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Assessment of water quality in the lower Nyong estuary (Cameroon, Atlantic Coast) from environmental variables and phytoplankton communities' composition

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The aim of this study was to provide a first-hand water quality assessment of the River Nyong estuary, Southern Atlantic coast of Cameroon. Environmental variables and phytoplankton communities were monitored at four surface stations in the estuary for 2 season cycles from 2014 to 2015. A total of 208 species of phytoplankton, belonging to five (5) groups of microalgae, were identified. The Shannon-Weaver diversity index showed a qualitative seasonal difference in composition of the phytoplankton community. Dissolved nutrients (nitrogen and phosphorus) values showed seasonal fluctuations throughout the sampling period. A ratio appeared high (42.78) in the rainy season and low (5.89) in the dry season, two values corresponding to the change in specific richness (high and low respectively during the major rainy season and the small dry season). The Water Quality Index (WQI) showed that water quality fluctuates from good to bad, in conjunction with biological indicators (Shannon-Weaver, Abundance and Specific richness).

Key words: Quality assessment, Nyong estuary, environmental variables, phytoplankton, water quality index.

INTRODUCTION

Marine and coastal zone of Cameroon are subjected to huge economic, social and environmental issues, which, like elsewhere in the world, make it a highly sensitive area. This coastal area of Cameroon is increasingly being sought by a number of economic activities, mainly fishing and tourism. There are also numerous development projects, industries (Kribi deep-sea port, gas plant, Douala autonomous port, cement plant, agro-industries, fisheries) and the future Kribi marine protected area that aims at sheltering several patrimonial species (Turtles,

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Manatees, Sharks and pelagic species) (Folack, 2011).

The overall environmental concerns of this zone are potentially linked to oil, industrial, agro-industrial, port, urban and cross-border pollution, as well as fishing, navigation and maritime transport. Since the middle of the last century, estuaries are being profoundly modified regarding not only their geometry but also the natural hydrological and sedimentological processes. In addition, waste and pollutant releases resulting from uncontrolled urbanization and industrialization often exceed estuaries assimilative capacity, modifying the ecological balance of estuaries (Boto and Bunt, 1981; Poulin, 2008). It is therefore appropriate to propose models of balanced management of these sensitive hydrosystems. The major challenge is to find methods to evaluate the potential of these ecosystems, to diagnose their disturbances through basic research works and to predict their evolution at lower cost.

Water quality is generally assessed by the coupled use of physico-chemical and biological parameters collected from the field. Monitoring based solely on physicochemical analysis is often insufficient, and reliable results rely mainly on investigations close to the contamination sources (Samocha and Lawrence, 1995; Casé et al., 2008). However, although physico-chemical analyzes provide information on water quality during sampling, living organisms that fulfill all or part of their life cycle in the aquatic environment also provides information on the conditions of their evolution/growth (Beyene et al., 2009). A more robust investigation of water quality then requires the combination of both physicochemical variables and biological indicators (Jones et al., 2001; Casé et al., 2008; Gharib et al., 2011). Among water quality bioindicators, phytoplankton organisms are recognized as good indicators of the health status of aquatic environments due to their sensitivity to human activities and climate change at different time scales (Fathy et al., 2001; Zeng et al., 2004; Pongsarun et al., 2007; Fonge et al., 2013). In addition, the composition of the phytoplankton stand reflects previous conditions that would have characterized the environment before the study (Gharib et al., 2011).

The presence of some algal groups in a particular environment is related to specific levels of pollution. The group of Chlorophyta, Cyanophyta and some spcecies of Chrysophyta which are found in tropical estuaries are common species with tolerance of pollution. Some species are indicators of moderate pollution and other are indicators of organic pollution (Luan and Sun, 2010; Ganai and Parveen, 2013). *Closterium aciculare* and *Nitszchia sp* were used as the best single indicator of pollution and were associated with the highest degree of civic pollution at Yangtze River Estuary and the adjacent east China sea in summer, 2004 (Nandan and Aher, 2005).

In Cameroon, very few studies have been done on phytoplankton of estuaries with existing data relates mainly to the Wouri estuary (Fonge et al., 2013). Data on coastal and port-industrial city of Kribi are disconnected and refer only to aquatic insects (Tchakonté et al., 2014a; 2014b) or to marine and freshwater shrimps (Makombu et al., 2014). However, due to their nutrient enrichment by continental waters, estuaries constitute precious nursery and breeding habitats for many living species.

