 (8.1)	83.3 (0.8)	20.8-31.3	27.8 ± 3.5	Mann-Withney test: T = 5.5; p=0.800 ns
Pseudanabaenales					
Pseudanabaenaceae	1 (2.7)	62.5 (0.6)	62.5	62.5 ± 0.0	-
Synechococcales					
Coelosphaeriaceae	1 (2.7)	375.0 (3.5)	375.0	375.0 ± 0.0	-
Global	37 (100.0)	10802.1 (100.0)	20.8-1541.7	291.9 ± 54.1	Student test: t = -0.855, df = 57, p = 0.396 ns
Comparison	FFH: df=15 p=0.112 ns	FFH: df=15 p<0.001 *	-	KW: df=19 p=0.305 ns	

S: species richness, se: standard error, n: Global sample size, df: degree of freedom, Min.: Minimum abundance, Max.: Maximum abundance. FFH: Fisher-Freeman-Halton test, KW: Kruskall-Wallis multiple non-parametric rank-sum test, #: parametric one-way ANOVA, ns: not significant difference (p>0.05), *: significant difference (p<0.05)

Table 4. *Absolute and relative abundances of the blue-green algae species. Percentages were determined relative to the overall collection.*

		A. Nyong River mouth x10^5			B. Kienké River mouth x10^5		
ORDERS/Families/Species	**References**	**I: n (%)**	**II: n (%)**	**Total: n (%)**	**I: n (%)**	**II: n (%)**	**Total: n (%)**
CHROOCOCALES/Chroococcaceae							
Chroococcus turgidus #, †, ‡, US(BC, AM, PB)	[8, 40]	-	-	-	-	62.5 (0.6)	62.5 (0.6)
CHROOCOCALES/Cyanothrichaceae							
Limnococcus limneticus #, UN(NTS)	[8, 41]	93.8 (0.9)	104.2 (1.0)	197.9 (1.8)	93.8 (0.9)	125.0 (1.2)	218.8 (2.0)
CHROOCOCALES/Gomphosphaeriaceae							
Gomphosphaeria aponina #, ‡, US(BC)	[8, 48-50]	-	62.5 (0.6)	62.5 (0.6)	-	-	-
CHROOCOCALES/Microcystaceae							
Aphanocapsa delicatissima #, UN(NTS)	[8]	62.5 (0.6)	-	62.5 (0.6)	41.7 (0.4)	-	41.7 (0.4)
Ap. elachista #, UN(NTS)	[8]	-	-	-	83.3 (0.8)	-	83.3 (0.8)
Aphanothece elabens #, TS	[8, 45]	125.0 (1.2)	125.0 (1.2)	250.0 (2.3)	83.3 (0.8)	458.3 (4.2)	541.7 (5.0)
Coelosphaerium confertum #, TS(PT)	[8]	20.8 (0.2)	-	20.8 (0.2)	-	312.5 (2.9)	312.5 (2.9)
Ce. kuetzingianum #, UN(PT)	[8, 51-53]	-	62.5 (0.6)	62.5 (0.6)	-	250.0 (2.3)	250.0 (2.3)
Merismopedia elegans *, #, †, ‡, US(PPP)	[8, 54]	31.3 (0.3)	62.5 (0.6)	93.8 (0.9)	197.9 (1.8)	-	197.9 (1.8)
Microcystis aeruginosa #, †, TS	[8, 19, 42-44, 55]	-	364.6 (3.4)	364.6 (3.38)	62.5 (0.6)	125.0 (1.2)	187.5 (1.7)
Synechocystis aquatilis #, TS	[8, 20]	375.0 (3.5)	343.8 (3.2)	718.8 (6.7)	250.0 (2.3)	312.5 (2.9)	562.5 (5.2)
GOMONTIELLALES/Cyanothecaceae							
Cyanothece aeruginosa #, ‡, US(BF, NF)	[8, 47]	145.8 (1.4)	-	145.8 (1.4)	20.8 (0.2)	312.5 (2.9)	333.3 (3.1)
NODOSILINEALES/Cymatolegaceae							
Romeria leopoliensis #, UN(TS)	[8]	93.8 (0.9)	72.9 (0.7)	166.7 (1.5)	-	187.5 (1.7)	187.5 (1.7)
NOSTOCALES/Aphanizomenonaceae							
Anabaena flos-aquae f. gracilis #, TS	[8, 19, 42-44, 55]	-	-	-	312.5 (2.9)	62.5 (0.6)	375.0 (3.5)
An. sphaerica #, TS	[8, 19, 42-44, 55]	-	-	-	-	187.5 (1.7)	187.5 (1.7)
Raphidiopsis mediterranea #, TS	[8, 52, 56]	104.2 (1.0)	125.0 (1.2)	229.2 (2.1)	625.0 (5.8)	687.5 (6.4)	1312.5 (12.2)
Gloeotrichia natans #, US(BF, NF)	[8, 15]	-	83.3 (0.8)	83.3 (0.8)	62.5 (0.6)	-	62.5 (0.6)
NOSTOCALES/Hapalosiphonaceae							
Hapalosiphon spp. #, †, ‡, TS	[8, 19, 42-44]	52.1 (0.5)	-	52.1 (0.5)	20.8 (0.2)	-	20.8 (0.2)
Mastigocladus laminosus #, ‡, US(BF, CF & NF)	[8, 57]	20.8 (0.2)	-	20.8 (0.2)	-	-	-
NOSTOCALES/Nodulariaceae							
Anabaenopsis arnoldii #, TS	[8, 42-44]	62.5 (0.6)	-	62.5 (0.6)	250.0 (2.3)	62.5 (0.6)	312.5 (2.9)
Aa. circularis #, TS	[8, 19, 42-44]	375.0 (3.5)	-	375.0 (3.5)	41.7 (0.4)	-	41.7 (0.4)
Aa. tanganyikae #, US(BF, NF)	[8, 46]	-	31.3 (0.3)	31.3 (0.3)	31.3 (0.3)	-	31.3 (0.3)
NOSTOCALES/Nostocaceae							
Nostoc linckia #, ‡, US(NF)	[8, 16, 19, 42-44]	125.0 (1.2)	-	125.0 (1.2)	20.8 (0.2)	-	20.8 (0.2)
No. paludosum #, ‡, TS	[8, 19, 42-44]	-	-	-	62.5 (0.6)	-	62.5 (0.6)
NOSTOCALES/Rivulariaceae							
Calothrix brevissima #, US(BF, NF)	[8, 16]	-	31.3 (0.29)	31.3 (0.3)	41.7 (0.4)	62.5 (0.6)	104.2 (1.0)
Ca. scytonemicola #, US(BF, NF)	[8, 17]	93.8 (0.9)	187.5 (1.7)	281.3 (2.6)	62.5 (0.6)	62.5 (0.6)	125.0 (1.2)
Microchaete investiens #, US(OX)	[8, 58]	-	-	-	-	93.8 (0.9)	93.8 (0.9)
Mi. uberrima #, ‡, US(OX)	[8, 58]	187.5 (1.7)	-	187.5 (1.7)	-	-	-
Rivularia aquatica #, US(BF, NF)	[8, 60]	166.7 (1.5)	156.3 (1.1)	322.9 (3.0)	187.5 (1.7)	-	187.5 (1.7)
NOSTOCALES/Tolypothrichaceae							
Tolypothrix sp. *, #, †, ‡, US(BF, NF)	[8, 59]	62.5 (0.6)	125.0 (1.2)	187.5 (1.7)	-	-	-
OSCILLATORIALES/Microcoleaceae							
Lyngbya martensiana *, #,†, ‡, TS	[8, 10, 11 13, 14]	-	-	-	-	20.8 (0.2)	20.8 (0.2)
Microcoleus lacustris #, US(BC, AM)	[8, 61]	62.5 (0.6)	31.3 (0.3)	93.8 (0.9)	83,3 (0.8)	31.3 (0.3)	114.6 (1.1)
OSCILLATORIALES/Oscillatoriaceae							
Oscillatoria chalybea var. luticola #, TS	[8, 10, 11, 13, 14, 55]	-	20.8 (0.2)	20.8 (0.2)	-	-	-
Os. terebriformis f. amphigranulata #, TS	[8, 10, 11, 13, 14, 55]	-	-	-	-	31.3 (0.3)	31.3 (0.3)
Phormidium breve #, TS	[8, 19, 42-44]	31.3 (0.3)	-	31.3 (0.3)	-	-	-
PSEUDANABAENALES/Pseudanabaenaceae							
Pseudanabaena catenata #, UN(TS)	[8]	-	-	-	-	62.5 (0.6)	62.5 (0.6)
SYNECHOCOCCALES/Coelosphaeriaceae							
Woronichinia naegeliana #, TS	[8, 47]	62.5 (0.6)	94.3 (0.9)	156.8 (1.5)	-	218.3 (2.0)	218.3 (2.0)
Global		2354.2 (21.8)	2083.8 (19.3)	4438.0 (41.1)	2635.4 (24.4)	3728.7 (34.5)	6364.1 (58.9)

Table 4. *Continued.*

		C. Pooled data x10^5		
ORDERS/Families/Species	**References**	**I: n (%)**	**II: n (%)**	**Total: n (%)**
CHROOCOCALES/Chroococcaceae				
Chroococcus turgidus #, †, ‡, US(BC, AM, PB)	[8, 40]	-	62.5 (0.6)	62.5 (0.6)
CHROOCOCALES/Cyanothrichaceae				