The Nyong River is one of the most important rivers in South Cameroon. Its downstream runs through the Douala-Edéa Forest Reserve, where active fisheries develop in the mangrove zone. Intensive farming is settled on the banks of its middle course, whereas offshore oil and gas activities are developed in the surrounding area. On the upriver Nyong, several hydrological and geochemical studies have been performed (Ndam et al., 2007). Research studies on the downstream part which is influenced by tidal dynamics are recent, and revealed a high phytoplanktonic diversity consisting in marine and freshwater species, as reported from several other estuaries in the tropical zone (Okosisi et al., 2012; Mama et al., 2016).

The present study was designed in an attempt to investigate water quality of the Nyong estuary, by assessing its physicochemical status through/using the Water Quality Index (WQI) as well as the phytoplankton community structure, diversity and distribution.

MATERIALS AND METHODS

Study site and sampling stations

The Nyong estuary is part of the Campo-Nyong estuary hydrosystem of the Atlantic meridional Coast of Cameroon. The Campo-Nyong falls within the equato-guinean climatic zone characterized by four seasons known as the short rainy season (SRS), the major rainy season (MRS), the small dry season (SDS) and the large dry season (LDS) (Dzana et al., 2011). climate is influenced by the Southwest monsoon winds, limited in average at 10km/h because of the highly developed rainforest at the Southern plateau of Cameroon, and associated strong yearly rainfall (about2919mm/an) (Olivry, 1986). Four sampling stations N1, N2, N3 and N4 were chosen between latitudes 2°48' and 4°32'N, and longitudes 9°54' and 13°30'E (Figure 1). Point N1, a marine station, was fixed at 1 km offshore the mouth. The point N2 was chosen in the middle of the river mouth. N3 and N4 were located upstream respectively at 1.5 km and 4 km from the point N2. Stations were chosen according to their positions to give a global characteristic of the estuary. N1 was a marine station, while N2 was inside the mouth, behind the sandbar giving the mouth a lagoon aspect. The N3 and N4 stations were positioned respectively in the mangrove creeks and at the entrance of the mangrove islands upstream (Figure 1).

Water and phytoplankton sampling

All the seasons were covered during the survey: the major dry

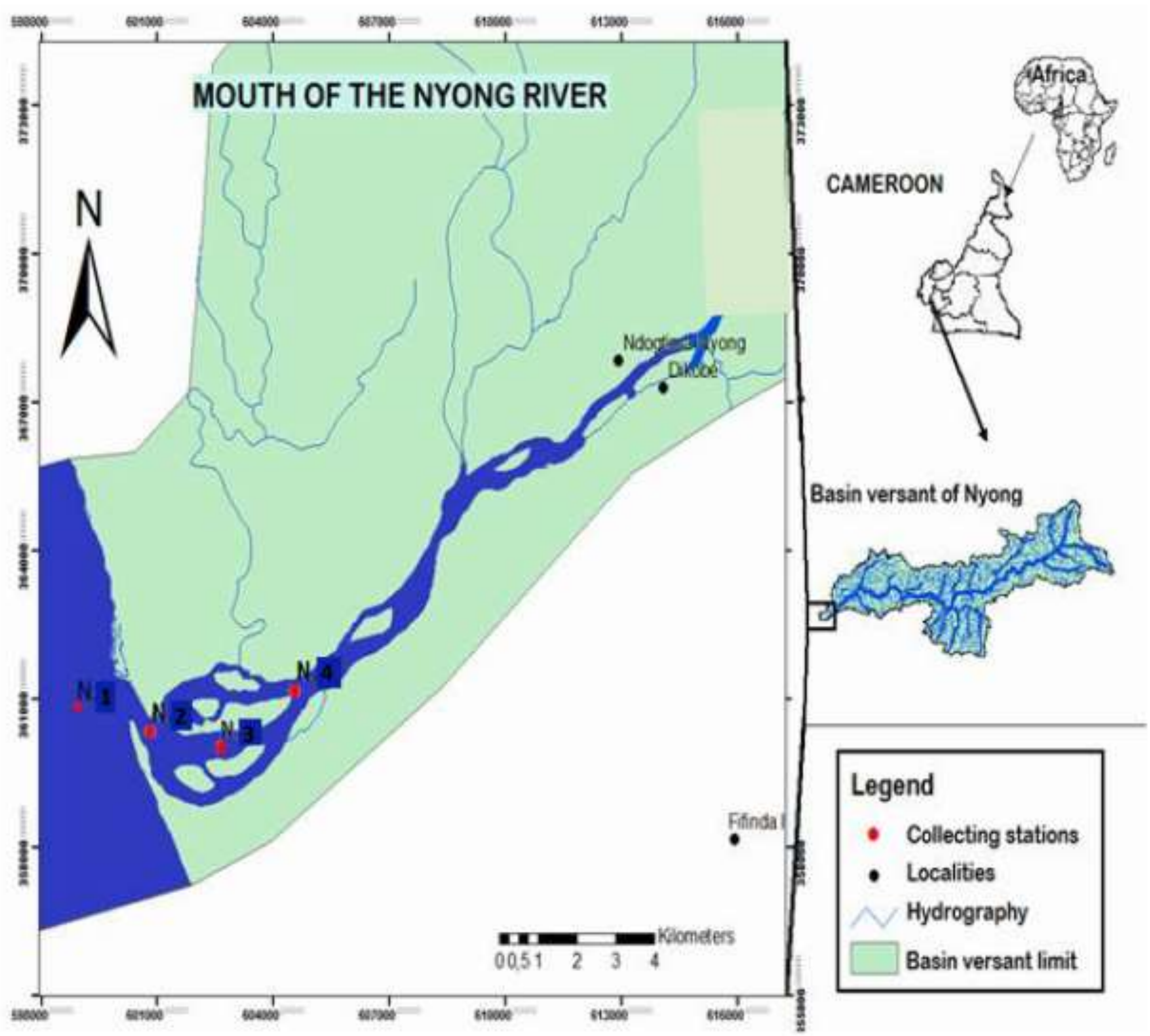

Figure 1. Map of the study area with the sampling stations (adapted from Mama et al., 2016).

season (MDS) in December 2014 and December 2015, the short dry season (SDS) in June 2014 and July 2015, the large rainy season (LDS) in September 2014 and September 2015 and the small rainy season (SRS) in March 2014 and April 2015. For each season, two samplings were carried out at each station during low tide and high tide respectively. Surface water (50cm) was sampled using a 1.7 L Niskin bottle. Water samples for analysis of physicochemical parameters were stored in 1.5 L double-capped polyethylene bottles and transported to the laboratory in an adiabatic enclosure at 4°C (APHA, 1998; Kaniz et al., 2014).

Physicochemical parameters (listed here) were determined according to the Aminot and Chaussepied (1998) method coupled with the standard methods of APHA (2005). Temperature and pH were measured using field pH-meter (Hanna model HI 98130, equipped with a SENTIX 4 electrode). Conductivity and salinity were recorded using a WTW series 3310 set2 connected to a tetracon electrode. Dissolved oxygen was recorded using the EXTECH oxymeter model Exstik II DO 600. Soluble reactive inorganic phosphorous (PO_4^{3-}), nitrites (NO_2^-), nitrates (NO_3^-), ammonium(NH_4^+), and total suspended solid (TSS), turbidity and total disolved solid (TDS) were determined using a spectrophotometer (HACH DR/2800), following APHA (1998) and Rodier et al. (2009) standard methods. BOD was measured following the standard protocol of Rodier (1996).

Identification and counting of phytoplankton

A total of 64 water samples were collected for phytoplankton analysis, 32 samples per tides. Surface water (50cm) was sampled using a 1.5 L bottle. These samples were immediately fixed by lugol's iodine solution (15 ml) containing 10% acetic acid, and left to stand for 24 h, to allow phytoplankton settle (Sournia, 1978). Then the lower layer (25 ml) containing the sedimented algae was used for identification and counting of algae, using Malassez's cell, under an upright Olympus optical microscope at 60x magnification. Identification of the phytoplankton species followed relevant textbooks and publications, including Iltis (1980), Botes (2001), Gopinathan et al. (2007), de Ba et al. (2006), Carmelor (1997), Verlencar (2004), and Karlson (2010).