		C. Pooled data x10^5		
ORDERS/Families/Species	**References**	**I: n (%)**	**II: n (%)**	**Total: n (%)**
Limnococcus limneticus #, UN(NTS)	[8, 41]	187.5 (1.7)	229.2 (2.1)	416.7 (3.9)
CHROOCOCALES/Gomphosphaeriaceae				
Gomphosphaeria aponina #, ‡, US(BC)	[8, 48-50]	-	62.5 (0.6)	62.5 (0.6)
CHROOCOCALES/Microcystaceae				
Aphanocapsa delicatissima #, UN(NTS)	[8]	104.2 (1.0)	-	104.2 (1.0)
Ap. elachista #, UN(NTS)	[8]	83.3 (0.8)	-	83.3 (0.8)
Aphanothece elabens #, TS	[8, 45]	208.3 (1.9)	583.3 (5.4)	791.7 (7.3)
Coelosphaerium confertum #, TS(PT)	[8]	20.8 (0.2)	312.5 (2.9)	333.3 (3.1)
Ce. kuetzingianum #, UN(PT)	[8, 51-53]	-	312.5 (2.9)	312.5 (2.9)
Merismopedia elegans *, #, †, ‡, US(PPP)	[8, 54]	229.2 (2.1)	62.5 (0.6)	291.7 (2.7)
Microcystis aeruginosa #, †, TS	[8, 19, 42-44, 55]	62.5 (0.6)	489.6 (4.5)	552.1 (5.1)
Synechocystis aquatilis #, TS	[8, 20]	625.0 (5.8)	656.3 (6.1)	1281.3 (11.9)
GOMONTIELLALES/Cyanothecaceae				
Cyanothece aeruginosa #, ‡, US(BF, NF)	[8, 47]	166.7 (1.5)	312.5 (2.9)	479.2 (4.4)
NODOSILINEALES/Cymatolegaceae				
Romeria leopoliensis #, UN(TS)	[8]	93.8 (0.87)	260.4 (2.4)	354.2 (3.3)
NOSTOCALES/Aphanizomenonaceae				
Anabaena flos-aquae f. gracilis #, TS	[8, 19, 42-44, 55]	312.5 (2.9)	62.5 (0.6)	375.0 (3.5)
An. sphaerica #, TS	[8, 19, 42-44, 55]	-	187.5 (1.7)	187.5 (1.7)
Raphidiopsis mediterranea #, TS	[8, 52, 56]	729.2 (6.8)	812.5 (7.5)	1541.7 (14.3)
Gloeotrichia natans #, US(BF, NF)	[8, 15]	62.5 (0.6)	83.3 (0.8)	145.8 (1.4)
NOSTOCALES/Hapalosiphonaceae				
Hapalosiphon spp. #, †, ‡, TS	[8, 19, 42-44]	72.9 (0.7)	-	72.9 (0.7)
Mastigocladus laminosus #, ‡, US(BF, CF & NF)	[8, 57]	20.8 (0.2)	-	20.8 (0.2)
NOSTOCALES/Nodulariaceae				
Anabaenopsis arnoldii #, TS	[8, 42-44]	312.5 (2.9)	62.5 (0.6)	375.0 (3.5)
Aa. circularis #, TS	[8, 19, 42-44]	416.7 (3.9)	-	416.7 (3.9)
Aa. tanganyikae #, US(BF, NF)	[8, 46]	31.3 (0.3)	31.3 (0.3)	62.5 (0.6)
NOSTOCALES/Nostocaceae				
Nostoc linckia #, ‡, US(NF)	[8, 16, 19, 42-44]	145.8 (1.4)	-	145.8 (1.4)
No. paludosum #, ‡, TS	[8, 19, 42-44]	62.5 (0.6)	-	62.5 (0.6)
NOSTOCALES/Rivulariaceae				
Calothrix brevissima #, US(BF, NF)	[8, 16]	41.7 (0.4)	93.8 (0.9)	135.4 (1.3)
Ca. scytonemicola #, US(BF, NF)	[8, 17]	156.3 (1.1)	250.0 (2.3)	406.3 (3.8)
Microchaete investiens #, US(OX)	[8, 58]	-	93.8 (0.9)	93.8 (0.9)
Mi. uberrima #, ‡, US(OX)	[8, 58]	187.5 (1.7)	-	187.5 (1.7)
Rivularia aquatica #, US(BF, NF)	[8, 60]	354.2 (3.3)	156.3 (1.1)	510.4 (4.7)
NOSTOCALES/Tolypothrichaceae				
Tolypothrix sp. *, #, †, ‡, US(BF, NF)	[8, 59]	62.5 (0.6)	125.0 (1.2)	187.5 (1.7)
OSCILLATORIALES/Microcoleaceae				
Lyngbya martensiana *, #,†, ‡, TS	[8, 10, 11, 13, 14]	-	20.8 (0.2)	20.8 (0.2)
Microcoleus lacustris #, US(BC, AM)	[8, 61]	145.8 (1.4)	62.5 (0.6)	208.3 (1.9)
OSCILLATORIALES/Oscillatoriaceae				
Oscillatoria chalybea var. luticola #, TS	[8, 10, 11, 13, 14, 55]	-	20.8 (0.2)	20.8 (0.2)
Os. terebriformis f. amphigranulata #, TS	[8, 10, 11, 13, 14, 55]	-	31.3 (0.3)	31.3 (0.3)
Phormidium breve #, TS	[8, 19, 42-44]	31.3 (0.3)	-	31.3 (0.3)
PSEUDANABAENALES/Pseudanabaenaceae				
Pseudanabaena catenata #, UN(TS)	[8]	-	62.5 (0.6)	62.5 (0.6)
SYNECHOCOCCALES/Coelosphaeriaceae				
Woronichinia naegeliana #, TS	[8, 62]	62.5 (0.6)	312.5 (2.9)	375.0 (3.5)
Global		4438.0 (41.1)	6364.1 (58.9)	10802.1 (100.0)

I: High tide: II: Low tide; *: brackish water species; #: freshwater species; †: marine species; ‡: terrestrial species; AM: antimicrobial producer, BC: bio-control agent, BF: Bio-fertilizer, CF: Carbon-fixer, PB: *producer of bio-chemicals,* NF: Nitrogen-fixer, OX: oxygen-fixer, PPT: protease producer, PT: potentially toxigenic, NTS: Non-toxigenic, TS: toxigenic, UN: unknown status, US: useful species:

Oscillatoriaceae was represented by two species (5.4%) in the Nyong River mouth, only one species (2.7%) in the Kienké River mouth, and three species (8.1%) in the pooled data. These three species were: (1) *Oscillatoria chalybea* var. *luticola* Meneghini ex Elenkin, 1949 (0.19%), (2) *Os. terebriformis f. amphigranulata* Elenkin & Kossinskaja, 1949 (0.29%) and (3) *Phormidium breve* (Kütz. ex Gomont) Anagn. & Komárek, 1988 (0.29%) (Table 4). Hapalosiphonaceae was represented by only two species (5.4%) in the Nyong River mouth and the pooled data respectively, and only one species (2.7%) in the Kienké River mouth. These two species were: (1) *Hapalosiphon* spp. Nägeli ex Bornet & Flahault, 1886 (0.68%) and (2) *Mastigocladus laminosus* Cohn ex Kirchner, 1898 (0.1%) (Table 4). Microcoleaceae was represented by only one species (2.7%) in the Nyong River mouth, and two species (5.4%) in the Kienké River mouth and the pooled data respectively. These two species were: (1) *Lyngbya martensiana* Meneghini ex Gomont, 1892 (0.19%), and (2)

Microcoleus lacustris Farlow ex Gomont 1892 (1.93%) (Table 4). Nostocaceae was represented by only one species (2.7%) in the Nyong River mouth, and two species (5.4%) in the Kienké River mouth and the pooled data respectively. These two species were: (1) *Nostoc linckia* Bornet ex Bornet & Flahault, 1886 (1.35%), and (2) *No. paludosum* Kützing ex Bornet & Flahault 1886 (0.58%) (Table 4). Only one species (2.7%) was recorded in each of the eight other families. These species were: (1) *Chroococcus turgidus* (Kützing) Nägeli, 1849 (Chroococales: Chroococcaceae) (0.58%), (2) *Limnococcus limneticus* (Lemmermann) Komárková, Jezberová, Komárek & Zapomelová, 2010 (Chroococales: Cyanothrichaceae) (3.86%), (3) *Gomphosphaeria aponina* (Chroococales: Gomphosphaeriaceae) (0.58%), (4) *Cyanothece aeruginosa* (Nägeli) Komárek 1976 (Gomontiellales: Cyanothecaceae) (4.44%), (5) *Romeria leopoliensis* (Raciborski) Koczwara 1932 (Nodosilineales: Cymatolegaceae) (3.28%), (6) *Tolypothrix* sp. Kützing ex Bornet & Flahault, 1886 (Nostocales: Tolypothrichaceae) (1.74%), (7) *Pseudanabaena catenata* Lauterborn 1915 (Pseudanabaenales: Pseudanabaenaceae) (0.58%), and (8) *Woronichinia naegeliana* (Unger) Elenkin, 1933 (Synechococcales: Coelosphaeriaceae) (3.47%) (Table 4). Comparison of abundances between the two river mouths was not significant. The most abundant species was *Ra. mediterranea* (14.3%), followed by *Sy. aquatilis* (11.9%), *Ap. elabens* (7.3%), and *Mr. aeruginosa* (5.1%) while other species were represented each by less than 5% of the total collection (Table 4). Six species (16.2%) were recorded exclusively in the Nyong River mouth (*Go. aponina*, *Ma. laminosus*, *Mi. uberrima*, *Os. chalybea*, *Ph. breve* and *Tolypothrix* sp.) (Table 4). Nine species (24.3%) were seen exclusively in the Kienké River mouth. These species were *Ap. elachista*, *An. flos-aquae*, *An. sphaerica*, *Ch. turgidus*, *Ly. martensiana*, *Mi. investiens*, *No. paludosum*, *Os. terebriformis f. amphigranulata* and *Ps. catenata* (Table 5). Twenty-two species (59.5%) were common to both mouths. These common species were *Aa. arnoldii*, *Aa. circularis*, *Aa. tanganyikae*, *Ap. elabens*, *Ap. delicatissima*, *Ca. brevissima*, *Ca. scytonemicola*, *Ce. confertum*, *Ce. kuetzingianum*, *Cy. aeruginosa*, *Gl. natans*, *Hapalosiphon* spp., *Li. limneticus*, *Me. elegans*, *Mr. aeruginosa*, *Mi. lacustris*, *No. linckia*, *Ra. mediterranea*, *Ri. aquatica*, *Ro. leopoliensis*, *Sy. aquatilis* and *Wo. naegeliana* (Table 5). Nine species (24.3%) were recorded at high tide: *Aa. circularis, Ap. elachista, Ap. delicatissima, Hapalosiphon* spp., *Ma. laminosus, Mi. uberrima, No. paludosum, No. linckia* and *Ph. breve* (Table 5). Nine species (24.3%) were recorded at low tide: *An. sphaerica, Ce. kuetzingianum, Ch. turgidus, Go. aponina*, *Ly. martensiana, Mi. investiens*, *Os. terebriformis, Os. chalybea* and *Ps. catenata*. Nineteen species (51.4%) were common to both tides: *Aa arnoldii, Aa. tanganyikae, An. flos-aquae, Ah. elabens, Ca. scytonemicola, Ca. brevissima, Ce. confertum, Cy. aeruginosa, Gl. natans, Li. limneticus, Me. elegans, Mc. lacustris, Mr. aeruginosa, Ra. mediterranea, Ri. aquatica, Ro. leopoliensis, Sy. aquatilis, Tolypothrix* sp. and *Wo. naegeliana* (Table 5). Making a total of 28 species (75.7%) in Nyong River mouth and 31 species (83.8%) in Kienké River mouth (Table 5). Six species (16.2%) were exclusively noted in Nyong River mouth, nine species (24.3%) were exclusively noted in Kienké River mouth, 22 species (59.5%) were simultaneously recorded in Nyong River mouth and Kienké River mouth. In the overall distribution, cosmopolitan species were more numerous than species found exclusively at each tide (Table 5).

All the relative abundance differences were significant, the cosmopolitan species being more numerous than the species found exclusively in a single tide (Table 5). Concerning the abundance percentages, all the differences were significant, the cosmopolitan species being more numerous than the two previous categories (Table 5).

As for the average distributions, the difference was not significant only between the species found only at a single tide while in the cosmopolitan species and the overall distribution, the average value was higher than in the previous two, categories (Table 5). Twenty five freshwater species (67.6%) and 12 tolerant species (32.4%) were recorded (Table 6), the later category being able to develop in freshwaters, brackish waters, marine and terrestrial environment. Freshwater species were divided into two species (5.4%) exclusively in Nyong (*Os. chalybea* and *Ph. breve*), six species (16.2%) exclusively in Kienké (*An. flos-aquae, An. sphaerica, Ap. elachista, Mi. investiens, Os. terebriformis f. amphigranulata* and *Ps. catenata*), and 17 species (45.9%) simultaneously recorded in the Nyong River Mouth and the Kienké River Mouth (*Aa. arnoldii, Aa circularis, Aa. tanganyikae, Ah. elabens, Ap. delicatissima*, *Ca. brevissima, Ca. scytonemicola, Ce. confertum, Ce. kuetzingianum, Gl. natans, Li. limneticus, Mi. lacustris, Ra. mediterranea, Ri. aquatica, Ro. leopoliensis, Sy. aquatilis* and *Wo. naegeliana*) (see Table 4). For tolerant species four of them (10.8%) were exclusively from the Nyong River mouth [*Go. aponina*, *Ma. laminosus*, *Mi. uberrima* and *Tolypothrix* sp.), three of them (8.1%) were exclusively from the Kienké River Mouth (*Ch. turgidus*, *Ly. martensiana* and *No. paludosum*) and five species (13.5%) were simultaneously seen in the two river mouths (*Cy. aeruginosa*, *Hapalosiphon* spp., *Me. elegans*, *Mr. aeruginosa* and *No. linckia*) (see Table 4). Nyong River mouth presented 19 freshwater species (51.4%) and nine tolerant species (24.3%) while Kienké River Mouth presented 23 freshwater species (62.2%) and eight tolerant species (21.6%) (Table 6). Among the species found exclusively in the Nyong River Mouth and those found exclusively in the Kienké River Mouth, the richness of freshwater species was not statistically different from that of tolerant species while among cosmopolitan species, the richness of species of freshwater was significantly higher than that of tolerant species (Table 6). In terms of relative abundance, species found exclusively in Nyong had a significantly high percentage among tolerant species than freshwater specialists. The situation was reversed among species exclusively found in the Kienké River Mouth and among cosmopolitan species (Table 6).