Data analysis

Water quality index

The water quality index (WQI) is a mathematical tool used to transform several water characterization data into a single number that express the water quality level according to Mishra and Patel (2001) scale (0 to 25 for excellent; 26 to 50 for good; 51 to 75 for bad; 76 to 100 for very bad; above 100 for unfit) (Sanchez et al., 2007; Gharib et al., 2011). In this study, seven physico-chemical parameters (pH, dissolved oxygen, nitrate, nitrite, ammonia, phosphate and silicate) were used as recommended by Wepener et al. (2006) for estuarine water quality assessment. Standard values for bathing water given by the World Health Organization were used to obtain the WQI, following the protocol described by Khwakaram et al. (2012) and Behnmanesh et al. (2013). Then, a quality value (Q value) from 0 to 100, based on the normal data range, was assigned to each parameter. Each Q value was multiplied by a weighing factor based on the importance of the parameter, and summation of the weighed Q values yielded the WQI. The determination of the WQI was made by the method of the arithmetic weight index, according to the following steps:

(1) The quality rating scale (q_n): Let n be water quality parameters, quality rating level (q_n) corresponding to the n^{th} parameter is a number representing the relative contribution of this parameter in polluted water with respect to its permissible standard value

$$q_n = \frac{V_n - V_{io}}{S_n - V_{io}} \cdot 100 \quad (1)$$

With, V_n = estimated value of the n^{th} parameter at a given sampling station;
S_n =the standard permissible value of the n^{th} parameter
V_{io} = the ideal value of the n^{th} parameter in pure water. All ideal values are taken equal to zero, except that of pH = 7 and that of dissolved oxygen OD = 14.6 mg / l.

(2) Unit weight (Wn): The unit weight (Wn) was calculated by a value inversely proportional to the recommended standard value $\mathbf{S_n}$ of the corresponding parameter

$$W_n = K/S_n \quad (2)$$

Where, K is a constant of proportionality with $K = 1/\sum 1/S_n$
S_n is a standard value for n^{th} parameters
The combination of all the aforementioned equations gives the formula of WQI that follows:

$$WQI = \frac{\sum(W_n \cdot q_n)}{\sum W_n} \quad (3)$$

Specific richness

Specific richness (S) is defined as the total number of identified species in a sample. This parameter can well be a distinctive criterion of ecosystems or stations studied within a given ecosystem.

Shannon-Weaver diversity (H')

Shannon-Weaver diversity index is a quantitative measure that reflects how many species there are in a sample (specific richness), and simultaneously takes into account how evenly the basic entities (such as individuals) are distributed among those types. The counts were expressed in relative abundances of the species or taxa of the different phytoplankton groups ($P_i = N_i/N$).

$$H' = -\sum_{i=1}^{s} P_i log_2 P_i \quad (4)$$

Where, $P_i = N_i/N$, N_i the number of individuals of one particular species found and N the total number of individuals

Statistical analysis

Simultaneous comparison of seasonal mean values of WQI was performed using the one-factor analysis of variance (ANOVA) test (Fisher's F test) when the conditions of normality and equality of variances are verified. The relationship between physicochemical and biological parameters were verified by the Pearson correlation at a significance level α = 0.05. Species abundance calculations were carried out and the structure of stands was studied for diversity by the Shannon index (Shannon and Weaver, 1963).Rapid variation in nutrient concentrations from one season to another or between two stations required the calculation of the ratio N / P (deviation from the mean redfield ratio N / P = 16. The Spearman correlation test was performed between the Redfield ratio and the specific diversity index. These analyzes were carried out in the STATSTICA 7.1 software.

RESULTS

Physico-chemical characteristics

Seasonal mean values of the physicochemical parameters measured at the Nyong River Estuary are shown in Table 1.

Temperature on the Nyong River varied between 23.57 and 28.70°C. Mean conductivities were higher during the dry season on Nyong (21337µS/cm), than in the major rainy season (12242.9µS/cm). Average dissolved oxygen values range from 5.88 mg/l to 2.58 mg/l. The highest value of the seasonal mean TSS was observed in the LDS (17.04 mg/l), and the lowest in the MRS (6.18 mg/l). In general, the Nyong estuary waters were almost neutral with the mean values of pH varying between 6.63 and 7.4. Nitrogen and phosphate nutrient values show seasonal fluctuations throughout the sampling period. The highest average ammonium concentration (1.24 mg/l) was observed in the large dry season. The average nitrate values ranged from 0.27 mg/l to1.42 mg/l. Nitrites showed a fluctuation between 0.0034 mg/l (major rainy season) and 2.20 mg/l (small rainy season). The highest

Table 1. The average seasonal physicochemical parameters of the Nyong estuary during the study period.

Seasons	LDS/DJF	SRS/MAS	SDS/JJO	MRS/SON
T (°C)	27.95±2.99	28.70±0.67	23.57±0.35	25.58±0.78
DO (MG/L)	4.69±0.70	4.72±0.80	4.2±1.03	2.58±0.64
CONDUCTIVITY (µS/CM)	21337±30205	12563±32741	14449±12031	12243±26372
TSS (MG/L)	17.04±8.90	8.47±7.00	7.91±5.94	6.18±5.12
PH	7.4±0.69	6.63±0.36	7.3±0.46	7.01±0.31
NH_4^+ (MG/L)	1.24±1.10	0.74±0.61	1.16±1.01	1.18±1.50
NO_3^-(MG/L)	1.08±10	1.38±20	1.42±1.24	0.27±0.36
NO_2^- (MG/L)	0.25±0.50	2.20±2.10	0.53±0.83	0.0034±0.004
PO_4^{2-} (MG/L)	0.36±0.23	0.67±0.69	1.9±0.59	0.80±0.85
BOD (MG/L)	45.88±29.19	14.65±9.53	12.6±25.63	24.68±22.22
N/P	42.78±69.4	18.7±1168	5.89±2.05	18.55±34.6
WQI	43.47±16.08	84.01±20.23	85.80±40.33	68.05±25.22

Table 2. Taxonomic composition and representation of phytoplankton groups in the Nyong estuary.

Division	Class	Order	Family	Genus	Species	Percentage (%)
Chrysophyta	4	14	19	49	77	37.01
Chlorophyta	4	12	22	49	68	32.69
Cyanophyta	2	4	9	22	35	16.90
Pyrrophyta	2	7	11	13	16	7.6
Euglenophyta	1	2	2	7	12	5.80
Total	13	39	63	140	208	100

average seasonal concentration of orthophosphate ions (1.9 mg/l) was observed in the small dry season and lower (0.36 mg/l) during the major dry season. The ratio (N/P = 16) was the highest in the main dry season (42.78) and the lowest in the short dry season (5.58). The seasonal mean of biological oxygen demand (BOD5) varied from 12.6 mg/l to 45.88 mg/l. Water quality index (WQI) values on the estuary indicate good water quality during the main dry season (43.47), and bad water quality during the short dry season and the small rainy season (85,80 and 84.01 respectively). During the major rainy season, Nyong estuarine water presents a moderate status with the mean WQI of 68.05. Significant difference was observed among WQI between seasons (ANOVA 1, $P < 0.05$). Pearson correlation revealed that some physicochemical parameters of Nyong were correlated: BOD and suspended matter ($r = 0.95$, $P < 0.05$) and WQI and Nitrites ($r = -0.97$, $p < 0.05$).

Phytoplankton stand structure

Specific richness

Of the 64 samples collected, a total of 208 species of phytoplankton were identified and distributed in 5 groups of microalgae (Mama et al., 2016): Chrysophyta, Chlorophyta, Cyanophyta, Pyrrophyta and Euglenophyta. Chrysophyta made up the highest number with 49 genera and 77 species; while Euglenophyta ranked low with 7 genera and 12 species identified (Table 2).

Seasonal variation of phytoplankton

Specific diversity

The evolution of diversity index on the Nyong estuary by box-whiskers shows a seasonal variation (Figure 2). During the MRS and the LDS, interquartile ranges were less spread than in the other two seasons, showing an appreciable level of homogeneity of observed species. Moreover, the distribution was symmetrical in all seasons. Shannon index values ranged from 3.3 to 5.4, with the greatest value obtained during the SDS and the smallest during the SRS. The diversity index values (H') were generally high at all stations on the estuary. The maximum (H'= 4.81) was observed at station N4, and the minimum (H'= 3.81) at station N3, during the small dry season / SDS (Figure 3). Shannon index (H') variances