The variation in average abundances is not significant in tolerant species while in freshwater species, the significant

difference was recorded only between the species found exclusively in the Nyong River Mouth and the cosmopolitan species (Table 6). Based on the ecological impact, the recorded species were divided into 15 useful ones (40.5%), 16 toxigenic species (43.2%) and six species (16.2%) of unknown status (Table 7).

Table 5. *Absolute and relative abundances of the blue-green algae species at high tide and low tide in the Nyong river mouth and the Kienké river mouth.*

	Species richness (%)				**Sample size: n x10^5 (%)**			
	A	**B**	**C**	**Global**	**A**	**B**	**C**	**Global**
I.	3 (8.1)	2 (5.4)	4 (10.8)	9 (24.3)	239.6 (2.2)	145.8 (1.4)	739.6 (6.8)	1125.0 (10.4)
II.	2 (5.4)	6 (16.2)	1 (2.7)	9 (24.3)	83.3 (0.8)	458.3 (4.2)	312.5 (2.9)	854.2 (7.9)
III.	1 (2.7)	1 (2.7)	17 (45.9)	19 (51.4)	187.5 (1.7)	375.0 (3.5)	8260.4 (76.5)	8822.9 (81.7)
IV.	6 (16.2)	9 (24.3)	22 (59.5)	37 (100.0)	510.4 (4.7)	979.2 (9.1)	9312.5 (86.2)	10802.1 (100.0)
FFH	FI=1.09	FI=4.35	FI=23.30	FI=7.72	FI=83.28	FI=184.52	FI=18853.0	FI=17772.0
(df=2)	p=0.870 ns	p=0.142 ns	p=5.5x10-6*	p=0.022 *	p=7.6x10^{-19} *	p=8.0x10^{-41}*	p=<0.001 *	p=<0.001 *
	I. FI=0.782, df=2, p=0.907 ns				I. FI=533.27, df=2, p<0.001 *			
	II. FI=4.354, df=2, p=0.142 ns				II. FI=296.54, df=2, p<0.001 *			
FFH test	III. FI=29.697, df=2, p=1.1x10^{-7} *				III. FI=21002.0, df=2, p<0.001 *			
	Pooled tides: FI=16.950, df=2, p=2.1x10^{-4} *				Pooled tides: FI=21909.0, df=2, p<0.001*			
	Overall distribution: FI=18.65, df=4, p=2.0x10^{-4} *				Overall distribution: FFH test: FI=2134.90, df=4, p<0.001			
	Mean values ± se x10^5							
	A	B	C	Global	ANOVA test: A *vs.* B *vs.* C			
I.	79.9±53.9	72.9±10.4	184.9±78.7	125.0±40.5	$F_{(2; 6)}$=0.842, p=0.476 ns			
II.	41.7±20.8	76.4±24.6	312.5±0.0	94.9±32.1	$F_{(1; 6)}$=0.565, p=0.481 ns			
III.	187.5±0.0	375.0±0.0	485.9±95.0	464.4±86.3	-			
IV.	85.1±33.0	108.8±36.0	423.3±78.3	292.0±54.1	$F_{(2; 34)}$=5.370, p=9.4x10-3 *			
ANOVA	$F_{(1; 3)}$=0.282, p=0.632 ns	$F_{(1; 6)}$=0.007, p=0.938 ns	$F_{(1; 19)}$=2.202, p=0.154 ns	F(2; 34)=7.221, p=0.002 *				
Test	Species richness (Bonferroni procedure): p-value (α')							
	C	Global		III	Pooled tides			
I *vs.* II	0.358 (0.050) ns	1.00 (0.050) ns	A *vs.* B	1.00 (0.050) ns	0.564 (0.05) ns			
I *vs.* III	1.6x10^{-3} (0.025) *	0.015 (0.025) *	A *vs.* C	1.7x10^{-5} (0.025) *	2.5x10^{-4} (0.017) *			
II *vs.* III	1.7x10^{-5} (0.017) *	0.015 (0.017) *	B *vs.* C	1.7x10^{-5} (0.017) *	4.3x10^{-3} (0.025) *			
Test	Sample size (Bonferroni procedure): p-value (α')							
	C	Global		I	II			
I *vs.* II	2.2x10^{-42} (0.050)*	1.8x10^{-10} (0.050) *	A *vs.* B	1.6x10^{-6} (0.05) *	2.9x10^{-65} (0.017) *			
I *vs.* III	0.00 (0.025) *	0.00 (0.025) *	A *vs.* C	1.7x10^{-62} (0.025) *	4.7x10^{-33} (0.025) *			
II *vs.* III	0.00 (0.017) *	0.00 (0.017) *	B *vs.* C	5.6x10^{-100} (0.017) *	1.2x10^{-7} (0.05) *			
Test	Mean values: SNK test			Relative abundance: p-value (α')				
	Global	Pooled tides		Both tides	Overall data			
I *vs.* II	p=0.825 ns	p=0.088 ns	A *vs.* B	1.1x10^{-15} (0.050)*	8.8x10^{-37} (0.050) *			
I *vs.* III	p=8.0x10^{-3} *	p=0.046 *	A *vs.* C	0.0 (0.017)*	0.0 (0.017) *			
II *vs.* III	p=5.8x10^{-3} *	p=0.011 *	B *vs.* C	0.0 (0.025)*	0.0 (0.025) *			

I: High tide exclusively, II: Low tide exclusively, III: Both tides, IV: Pooled tides, A: Nyong River mouth exclusively, B: Kienké River mouth exclusively, C: Both river mouths, n: total abundance, FFH: Fisher-Freeman-Halton test, FI: Fisher-Freeman-Halton's statistic, ns: not significant variation (p>0.05 or p≥ α'), *: significant difference (p< 0.05 or p<α'), SNK: Student-Newman-Keul test, se: standard error. Percentages were calculated in each case on the global recorded value, α': Bonferroni's corrected significance level.

Useful species were divided into three species (8.1%) exclusively in Nyong mouth (*Go. aponina, Ma. laminosus, Mi. uberrima* and *Tolypothrix* sp.), two species (5.4%) exclusively in Kienké mouth (*Ch. turgidus* and *Mi. investiens*) and nine species (24.3%) simultaneously recorded in both river mouths (*Aa. tanganyikae, Ca. scytonemicola, Ca. brevissima, Cy. aeruginosa, Gl. natans, Me. elegans, Mc. lacustris, No. linckia* and *Ri. aquatica*) (see Table 4). Toxigenic species were divided into two species (5.4%) exclusively in the Nyong (*Os. chalybea* and *Ph. breve*), five species (13.5%) exclusively in Kienké River mouth (*An. flos-aquae, An. sphaerica, Ly. martensiana, No. paludosum* and *Os. terebriformis*) (see Table 4). No species of species of unknown status, was recorded exclusively in Nyong river mouth while two of them (5.4%) were recorded exclusively in Kienké mouth (*Ap. elachista* and *Ps. catenata*) and four of them (10.8%) were recorded simultaneously in both rivers (*Ap. delicatissima, Ce. kuetzingianum, Li. limneticus* and *Ro. leopoliensis*) (see Table 4). Making six species (16.2%) exclusively in Nyong, nine species (24.3%) exclusively in Kienké, 22 species (59.5%) simultaneously noted in both rivers. Then Nyong river mouth presented 13 useful species (35.1%), 11 toxigenic species (29.7%) and four species (10.8%) of unknown status while Kienké river mouth presented 11 useful species (29.7%), 14 toxigenic species (37.8%) and six species (16.2%) of unknown status (Table 7).

Table 6. *Absolute and relative abundances of the freshwater and the tolerant blue-green algae species in the Nyong river mouth and the Kienké river mouth.*

Category	Species richness (%)				Sample size: n x10^5 (%)			
	A	**B**	**C**	**Global**	**A**	**B**	**C**	**Global**
I:	2 (5.4)	6 (16.2)	17 (45.9)	25 (67.6)	52.1 (0.5)	833.3 (7.7)	7770.8 (71.9)	8656.3 (80.1)
II.	4 (10.8)	3 (8.1)	5 (13.5)	12 (32.4)	458.3 (4.2)	145.8 (1.4)	1541.7 (14.3)	2145.8 (19.9)
FFH (df=2)	p=0.674 ns	p=0.479 ns	p=0.005 *	p=0.005 *	p<0.001 *	p<0.001 *	p<0.001 *	p<0.001 *
FFH test	I. FI=18260.00, df=2, p<0.001 *; II. FI=1602.80, df=2, p<0.001 *							
	Pooled species: FI=21909.00, df=2, p=2.1x10^{-4} * p<0.001							
	Overall data: FI=1249.70, df=2, p=1.8x10^{-272} *							
	Mean values ±se x10^5							
	A	B	C	Global	Kruskall-Wallis test: A *vs.* B *vs.* C			
I:	26.0±5.2	138.9±51.8	457.1±97.4	346.3±74.5	H=10.464, df=2, p= 0,005 *			
II.	114.6±43.0	48.6±13.9	308.3±92.4	178.8±51.1	H=5.724, df=2, p=0,051 ns			
Student test	t=-1.378, df= 4, p= 0,240 ns	t=1.177, df=7, p=0,278 ns	t = 0.788, df=20, p=0,440 ns	t=1.469, df=35, p=0.151 ns				
Comparisons								
	Species richness: p-value (α')		Abundances: p-value (α')		Means (Dunn's procedure)			
	I.	II. p-value (α')	I.	II. p-value (α')	Q=1.040, p>0.05 ns			
A *vs.* B	0.261 (0.050) ns	1.00 (0.050) ns	1.6x10^{-188} (0.050)*	2.0x10^{-39} (0.025) *	Q=2.606, p<0.05 *			
A *vs.* C	1.1x10^{-4} (0.017)*	1.00 (0.025) ns	0.00 (0.025) *	1.1x10^{-149} (0.017) *	Q=2.314, p>0.05 ns			
B *vs.* C	0.011 (0.025) *	0.711 (0.017)ns	0.00 (0.017) *	1.9x10^{-315} (0.050) *				

I: Freshwater species, II. Tolerant species, A: Nyong River mouth exclusively, B: Kienké River mouth exclusively, C: Both river mouths, n: total abundance, FFH: Fisher-Freeman-Halton test

Table 7. *Absolute and relative abundances of the useful, toxigenic and unknown status blue-green algae in the Nyong river mouth and the Kienké river mouth.*

Category	Species richness (%)				Sample size: n x10^5 (%)			
	A	**B**	**C**	**Global**	**A**	**B**	**C**	**Global**
I	4 (10.8)	2 (5.4)	9 (24.3)	15 (40.5)	458.3 (4.2)	156.3 (1.4)	2385.4 (22.1)	3000.0 (27.8)
II	2 (5.4)	5 (13.5)	9 (24.3)	16 (43.2)	52.1 (0.5)	677.1 (6.3)	5739.6 (53.1)	6468.7 (59.9)
III	-	2 (5.4)	4 (10.8)	6 (16.2)	-	145.8 (1.4)	1187.5 (11.0)	1333.3 (12.3)
FFH(df=2)	FI=3.140, df=4, p=0.547 ns			p=0.026 *	p=3.3x10^{-173}*	p=4.4x10^{-118}*	p<0.001 *	p<0.001 *
	Mean±se x10^5							
	A	B	C	Global	One-way ANOVA test			
I	114.6±43.0	78.1±15.6	265.1±54.8	200.0±40.0	$F_{(2; 12)}$=2.428, p=0.130 ns			
II	26.0±5.2	135.4±66.9	637.7±160.8	404.3±113.4	$F_{(2; 13)}$=3.791, p=0.050 ns			
III	-	72.9±10.4	296.9±67.7	222.2±63.8	$F_{(1; 4)}$=4.834, p=0.093 ns			
ANOVA	$F_{(1; 4)}$=1.899, p=0.240 ns	$F_{(2;6)}$=0.266, p=0.775 ns	$F_{(2; 19)}$=3.134, p=0.067 ns					
KW test	H=19.442, df=7, p=6.9x10^{-3} *.				I. FI=533.27, df=2, p<0.001; II. FI=296.54, df=2, p<0.001 III. FI=21002.0, df=2, p<0.001; Pooled species: FI=21909.0, df=2, p<0.001; Overall data: FI=982.90, df=4, p<0.001			
Comparisons	Species richness: p-value (α')		Relative abundance: p-value (α')					
	Global			A	B		C	
I vs. II	1.00 (0.050) ns		I vs. II	7.1x10-84 (0.025)*	6.8x10-81 (0.025) *		0.00 (0.025) *	
I vs. III	0.038 (0.017) ns		I vs. III	1.9x10-140 (0.017)*	0.602 (0.050) ns		4.8x10-08 (0.05) *	
II vs. III	0.021 (0.025) *		II vs. III	4.2x10-16 (0.050)*	2.2x10-85 (0.017) *		0.00 (0.017) *	
	Overall data							
I vs. II	0.00 (0.025) *							
I vs. III	5.7x10^{-180} (0.050)*							
II vs. III	0.00 (0.017) *							

I: Useful species, II. Toxigenic species, III. Species of unknown pest status, A: Nyong River mouth exclusively, B: Kienké River mouth exclusively, C: Both river mouths, n: total abundance, FFH: Fisher-Freeman-Halton test, KW: Kruskall-Wallis test

Table 8. *Matrix of the species richness, diversity, evenness and dominance indices.*

Statistics	A. Nyong River mouth			B. Kienké River mouth			C. Both rivers		
	I. High tide	**II. Low tide**	**Global**	**I. High tide**	**II. Low tide**	**Global**	**I. High tide**	**II. Low tide**	**Global**
n (x10^5 cells	2358	2083.83	4438.01	2635.41	3728.66	6364.07	4989.59	5812.89	10802.08
S (%)	21 (56.8)	18 (48.6)	28 (75.7)	21 (56.8)	21 (56.8)	31 (83.8)	28 (75.7)	28 (75.7)	37 (100.0)
n_{max}(x10^5 cells)	375.00	354.68	718.75	625.00	687.50	1,312.50	729.17	812.50	1,541.67
Mg	2.575	2.224	3.215	2.539	2.432	3.425	3.171	3.115	3.876
d = S/n	0.009	0.009	0.006	0.008	0.006	0.005	0.006	0.005	0.003
Chao1 (%)	21 (56.8)	18 (48.6)	28 (75.7)	21 (56.8)	21 (56.8)	31 (83.8)	28 (75.7)	28 (75.7)	37 (100.0)
SE (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Statistics	A. Nyong River mouth			B. Kienké River mouth			C. Both rivers		
	I. High tide	II. Low tide	Global	I. High tide	II. Low tide	Global	I. High tide	II. Low tide	Global
H' (bits)	2.747	2.606	2.960	2.590	2.682	2.941	2.943	2.914	3.136
H'_{max} (bits)	3.045	2.891	3.332	3.044	3.044	3.433	3.333	3.332	3.611
D	0.083	0.093	0.068	0.106	0.088	0.079	0.070	0.070	0.060
N_1 (%)	16 (43.2)	14 (37.8)	19 (51.4)	13 (35.1)	15 (40.5)	19 (51.4)	19 (51.4)	18 (48.6)	23 (62.2)
N_2 (%)	12 (32.4)	11 (29.7)	15 (40.5)	9 (24.3)	11 (29.7)	13 (35.1)	14 (37.8)	14 (37.8)	17 (45.9)
S-N_1 (%)	5 (13.5)	4 (10.8)	9 (24.3)	8 (21.6)	6 (16.2)	12 (32.4)	9 (24.3)	10 (27.0)	14 (37.8)
N_2/N_1	0.776	0.792	0.765	0.705	0.779	0.670	0.758	0.773	0.719
J	0.902	0.902	0.888	0.851	0.881	0.857	0.883	0.875	0.868
I_{BP}	0.159	0.175	0.162	0.237	0.184	0.206	0.146	0.140	0.143
Comparison (Student t-test)									
	A(I)*vs.*A(II)	B(I)*vs.*B(II)	Pooled I*vs.*II	A(I)*vs.*B(I)	A(I)*vs.*B(II)	A(II)*vs.*B(I)	A(II)*vs.*B(II)		
H'_{max} (bits)	$p=2.9x10^{-10}$ *	$p=2.8x10^{-5}$ *	p = 0.073 ns						
D	p = 0.002 *	$p=2.2x10^{-7}$ *	p = 0.706 ns						

A(I): Nyong River mouth at high tide, A(II): Nyong River mouth at low tide, B(I): Kienké River mouth at high tide, B(II): Kienké River mouth at low tide, Chao1: abundance based non parametric species richness estimator, H': Shannon-Weaver diversity index, H'_{max}: Maximum Shannon diversity index, D: Simpson's diversity index, Mg: Margalef's richness index, d: Species richness ratio, n: Sample size, n_{max}: maximum abundance, N_1: Hill's first order diversity number index, N_2: Hill's second order diversity number index, S: Species richness, SE: Sample effort (Chao1/S), S-N_1: observed rare species number, N_2/N_1: Hill's ratio evenness index, J: Pielou' evenness index, I_{BP}: Berger-Parker's dominance index.

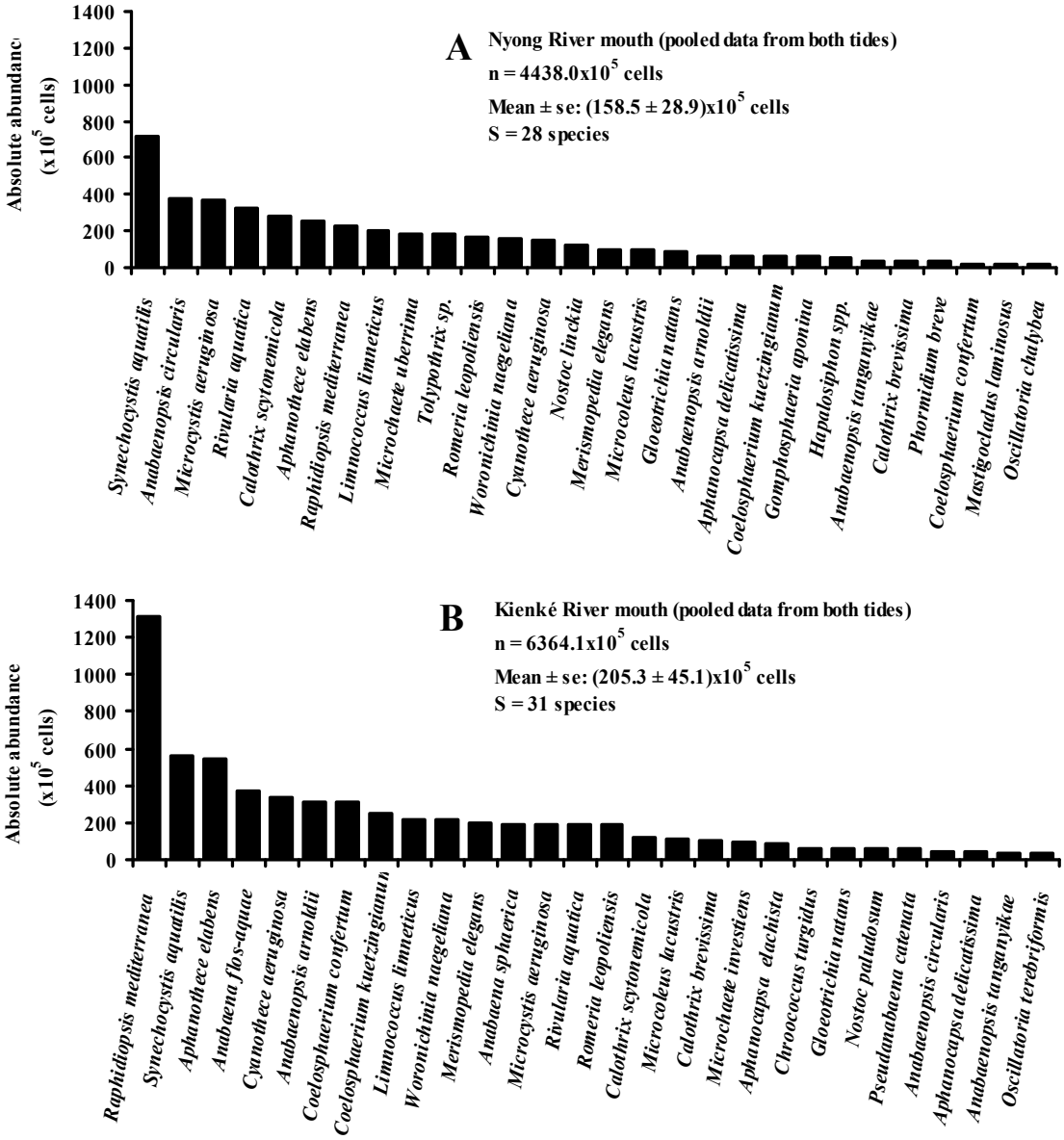

Figure 2. *Rank-frequency diagram of the pooled collected blue-green algae cells in Nyong and Kienké River mouths, showing species in decreasing order of numerical occurrence.*

Between useful species, toxigenic species and those of unknown status, the variation in species richness was in all cases non-significant, except in the combined data where the species of unknown status were significantly less numerous than the species of the other two categories, the difference being not significant between these two last categories (Table 7). As for abundances, pairwise comparisons showed significant difference in species found exclusively in Nyong River mouth (useful species were mostly represented than the two other categories). Cosmopolitan species and the overall distribution (toxigenic species were mostly represented than the other two categories) (Table 7).

3.3. Alpha Diversity and the Community Structure

Whatever the river mouth and the tide, the species richness and the species diversity were statistically low (close to 0) (Table 8). In the Nyong River mouth, the species diversity was higher at high tide than that recorded at low tide. In the Kienké River mouth, the diversity recorded at high tide was lower than that recorded at low tide, as evidenced by significant comparisons of Shannon-Weaver and Simpson indices. In the pooled data the difference between the two tides was not significant (Table 8).

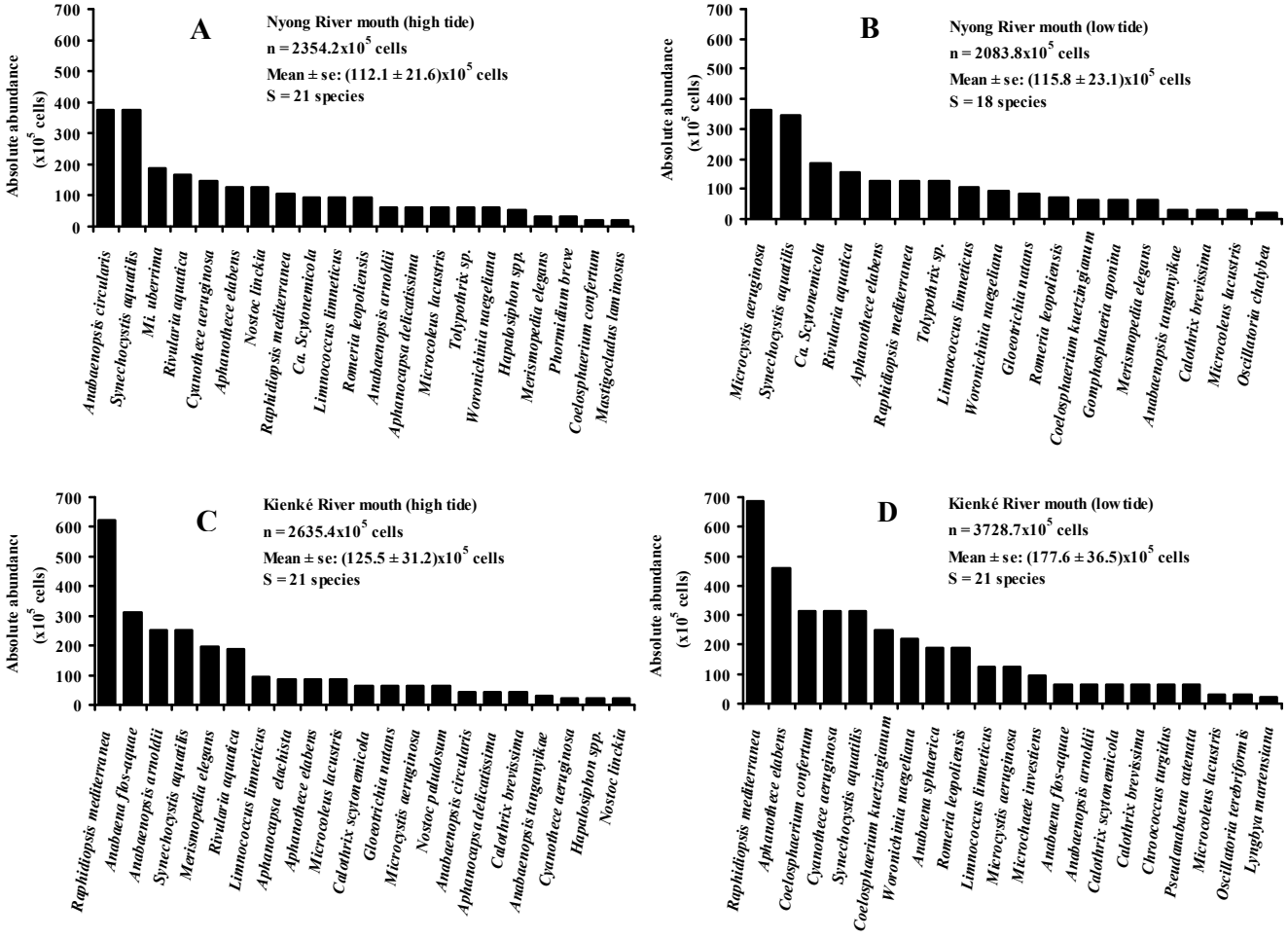

Figure 3. *Rank-frequency diagram of the collected blue-green algae cells at low and high tides in Nyong and Kienké River mouths, showing species in decreasing order of numerical occurrence.*

High tide species diversity in the Nyong River mouth was higher than that noted in Kienké River mouth while it was the contrary at low tide (Table 8). Diversity indices were not statistically different in the pooled data except Simpson index between data from Nyong River mouth and Kienké River mouth (Table 8). Based on the Chao1 (non-parametric estimator of the 'TRUE" species richness), the sampling success was maximal (100.0%). Highly even assemblages were recorded (Hill ratio and Pielou's indexes closed to one) and all assemblages were lowly dominated by a few species (values of the Berger-Parker index closed to 0) (Table 8). Based on the individual rarefaction analysis, for a standard sample of 1901.0x10^5 cells, assemblage was lowly diverse at low tide in the Nyong River Mouth [E(S)=18±0 species], equally diverse at high and low tide in the Kienké River Mouth [(E(S)=21±0 species respectively], equally diversed at high and low tide in the pooled data [(E(S)=28±0 species respectively]. The assemblage was highly diverse in the pooled distribution [(E(S)=37±0 species]. The global assemblage recorded in the Nyong River Mouth [E(S)=28±0

species] and in the Kienké River Mouth [(E(S)=31±0 species] occupied the intermediate position between the two extremes. The Species Abundance Distributions (SADs) presented a concave appearance close to the Fisher's log-series model [Nyong Mouth: α=3.988, x=0.9991, χ^2=6871.0, p=0 (Figure 2A); Kienké Mouth: α=4.233, x=0.999, χ^2=8,623.0, p=0 (Figure 2B)]. A similar shape was seen at each tide in the Nyong [high tide: α=3.176, x=0.9987, χ^2=4633.0, p=0 (Figure 3A); low tide: α=2.706, x=0.999, χ^2=3676.0, p=0 (Figure 3B)] and in Kienké [high tide: α=3.112, x=0.999, χ^2=2894.0, p=0 (Figure 3C); low tide: α=2.997, x=0.999, χ^2=6855.0, p=0 (Figure 3D)]. It was the same in the pooled data at high tide [α=3.913; x=0.999; χ^2=8474.0, p=0] and at low tide [α=3.819; x=0.999; χ^2=9643.0, p=0; overall assemblage: α=4.789, x=0.9996; χ^2=1.6x10^4, p=0].

3.3.1. Abundant Species

Based on the Hill's N_1 index (Table 4 and 8) and the SADs (Figures 2 and 3), numbers of abundant species varied from 13 species (35.1%) at high tide in Kienké to 23 species (62.2%) in the pooled assemblage (Tables 4 and 8). *Aa. circularis, Ap. delicatissima, Mi. uberrima* and *No. linckia* were abundant exclusively at high tide in the Nyong River Mouth. *Go. aponina* was abundant exclusively at low tide in Nyong. *Ap. elachista* was abundant exclusively at high tide in the Kienké River Mouth. *An. sphaerica, Ce. confertum* and *Mi. investiens* were abundant exclusively at the low tide in the Kienké River Mouth. *Tolypothrix* sp. was abundant at both tides in the Nyong River Mouth. *An. flos-aquae* was abundant at both tides in the Kienké River Mouth. *Mc. lacustris* was abundant at high tide in both rivers. *Ce. kuetzingianum* was abundant at low tide in both river mouths. *Cy. aeruginosa* was abundant at high tide in the Nyong River Mouth and the low tide in the Kienké River Mouth. *Gl. natans* and *Me. elegans* were abundant at low tide in the Nyong River Mouth and high tide in the Kienké River Mouth. *Aa. arnoldii* was abundant at high tide in the Nyong River Mouth and at both tides in the Kienké River Mouth. *Mr. aeruginosa* was abundant at low tide in the Nyong River Mouth and at both tides in the Kienké River Mouth. *Ri. aquatica* was abundant at both tides in the Nyong River Mouth and high tide in the Kienké River Mouth. Ro. leopoliensis and *Wo. naegeliana* were abundant at both tides in the Nyong River Mouth and at low tide in the Kienké River Mouth. *Ah. elabens, Ca. scytonemicola, Li. limneticusn, Ra. mediterranea* and *Sy. aquatilis* were abundant at both tides in both river mouths.

3.3.2. Co-dominant Species

Based on the Hill's N_2 index (see Tables 4 and 8) and the rang-abundance plotting (Figures 2 and 3), the numbers of co-dominant species varied from nine species (24.3%) in the assemblage at high tide in the Kienké River mouth to 17 species (45.9%) in the overall pooled assemblage. *Aa. circularis, Mi. uberrima* and *No. linckia* were co-dominants exclusively at high tide in the Nyong River Mouth. *Gl. natans* and *Tolypothrix* sp. were co-dominants exclusively at low tide in the Nyong River mouth. *Ca. brevissima*, *Ch. turgidus* and *Hapalosiphon* spp. were co-dominants exclusively in the pooled data. Making 29 co-dominants (78.4%) (six co-dominants i.e. 16.2% exclusively in the Nyong River Mouth, five co-dominants (13.5%) exclusively in the Kienké River mouth, two co-dominants (5.4%) simultaneously in both rivers and 16 co-dominants (43.2%) in other combinations between the two tides and the two rivers). Pairwise comparison of the recorded percentages showed that abundant species in other combinations were more numerous than the records exclusively in a single or both river mouths while other comparisons were not significant (Fisher's exact test: Nyong exclusively *vs.* Kienké exclusively: p=1.00, Bonferroni significance level α'=0.05; Nyong exclusively *vs.* both rivers: p=0.253, α'=0.017; Nyong exclusively *vs.* other combinations: p=0.014, α'=0.013; Kienké exclusively *vs.* both rivers: p=0.423, α'=0.025; Kienké exclusively *vs.* other combinations: p=0.006, α'=0.010; both rivers *vs.* other combinations: p=1.0x10^{-4}, α'=0.009). *An. flos-aquae f. gracilis, Ap. elachista* and *Me. elegans* were co-dominants exclusively at high tide's assemblage in the Kienké River mouth. *An. sphaerica, Ce. confertum* and *Ce. kuetzingianum* co-dominated the low tide's assemblage exclusively in the Kienké River mouth. *Ri. aquatica* dominated assemblages at high tide and that at low tide in the Nyong River mouth and the high tide assemblage in the Kienké River mouth. *Cy. aeruginosa* dominated the high tide's assemblage from the Nyong River mouth and the low tide's assemblage from the Kienké River mouth. *Ro. leopoliensis* dominated the two tides' assemblages in the Nyong River Mouth and the low tide's assemblage in the Kienké River Mouth. *Aa. arnoldii* dominated the high tide's assemblage in both river mouths. *Mr. aeruginosa* and *Wo. naegeliana* co-dominated the assemblage at low tide in both river mouths. *Ca. scytonemicola* was dominated the assemblage in both tides exclusively in Nyong. *Ah. elabens, Li. limneticusn, Ra. mediterranea* and *Sy. aquatilis* co-dominated assemblages at both tides in both rivers. *Mc. lacustris* dominated the pooled assemblage. Making 23 co-dominants (62.2%) (Six species i.e. 16.2% exclusively in Nyong River mouth and Kienké River mouth respectively, four species i.e. 10.8% simultaneously at both tides in both river mouths, and seven co-dominant species i.e. 18.9% simultaneously in combinations between the two tides and two river mouths). The global variation was not significant (Fisher-Freeman-Halton test: FI=1.178, df=3, p=0.831).

3.4. Beta Diversity and Adjustment of SADs

Although cosmopolitan species were recorded, a median level of dissimilarity of the assemblages was noted (Bray-Curtis index close to 0.5) between high tide in the Nyong River mouth and low tide in the same river, the pooled assemblage in the same river, the high tide's assemblage in the Kienké River mouth and the high tide's one in the pooled data.

It was the same between assemblage at low tide in Nyong and the pooled tides in the same river mouth, the high tide in Kienké and both tides in the pooled data from both rivers (Table 9).

Table 9. *Matrix of the Bray-Curtis dissimilarity index between species assemblages recorded in Nyong and Kienké river mouths.*

River	Tide	I	II	III	I	II	III	I	II	III
Nyong exclusively	I. High tide exclusively	1.000								
	II. Low tide exclusively	0.530	1.000							
	III. Both tides	0.694	0.639	1.000						
Kienké exclusively	I. High tide exclusively	0.426	0.446	0.419	1.000					
	II. Low tide exclusively	0.367	0.394	0.436	0.439	1.000				
	III. Both tides	0.359	0.382	0.517	0.586	0.739	1.000			
Both river mouths	I. High tide exclusively	0.641	0.421	0.723	0.691	0.459	0.661	1.000		
	II. Low tide exclusively	0.365	0.528	0.624	0.412	0.782	0.786	0.540	1.000	
	III. Both tides	0.358	0.323	0.583	0.393	0.514	0.742	0.632	0.700	1.000

It was once more the same between the pooled assemblage in Nyong River and all other assemblages in Kienké and in the pooled assemblage. The dissimilarity was of median quality between the assemblage at high tide in Kienké and the assemblages at low tide in Kienké or the pooled data, except that recorded at pooled tides. Similar result was recorded between the assemblage at low tide in Kienké and the pooled tides in Kienké or the overall pooled data. It was the same between the assemblage at the pooled tides in Kienké and the overall pooled assemblage.

3.4.1. Correlation Between Species

A global negative net association was noted [n=16 sample units, S=37 species, Schluter's variance ratio: VR=0.848, statistic W=13.57, df=15, $p<0.001$] while it was positive in Nyong (n=8, S=28 species, VR=1.309, W=10.47, df=27, $p<0.001$) and Kienké (n=8, S=31 species, VR=1.908, W=15.26, df=30, $p<0.001$). Significant Kendall correlations was negative between *An. flos-aquae f. gracilis* and *Ca. scytonemicola*, *Ca. scytonemicola* and two species (*Cy. aeruginosa* and *Gl. natans*) (Table 10). In contrast *An. flos-aquae f. gracilis* was positively correlated with *Aa. arnoldii*, *Ap. elachista*, *Ca. brevissima* and *No. paludosum* (Table 10). *Aa. arnoldii* was positively correlated with *Ca. brevissima*, *Ch. turgidus*, *Mi. investiens*, *No. paludosum*, *Os. terebriformis f. amphigranulata* and *Ra. mediterranea*. *Aa. circularis* was positively correlated with *Ma. laminosus, Mi. uberrima*, *No. paludosum*, *Ph. breve* and *Sy. aquatilis* and *Tolypothrix* sp.. *An. sphaerica* was positively correlated with *Cy. aeruginosa*. *Aa. tanganyikae* was positively correlated with *Ah. elabens*, *Ap. elachista*, *Mr. aeruginosa* and *No. linckia* (Table 10). *Ap. delicatissima* was positively correlated with *Ce. kuetzingianum*, *Gl. natans* and *Ly. martensiana*. *Ap. elachista* was positively correlated with *Hapalosiphon* spp., *Li. Limneticus, Me. elegans*, *Mc. aeruginosa* and *No. linckia*. *Ah. elabens* was positively correlated with *Mc. lacustris, Ps. catenata,* and *Tolypothrix* sp.. *Ca. brevissima* was positively correlated with *Ch. turgidus*, *Ly. martensiana*, *Mi. investiens*, *Os. terebriformis f. amphigranulata*. *Ch. turgidus* was positively correlated with *Mi. investiens, Os. terebriformis* and *Wo. naegeliana*. *Ca. scytonemicola* was positively correlated with *Ma. laminosus, Mi. uberrima* and *Ph. breve*. *Ce. confertum* was positively correlated with *Ce. kuetzingianum*, *Ma. laminosus, Mi. uberrima, Ph. breve* and *Ps. catenata*. *Ce. confertum* was positively correlated with *Ce. kuetzingianum*, *Ma. laminosus*, *Mi. uberrima Ph. breve* and *Ps. catenata*. *Ce. kuetzingianum* was positively correlated with *Ly. martensiana*. *Cy. aeruginosa* was positively correlated with two species (*Hapalosiphon* spp. and *No. linckia*). *Gl. natans* was positively correlated with *Hapalosiphon* spp.. *Go. aponina* was positively correlated with *Os. chalybea* and *Tolypothrix* sp. *Hapalosiphon* spp. was positively correlated with *No. linckia*. *Ma. laminosus* was positively correlated with *Mi. uberrima*, *Mc. lacustris*, *Ph. breve* and *Tolypothrix* sp.. *Me. elegans* was positively correlated with *Mc. lacustris* and *Ri. aquatica*. *Mi. investiens* was positively correlated with *Os. terebriformis* and *Wo. naegeliana*. *Mi. uberrima* was positively correlated with *Mc. lacustris*, *Ph. breve, Sy. aquatilis* and *Tolypothrix* sp.. *Mc. lacustris* was positively correlated with *Ph. breve*. *Os. chalybea var. luticola* was positively correlated with *Tolypothrix* sp.. *Os. terebriformis* was positively correlated with *Wo. naegeliana*. *Ph. breve* was positively correlated with *Sy. aquatilis* and *Tolypothrix* sp.. *Ro. leopoliensis* was positively correlated with *Wo. naegeliana*. Other correlations were not significant.

3.4.2. Species and Physico-Chemical Parameters

Ca. brevissima and *Ce. confertum* were negatively correlated with NH_4^+ ($r_{.bis}$=-0.412, df=52, t=3.259, $p<0.05$ respectively). *Ca. scytonemicola, Li. limneticus, Me. elegans, Ri. aquatica* and *Ro. leopoliensis* were positively correlated with FC ($r_{.bis}$=+0.378, df=52, t=2.944, $p<0.05$ for the first species; $r_{.bis}$=+0.329, df=52, t=2.511, $p<0.05$ for the second and third species respectively; $r_{.bis}$=+0.385, df=52, t=3.006, $p<0.05$ for fouth species; $r_{.bis}$=+0.328, df=52, t=2.505, $p<0.05$ for the last species). *Go. aponina, Hapalosiphon* spp., *Ly. martensiana, Ma. laminosus, Mi. uberrima* and *Os. chalybea* were positively correlated with BOD_5 ($r_{.bis}$=+0.268, df=52, t=2.005, $p<0.05$ for the first, third, fourth, fith and sith species; $r_{.bis}$=+0.344, df=52, t=2.640, $p<0.05$ for the second species). *An. flos-aquae* was negatively correlated with conductivity and NH_4^+ ($r_{.bis}$=-0.404, df=52, t=3.183, $p<0.05$ and $r_{.bis}$=-0.323, df=52, t=2.457, $p<0.05$ respectively). *Aa. arnoldii* was positively correlated with TSS ($r_{.bis}$=+0.294, df=52, t=2.215, $p<0.05$) and negatively correlated with conductivity and NH_4^+ ($r_{.bis}$=-0.273, df=52, t=2.044, $p<0.05$ and $r_{.bis}$=-0.407, df=52, t=3.211, $p<0.05$ respectively). *Aa. circularis, Aa. tanganyikae, Ce. kuetzingianum, Cy. aeruginosa, Mc. lacustris* and *No. linckia* were positively correlated with BOD_5 ($r_{.bis}$=+0.290, df=52, t=2.188, $p<0.05$ for the three first species and the sith species respectively; $r_{.bis}$=+0.267, df=52, t=1.999, $p<0.05$ for the fourth and fith

species) and negatively correlated with NH_4^+ ($r_{.bis}$=-0.308, df=52, t=2.332, p<0.05 for the first three species and the sith species respectively; $r_{.bis}$=-0.298, df=52, t=2.252, p<0.05 for the fourth and fith species). *An. sphaerica, Ap. elachista, Ch. turgidus, Mi. investiens, No. paludosum, Os. terebriformis* and *Ps. catenata* were negatively correlated with pH ($r_{.bis}$=-0.288, df=52, t=2.171, p<0.05 respectively) and with NH_4^+ ($r_{.bis}$=-0.462, df=52, t=3.752, p<0.05 respectively). *Ap. delicatissima* was positively correlated with pH, transparency and BOD_5 ($r_{.bis}$=+0.280, df=52, t=2.106, p<0.05; $r_{.bis}$=+0.320, df=52, t=2.437, p<0.05 and $r_{.bis}$=+0.313, df=52, t=2.373, p<0.05 respectively). *Gl. natans* was positively correlated with pH and FC ($r_{.bis}$=+0.263, df=52, t=1.963, p<0.05 and $r_{.bis}$=+0.312, df=52, t=2.365, p<0.05 respectively). *Ph. breve* was positively correlated with pH and BOD_5 ($r_{.bis}$=+0.176, df=52, t=1.290, p<0.05 and $r_{.bis}$=+0.268, df=52, t=2.365, p<0.05 respectively). *Ra. mediterranea* was positively correlated with BOD_5 and PO_4^{3-} ($r_{.bis}$=+0.271, df=52, t=2.027, p<0.05 and $r_{.bis}$=+0.607, df=52, t=5.505, p<0.05 respectively). *Tolypothrix* sp. was positively correlated with pH ($r_{.bis}$=+0.363, df=52, t=2.811, p<0.05), salinity ($r_{.bis}$=+0.274, df=52, t=2.053, p<0.05), transparency ($r_{.bis}$=+0.297, df=52, t=2.244, p<0.05) and with FC ($r_{.bis}$=+0.265, df=52, t=1.979, p<0.05).

Table 10. *Values of the significant Kendall's tau (τ) correlation coefficient between the blue-green algae species recorded in Nyong and Kienké River mouths (16 sample units).*

Species 1/species 2	τ (p-value)	Species 1/species 2	τ (p-value)	Species 1/species 2	τ (p-value)
Anabaena flos-aquae f. gracilis		*Aphanothece elabens*		*Hapalosiphon spp.*	
Anabaenopsis arnoldii	0.837 (6.2x10-6)*	*Microcoleus lacustris*	0.561 (0.002) *	*Nostoc linckia*	0.696 (1.7x10-4)*
Aphanocapsa elachista	0.390 (0.035) *	*Ps. catenata*	0.411 (0.027) *	*Mastigocladus laminosus*	
Calothrix brevissima	0.466 (0.012) *	*Tolypothrix* sp.	0.425 (0.022) *	*Microchaete uberrima*	1.0 (6.6x10-8) *
Ca. scytonemicola	-0.386 (0.037) *	*Calothrix brevissima*		*Microcoleus lacustris*	0.455 (0.014) *
Nostoc paludosum	0.497 (0.007) *	*Chroococcus turgidus*	0,518 (0.005) *	*Phormidium breve*	1.0 (6.6x10-8) *
Anabaena sphaerica		*Lyngbya martensiana*	0,438 (0.018) *	*Synechocystis aquatilis*	0.385 (0.037) *
Cyanothece aeruginosa	0.480 (0.009) *	*Microchaete investiens*	0,518 (0.005) *	*Tolypothrix* sp.	0.598 (0.001) *
Anabaenopsis arnoldii		*Os. terebriformis*	0,518 (0.005) *	*Merismopedia elegans*	
Calothrix brevissima	0.602 (0.001) *	*Calothrix scytonemicola*		*Microcoleus lacustris*	0,734 (7.2x10-5)*
Chroococcus turgidus	0.444 (0.017) *	*Cyanothece aeruginosa*	-0.436 (0.019) *	*Rivularia aquatica*	0,392 (0.034) *
Microchaete investiens	0.444 (0.017) *	*Gloeotrichia natans*	-0.390 (0.035) *	*Microchaete investiens*	
Nostoc paludosum	0.565 -0.002) *	*Ma. laminosus*	0.423 (0.022) *	*Os. terebriformis*	1,0 (6.6x10-8) *
Oscillatoria terebriformis	0.444 (0.017) *	*Microchaete uberrima*	0.423 (0.022) *	*Wo. naegeliana*	0,430 (0.020) *
Raphidiopsis mediterranea	0.473 (0.011) *	*Phormidium breve*	0.423 (0.022) *	*Microchaete uberrima*	
Anabaenopsis circularis		*Chroococcus turgidus*		*Microcoleus lacustris*	0,455 (0.014) *
Mastigocladus laminosus	0.719 (1.0x10-4)*	*Microchaete investiens*	1.000 (6.6x10-8)*	*Phormidium breve*	1,0 (6.6x10-8) *
Microchaete uberrima	0.719 (1.0x10-4)*	*Os. terebriformis*	1.0 (6.6x10-8) *	*Synechocystis aquatilis*	0,385 (0.037) *
Nostoc paludosum	0.623 (0.001) *	*Wo. naegeliana*	0.430 (0.020) *	*Tolypothrix sp.*	0,598 (0.001) *
Synechocystis aquatilis	0.499 (0.007) *	*Ce. confertum*		*Microcoleus lacustris*	
Tolypothrix sp.	0.372 (0.044) *	*Ce. kuetzingianum*	0.372 (0.044) *	*Phormidium breve*	0.455 (0.014) *
Anaboenopsis tanganyikae		*Ma. laminosus*	0.438 (0.018) *	*Nostoc paludosum*	
Aphanocapsa elachista	0,719 (1.0x10-4) *	*Microchaete uberrima*	0.438 (0.018) *	*Ra. mediterranea*	0.391 (0.035) *
Aphanothece elabens	0,374 (0.043) *	*Phormidium breve*	0.438 (0.018) *	*Oscillatoria chalybea*	
Microcystis aeruginosa	0,583 (0.002) *	*Ps. catenata*	0.518 (0.005) *	*Tolypothrix* sp.	0.438 (0.018) *
Nostoc linckia	0,414 (0.025) *	*Ce. kuetzingianum*		*Oscillatoria terebriformis*	
Aphanocapsa delicatissima		*Lyngbya martensiana*	0.623 (0.001) *	*Wo. naegeliana*	0,430 (0.020) *
Ce. kuetzingianum	0.386 (0.037) *	*Cyanothece aeruginosa*		*Phormidium breve*	
Gloeotrichia natans	0.629 (0.001) *	*Hapalosiphon* spp.	0,639 (0.001) *	*Synechocystis aquatilis*	0.385 (0.037) *
Lyngbya martensiana	0.683 2.2x10-4) *	*Nostoc linckia*	0,438 (0.018) *	*Tolypothrix sp.*	0.598 (0.001) *
Aphanocapsa elachista		*Gloeotrichia natans*		*Raphidiopsis mediterranea*	
Hapalosiphon spp.	0.484 (0.009) *	*Hapalosiphon* spp.	0.476 (0.010) *	*Romeria leopoliensis*	-0,426 (0.021) *
Limnococcus limneticus	0.452 (0.015) *	*Gomphosphaeria aponina*		*Romeria leopoliensis*	
Merismopedia elegans	0.480 (0.009) *	*Oscillatoria chalybea*	1.0 (6.6x10-8) *	*Wo. naegeliana*	0,496 (0.007) *
Microcystis aeruginosa	0.390 (0.035) *	*Tolypothrix* sp.	0.438 (0.018) *		
Nostoc linckia	0.623 (0.001) *				

*: Significant correlation (p<0.05)

3.5. Adjustment of SADs to the Theoretical Models

Log-linear model fitted the pooled assemblage at high tide in Nyong and Kienké River mouths with a high environmental constant (close to 1) (Table 11), characterizing a better balance of the assemblages [deviance=118.86, maximum abundance: n_1=812.5x10^5 cells, S=28 species, environmental constant representing the decay rate of abundance per rank: m=0.883, Pearson correlation: r=-0.985, coefficient of determination: r²=0.970, adjusted GM model: n_i=797.5x10^5*[0.883]$^{(i)}$ where "i" represented the rank of the species in descending order of abundances].

The log-normal model fitted eight algae assemblages (Table 11). In Nyong River mouth, the fit at high tide was satisfactory with a low environmental constant (m'<1) (Table 11) [deviance=59.87, n_1=375.0x10^5 cells, S=21 species, Pearson correlation: r=-0.968, lognormal correlation: r=-0.979, mean

of logarithms of abundance: x=1.917, lognormal variance: σ^2=0.121, lognormal standard deviation: σ=0.340, environmental constant: m'=0.784, LN model: $n_i=6853.8x10^5*(0.423)^{Pi}$] with P_i the probits of cumulative percentages of species ranks] (Table 11). At low tide, the fit was satisfactory with a low environment constant [deviance=43.78, $n_l=364.6x10^5$ cells, S=18 species, x=1.935, r=-0.981, σ^2=0.120, σ=0.340, m'=0.782, $n_i=7534.4x10^5*(0.419)^{Pi}$] similarly the fit was satisfactory in the pooled assemblage from both tides [deviance=72.41, $n_l=718.8x10^5$ cells, S=28 species, x=2.016, r=-0.985, σ^2=0.181, σ=0.419, m'=0.515, $n_i=21005.9x10^5*(0.352)^{Pi}$] (Table 11).

Table 11. *Values of Akaike Information Criteria (AIC) and the Bayesian Information Criteria (BIC) and the best fitted theoretical models in the Nyong and the Kienké River mouths.*

	AIC (BIC) in the Nymong River mouth			**AIC (BIC) in the Kienké River mouth**			**AIC (BIC) in the pooled assemblage**		
SADs	**High tide: S = 21 n=2354x10^5**	**Low tide S = 18 n=2084x10^5**	**Global S = 28 n=4438x10^5**	**High tide S = 21 n=2635x10^5**	**Low tide S = 21 n=3729x10^5**	**Global S = 31 n=6364x10^5**	**High tide: S = 28 n=4990x10^5**	**Low tide S = 28 n=5813x10^5**	**Global S = 37 n=10802x10^5**
BS	273.4 (273.4)	222.0 (222.0)	264.9 (264.9)	297.2 (297.2)	230.9 (230.9)	568.4 (568.4)	280.2 (280.2)	343.5 (343.5)	647.72 (647.72)
GM	254.7 (255.8)	199.1 (200.0)	322.5 (323.8)	309.5 (310.5)	239.2 (240.2)	769.9 (771.3)	314.0 (315.3)	308.2 (309.5)*	908.29 (909.90)
LN	195.3 (197.4)*	161.1 (162.9)*	257.9 (260.6)*	199.9 (202.0)*	220.1 (222.2)*	330.4 (333.2)*	255.6 (258.3)*	392.1 (394.7)	563.44 (566.66)*
Z	255.1 (257.2)	220.2 (222.0)	549.0 (551.6)	255.5 (257.6)	422.9 (425.0)	634.5 (637.3)	538.5 (541.2)	833.1 (835.8)	1,396.89 (1400.11)
ZM	206.9 (210.0)	172.5 (175.1)	313.5 (317.5)	207.3 (210.4)	226.3 (229.4)	557.0 (561.3)	264.9 (268.9)	307.8 (311.8)	906.94 (911.77)

AIC: Akaike Information Criteria, BIC: Bayesian Information Criteria, BS: Broken Stick theoretical model (McArthur's model, GM: Geometric theoretical model (Motomura log-linear model), LN: Lognormal theoretical model (Preston's model), n: sample size, S: Species richness, Z: Zipf theoretical model, ZM: Zipf-Mandelbrot theoretical model, *: the best fitted theoretical model, SADs: Species Abundance Distributions

In Kienké River mouth, the fit was satisfactory at high tide and the environmental constants was low [deviance=65.310, $n_l=625.0x10^5$ cells, S=21 species, x=1.899, r=-0.967, σ^2=0.171, σ=0.399, m'=0.568, $n_i=14968.3x10^5*(0.364)^{Pi}$] (Table 11). At low tide, the fit was satisfactory and the environmental constant was low [deviance 77.17, $n_l=687.5x10^5$ cells, S=21 species, x=2.072, r=-0.981, σ^2=0.171, σ=0.406, m'=0.549, $n_i=22893.7x10^5*(0.358)^{Pi}$] (Table 11). In the pooled assemblage at both tides in Kienké, the fit was excellent with a low environmental constant [deviance=120.53, $n_l=1312.5x10^5$ cells, S=28 species, x=2.165, r=-0.982, σ^2=0.164, σ=0.398, m'=0.572, $n_i=23715.1x10^5*(0.371)^{Pi}$] (Table 11). The pooled assemblage at low tide from Nyong and Kienké was excellent with a low environmental constant [deviance=67.00, $n_l=729.2x10^5$ cells, S=28 species, x=2.064, r=-0.990, σ^2 = 0.177, σ=0.417, m'=0.522, $n_i=22909.7x10^5*(0.355)^{Pi}$] (Table 11). The overall pooled SAD at both tides and both rivers showed a satisfactory fit with a very low environmental constant [deviance=301.99, $n_l=1541.7x10^5$ cells, S=37 species, x=2.222, r=-0.985, σ^2=0.245, σ=0.488, m'=0.380, $n_i=72126.4x10^5*(0.302)^{Pi}$].

4. Discussion

4.1. Physicochemical Characteristics and the Water Quality

Nyong and Kienké River mouths are warm rivers according to the classification of [33]. Temperature controls the growth rate of Cyanobacteria and the concentration of toxins, the optimum being 25-32.5°C [63]. The tolerable range for *Chroococcus*, *Dolichospermum* (formerly *Anabaena*) and *Microcystis* is 30-38°C [64]. The optimum growth of *Mr. aeruginosa* is at 30-32.5°C and that of *Aphanizomenon gracile* is at 32.5°C, the lower growth temperature in *Cynlindrospermopsis raciborskii* and *Planktothrix agardhii* is 27.5°C respectively while that of *Anabaena* sp. is 25°C [63]. The minimum requirements for the aquatic live are the penetration of light (128 to 153 cm) and the DO [34] and harmful algae bloom in slow-moving water when temperature is warmer than usual, under good conditions of nutrients, hydrology, and climate [21]. They cause the decrease in transparency, depletion of DO [65], bacterial mineralization of blooms, mortality of aquatic life by ingestion of prey with high level of toxins [66], degradation of the water chemical quality, in short a number of ecological and public health consequences [67]. At both tides and both rivers, temperatures were around the optimal range of the standards and therefore bring together optimal environmental conditions for Cyanobacteria and other aquatic living organisms. The eutrophication risk is obvious and bloom situation could occur in Nyong and Kienké river mouths. Fortunately, waters are not stable but constantly diluted by freshwater contributions of continental origin from tributary rivers, and frequently stirred by the current and several particles of freshwater species are drained towards brackish environments where conditions are unfavorable thus regulating the populations of the freshwater specialists. The observed high DO is either due to the renewal and mixing of water, or to the activity of Cyanobacteria O_2-producers, as the case of *Mi. investiens* and *Mi. uberrima* [58] who are able to absorb a large amount of carbon dioxide during day time and produce a large amount of oxygen. O_2-producers would intervene in the reinforcement of the oxygenation of the water [58]. The pH in Nyong and Kienké

river mouths varied from slightly acidic to slightly basic and it is well known that many species are able to grow in acidic medium as well as in basic medium but pH higher than 9 or lower than 6 can inhibit the photosynthesis and adversely affect the morphology of Cyanobacteria. Extreme values were not recorded in the studied river mouths. NO_2^-, NH_4^+ and PO_4^{3-} to which was added a high water transparency, suggested that the rivers contained abundant mineral nutrients necessary for bio-fertilizers or toxin-producers [32]. For example, *Calothrix* is a N_2-fixing genus commonly recorded in rice fields where it helps in maintaining soil fertility by improving the nitrogen status [68]. This is also the case of *Aa. tanganyikae* in lake Tanganyika [46]. *Cy. aeruginosa*, *Gl. natans*, *Ri. aquatica* and *Tolypothrix* sp. are N_2-fixing species able to push lakes and freshwaters towards eutrophication and since they produce deadly toxins, they are used as bio-fertilizers [47, 59, 60]. *Ma. laminosus* is able to fix carbon and nitrogen and due to this dual ability it can be used as bio-fertilizer in rice field [57]. To date, more than 40 genera are cyanotoxins producers, of which the most common bloom-forming genera include *Aphanizomenon, Cylindrospermopsis, Dolichospermum, Microcystis, Nodularia, Planktothrix, Oscillatoria* and *Trichodesmium* [18]. *An. flos-aquae, An. sphaerica*, *Nostoc linckia, No. paludosum*, *Aa. arnoldi* and *Aa. circularis, Hapalosiphon* spp., *Mr. aeruginosa* and *Ph. breve* are known to form blooms in invaded freshwater environments and produce microcystins at high concentrations [42-44]. A large number of cyanotoxins are reported from different species of Cyanobacteria [10-19]. Blooms of *Wo. naegeliana* show toxic effect against zooplankton [62]. *Ra. mediterranea* frequently blooms in eutrophic lakes and reservoirs [63]. Due to the ability to produce toxins, toxigenic Cyanobacteria species are regarded as a potential health risk [47, 56, 59, 70]. Toxigenic species usually cause eutrophication, which is a result of the complex interactions between physicochemical and biological factors [71]. Water in Nyong and Kienké River mouths presented 16 toxigenic species, suggesting existence of cyanotoxins. *Li. limneticus* (formerly *Chroococcus limneticus*), *Ap. delicatissima* and *Ap. elachista* and *Ps. catenata* and *Ro. leopoliensis* are non-toxigenics although they produce low amounts of microcystins and they do not form blooms [41]. In contrast, several species are useful since they produce intracellular and extra-cellular metabolites with diverse biological activities (antibacterial, antifungal, antiviral and anticancer activities). This is the case of *Mc. lacustris* and *Planktothrix rubescens* (=*Oscillatoria rubescens*) [61]. *Ch. turgidus* is industrially cultivated for the production of bio-chemicals such as pigments, vitamins, antibiotics, polysaccharides, proteins, essential fatty acids, bio-flocculants, bio-fuel and enzymes [40]. *Go. aponina* produces a substance termed aponin a biochemical compound acting as bio-control agent against blooms of the dinoflagellate *Karenia brevis* (=*Gymnodinium breve*) [50]. Waters in the two rivers presented 13 useful species, presented low concentrations of chlorophyll a and biomass, suggesting a relatively low health risk since values were less than the norm (10 $\mu g.l^{-1}$) [12, 35]. FC contains exceeded the standard limits for drinking water [37] and suggested a contamination as a result of human or animal activities. TSS contains exceeded standard limits for drinking water (0 $mg.l^{-1}$) [36, 37] but were within the standards for fish farming (10-20 $mg.l^{-1}$) [38], as well as standards of the World Hearth Organization's guidelines (>25–40 $mg.l^{-1}$) [39].

4.2. Species Richness and Diversity of Blue-Green Algae

The present study is the first step in an in-depth study of the green-blue algae assemblage in the Nyong river mouth and Kienké River mouth (Southern Cameroon), evaluating the place occupied by zoonotic species, the toxigenic species or those useful for the nutrition of fish. Collected cells belonged to four orders of the Cyanaphyceae class, 15 families, 28 genera and 37 species (25 freshwater specialists, 12 tolerant species, distributed in 15 useful species, 16 toxigenic species and six species of unknown status). Toxigenic species are known to form blooms in stagnant waters of lakes, ponds and reservoirs as well as in slow-moving freshwaters, when water temperatures are warmer than usual [21, 66]. In the studied waters, blue-green algae are abundant and diverse, suggesting either the continuous re-colonization from the tributary rivers, or the replenishment following drainage by rainwater from the neighboring terrestrial micro-flora species, or an appearance of tolerant species adapted to the unstable conditions. Adaptation is well illustrated by tolerant species that are able to develop themselves in brackish, freshwater and terrestrial environments [8]. The present record is weak compared to the situation in New Zealand where 413 freshwater species and 87 genera reported by Broady and Merican [1]. The two studied river mouths presented a low cyanobacteria-species richness compared to the situation in other freshwater environments. For example, 124 species were recorded distributed in 26 orders, 50 families and 87 genera in the Londji mangrove area (Kribi, Cameroon) [72]. Our results are close to the previous reports in Nyong River mouth alone where 37 species of cyanobacteria, nine families and three orders were identified [25] among which seven species do not appear in our collection and four species *An. sphaerica, Mi. uberrima*, *No. linckia, No. paludosum*, *Ph. breve, Ps. catenata* and *Ro. leopoliensis* could be added to their list. The species richness in the studied river mouths is reminiscent of the reports in Burkina Faso where 37 species were inventoried in the Loumbila reservoir and among which 30 toxin-producing species and 28 microcystin-producers had the highest number [73]. However, our recordings are higher than that reported in mangrove environments in India where 31 species of Cyanobacteria belonging to 10 genera and 4 families were recorded, the genus *Oscillatoria* being observed with maximum distribution, followed by *Nostoc* and *Lyngbya*. Moreover, our recordings were high compared to that reported in the mangrove environments of Kerala situated in India [74]. It is also the case for lakes such as the Crater Lake at Barombi Kotto (North-West Cameroon) where eight species belonging to seven genera were recorded [75]. It is possible that patterns in Nyong and Kienké river mouths are dependent on local environmental conditions or the sampling methodology and

design. Non-toxigenic and toxigenic species appeared together but the low representation of non-toxigenic species could be the result either of the regulation of their populations by local natural enemies, or a negative force of toxigenic species.

4.3. Community Structure and Functioning Model

Twenty-three species (62.2%) were co-dominants (six species i.e 16.2% exclusively in Nyong River mouth and Kienké River mouth respectively, four species i.e. 10.8% simultaneously in the two tides and the two mouths, and seven species i.e. 18.9% simultaneously in combinations between the two tides and the two mouths). Twenty-nine species (78.4%) were abundant (six species i.e. 16.2% exclusively in Nyong River mouth, five species i.e. 13.5% exclusively in Kienké River mouth, two species i.e. 5.4% simultaneously in both rivers, and 16 species i.e 43.2% in other combinations between both tides and both rivers). Twenty-three species (62.2%) were co-dominants (six species i.e. 16.2% exclusively in Nyong River mouth and Kienké River mouth respectively, four co-dominants i.e. 10.8% simultaneously at both tides in both rivers, and seven co-dominants i.e. 18.9% simultaneously in combinations between the two tides and two rivers). Although cosmopolitan species were recorded, a median dissimilarity of assemblages was noted between high tide in Nyong River mouth and low tide in the same river, the pooled assemblage in the same river, high tide in Kienké River mouth, and high tide in the pooled data. The overall assemblage showed a global net negative association while it was positive in each river. Cyanobacteria assemblage from the pooled distribution at low tide from both rivers fitted the log-linear model with a high environmental constant (m=0.883), suggesting a strong species diversity and a better demographic balance of the population. Other assemblage fitted the lognormal model with in each case a low environmental constant (m'<1). The Motomura model describes a linear relationship between the abundances of the species (transformed into a logarithm) and the ranks. Contrary to the lognormal model which describes the relationship between the logarithm of the abundance and the probit of the ranks of the species and which reflects a community where the majority of species shows moderate abundances, the log-linear model corresponds to a community in which a reduced number of dominants is recorded. Motomura niche partitioning model and/or lognormal model are reported fitting SADs of zooplankton along a salinity-temperature gradient from coastal neritic to estuarine conditions in the Arcachon Bay (France) [76], the freshwater snails' assemblage at the swampy areas and streams edges in Douala (Cameroon) [77]. Given that nomocenosis are associations of species subject to the influence of the same factors and whose species profile is sufficiently close to be assimilated to the log-linear or log-normal model, they seem to characterize the stands of disturbed environments with a strong competition between species for the exploitation of available resources.

5. Conclusion

The aim of the study was to determine the water quality and biodiversity of Cyanobacteria at both tides during both seasons in Nyong and Kienké river mouths. These rivers are warm, presented low concentrations of chlorophyll a and low phytoplankton biomass, suggesting a low health risk. Yet, FC contain exceeded the standard limits for drinking water. The TSS exceeded limits for drinking water but were within the standard range for fish farming. Moreover 16 harmful toxigenic species were recorded. A total of $10802.1x10^5$ cells from both river mouths belonged to four orders, 16 families, 28 genera and 37 species (six species exclusively in Nyong River mouth, nine species exclusively in Kienké River mouth and 22 species simultaneously in both river mouths). The species diversity was low. The most species-rich family was Microcystaceae (Chroococales) (eight species i.e. 21.6% of the total species richness) and it was the most abundant family (34.7% of the total collection). It was followed by Rivulariaceae (Nostocales) with five species i.e. 13.5% of the total species richness and 12.4% of the total collection. Aphanizomenonaceae (Nostocales) was represented by four species i.e. 10.8% of the total species richness and 20.8% of the total collection. Hapalosiphonaceae (Nostocales) was represented by two species i.e. 5.4% of the total species richness and 0.8% of the total collection. Microcoleaceae (Oscillatoriales) was represented by two species i.e. 5.4% of the total species richness and 2.1% of the total collection. Nodulariaceae (Nostocales) was represented by three species i.e. 8.1% of the total species richness and 7.9% of the total collection. Nostocaceae (Nostocales) was represented by two species i.e. 5.4% of the total species richness and 1.9% of the total collection. Oscillatoriaceae (Oscillatoriales) was represented by three species i.e. 8.1% of the total species richness and 0.8% of the total collection. Eight families [Chroococcaceae (Chroococales), Coelosphaeriaceae (Synechococcales), Cyanothecaceae (Gomontiellales), Cymatolegaceae (Nodosilineales), Cyanothrichaceae (Chroococales), Gomphosphaeriaceae (Chroococales), Pseudanabaenaceae (Pseudanabaenales), and Tolypothrichaceae (Nostocales)] were each represented by only one species (2.7% of the total species richness) and rarely abundant (0.58%, 3.47%, 4.44%, 3.28%, 3.86%, 0.58%, 0.58%, 1.74% of the total collection respectively). Twenty-five freshwater specialists (67.6%) and 12 tolerant species (32.4%) were identified. Fifteen useful species (40.5%), 16 toxigenic species (43.2%) and six species (16.2%) of unknown potential were collected. Twenty-three co-dominant species (62.2%) were identified (six co-dominants i.e. 16.2% exclusively in Nyong River mouth and Kienké River mouth respectively, four co-dominants i.e. 10.8% simultaneously at both tides in both rivers, and seven co-dominants i.e. 18.9% simultaneously in combinations between the two tides and two rivers). Globally, species exhibited a negative global net association while it was positive in both river mouths. The pooled assemblage at low tide from both river mouths operated in accordance to the

Motomura log-linear niche partitioning model with a high environmental constant while other tested assemblages operated in accordance to the Preston lognormal nomocenosis model with in each case a low environmental constant. The low diversity of Cyanobacteria assemblages was associated with the low abundance in non-toxigenic species and/or those of unknown status, resulting in the weak exploitation of resources by non-toxigenic species.

Abbreviations

AIC: Akaike Information Criteria
An. flos-aquae: *Anabaena flos-aquae f. gracilis* (Klebahn) Elenkin, 1938
An. sphaerica: *Anabaena sphaerica* Bornet & Flahault, 1886
Aa. arnoldii: *Anabaenopsis arnoldii* Aptekar, 1926
Aa. circularis: *Anabaenopsis circularis* (G. S. West) Wołoszyńska & V. V. Miller, 1923
Aa. tanganyikae: *Anabaenopsis tanganyikae* (G. S. West) Woloszynska & V. V. Miller, 1923
Ah. elabens: *Aphanothece elabens* (Meneghini) Elenkin, 1936
ANOVA: Analysis of Variances
Ap. delicatissima: *Aphanocapsa delicatissima* West & West, 1912
Ap. elachista: *Aphanocapsa elachista* West & West, 1894
BIC: Bayesian Information Criteria
BOD_5: Biochemical Oxygen Demand for five days
BS: Broken-Stick theoretical model (McArthur's model)
Ca. brevissima: *Calothrix brevissima* West, 1907
Ca. scytonemicola: *Calothrix scytonemicola* Tilden, 1910
Ce. confertum: *Coelosphaerium confertum* West & West, 1896
Ce. kuetzingianum: *Coelosphaerium kuetzingianum* Nägeli, 1849
Ch. turgidus: *Chroococcus turgidus* (Kützing) Nägeli, 1849
Cy. aeruginosa: *Cyanothece aeruginosa* Nägeli Komárek, 1976
DO: Dissolved Oxygen
FC: Faecal Coliforms
FFH: Fisher-Freeman-Halton test
Gl. natans: *Gloeotrichia natans* Rabenhorst ex Bornet & Flahault, 1886
GM: Geometric model
Go. aponina: *Gomphosphaeria aponina* Kützing, 1836
KW: Kruskall-Wallis non-parametric rank-sum test
Li. limneticus: *Limnococcus limneticus* (Lemmermann) Komárková, Jezberová, Komárek & Zapomelová, 2010
LL: Lognear
LN: Lognormal
Ly. martensiana: *Lyngbya martensiana* Meneghini ex Gomont, 1892
m: Motomura's environmental constant
m': Preston's environmental constant
Ma. laminosus: *Mastigocladus laminosus* Cohn ex Kirchner, 1898
Me. elegans: *Merismopedia elegans* Braun ex Kützing, 1849
Mi. investiens: *Microchaete investiens* Frémy, 1930
Mi. uberrima: *Microchaete uberrima* Carter, 1926
Mc. lacustris: *Microcoleus lacustris* Farlow ex Gomont, 1892
Mr. aeruginosa: *Microcystis aeruginosa* (Kützing) Kützing, 1846
No. linckia: *Nostoc linckia* Bornet ex Bornet & Flahault, 1886
No. paludosum: *Nostoc paludosum* Kützing ex Bornet & Flahault, 1886
Os. chalybea: *Oscillatoria chalybea* var. *luticola* Meneghini ex Elenkin, 1949
Os. Terebriformis: *Oscillatoria terebriformis f. amphigranulata* Elenkin & Kossinskaja, 1949
pH: potential of hydrogen
Ph. breve: *Phormidium breve* (Kützing ex Gomont) Anagnostidis & Komárek, 1988)
Ps. catenata: *Pseudanabaena catenata* Lauterborn, 1915
Ra. mediterranea: *Raphidiopsis mediterranea* Skuja, 1937
Ri. aquatica: *Rivularia aquatica* De Wildeman, 1897
Ro. leopoliensis: *Romeria leopoliensis* Raciborski Koczwara, 1932
SAD(s): Species Abundance Distribution(s)
sp.: *species plurimae* or unidentified species
spp.: complex of several *species plurimae*
Sy. aquatilis: *Synechocystis aquatilis* Sauvageau, 1892)
TSS: Total Suspended Solids
TTC: TriphenylTetrazolium Chloride
VR: Variance Ratio of Schluter
Wo. naegeliana: *Woronichinia naegeliana* (Unger) Elenkin, 1933
Z: Zipft
ZM: Zipft-Mandelbrot.

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Conflicts of Interests

The authors declare no conflicts of interest.

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