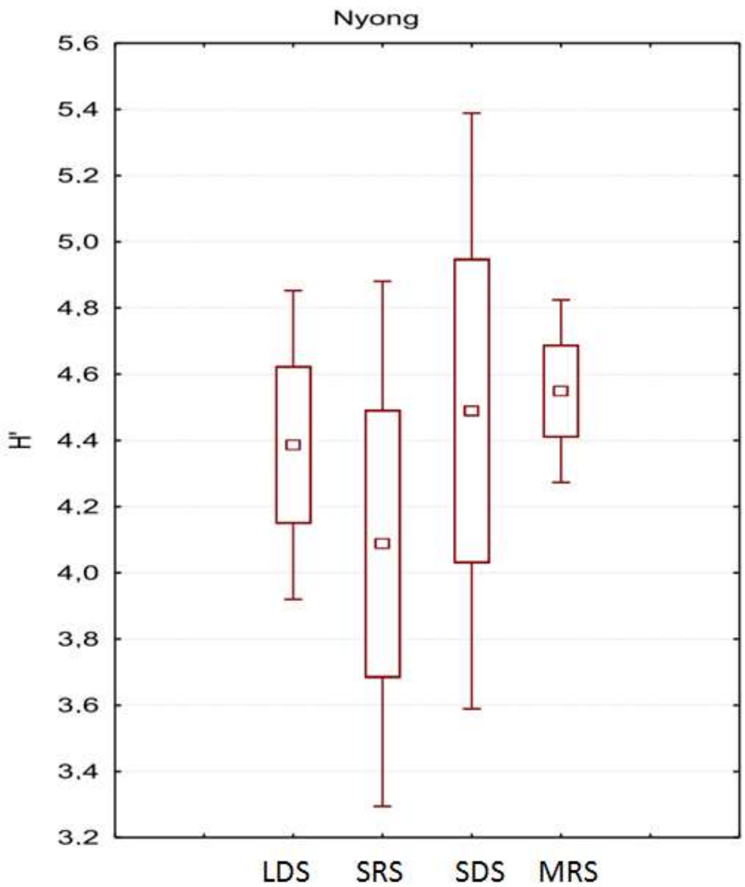

Figure 2. Seasonal variability of the Shannon-Weaver Diversity Index on the Nyong Estuary.

between seasons indicated a significant difference (ANOVA 1, P <0.05) (Figure 2).

During the study period, Chrysophyta and Chlorophyta groups were found to be the dominant microalgae on the Nyong estuary during the whole study period. These two groups constituted respectively 38.50% and 29.70% of the total cells counted (351.7×10^5 cells/l) during the study. Their specific abundances and compositions varied from one station to another depending on the season (Figure 3). Chrysophyta division rank first in all seasons, except in the LDS where they contributed only 12.22% of the total counts. During this season the Chlorophyta were dominant (51.15%) followed by Cyanophyta (23.53%). A seasonal fluctuation of phytoplankton abundance was observed, from 113.50×105 cell/l during the MRS to 93.90×105 cell/l in the SRS/short rainy season. The minimum was observed during the SDS with 71.64×105 cell/l. The contribution of Euglenophyta and Pyrrophyta were the least important at all seasons, with a percentage abundance of 6.20 and 4.08% respectively.

The total mean of microalgae abundance was $18.78\times10^5\pm12.14\times10^5$ cell/l. Chlorophyta was the most abundant phytoplankton group (31.33×10^5 cell/l), followed by Chrysophyta (27.71×10^5 cell/l). Phytoplankton groups were present at all stations in different proportions. At the N1 marine station, Chlorophyta dominated in quantity on the other groups with 15.16×10^5 cell/l. From a spatial point of view, Chlorophyta of the genus *Closterium* was more abundant (2.75×10^5 cell/l) at station N1. At station N2, *Calothrix brevissima* (Cyanophyta) was the dominant species. Station N3 was dominated in terms of cell abundance by the genus *Ophiocytium* of the Chrysophyta group (1.67×10^5 cell/l); and the N4 station by 1.75×10^5 cell/l of *Synedraulna*.

The average phytoplankton abundance during the LDS was $14.53\times10^5\pm$ 9.53×10^5cell/l. The highest percentage of abundance was Chlorophyta group (38%), followed by Cyanophyta (27.62%). Chlorophyta was dominant at all stations except at station N3 where the Cyanophyta group predominated with 5.65×105 cell/l. *Botryococcus braunii* species (Chlorophyta) dominated at stations N1

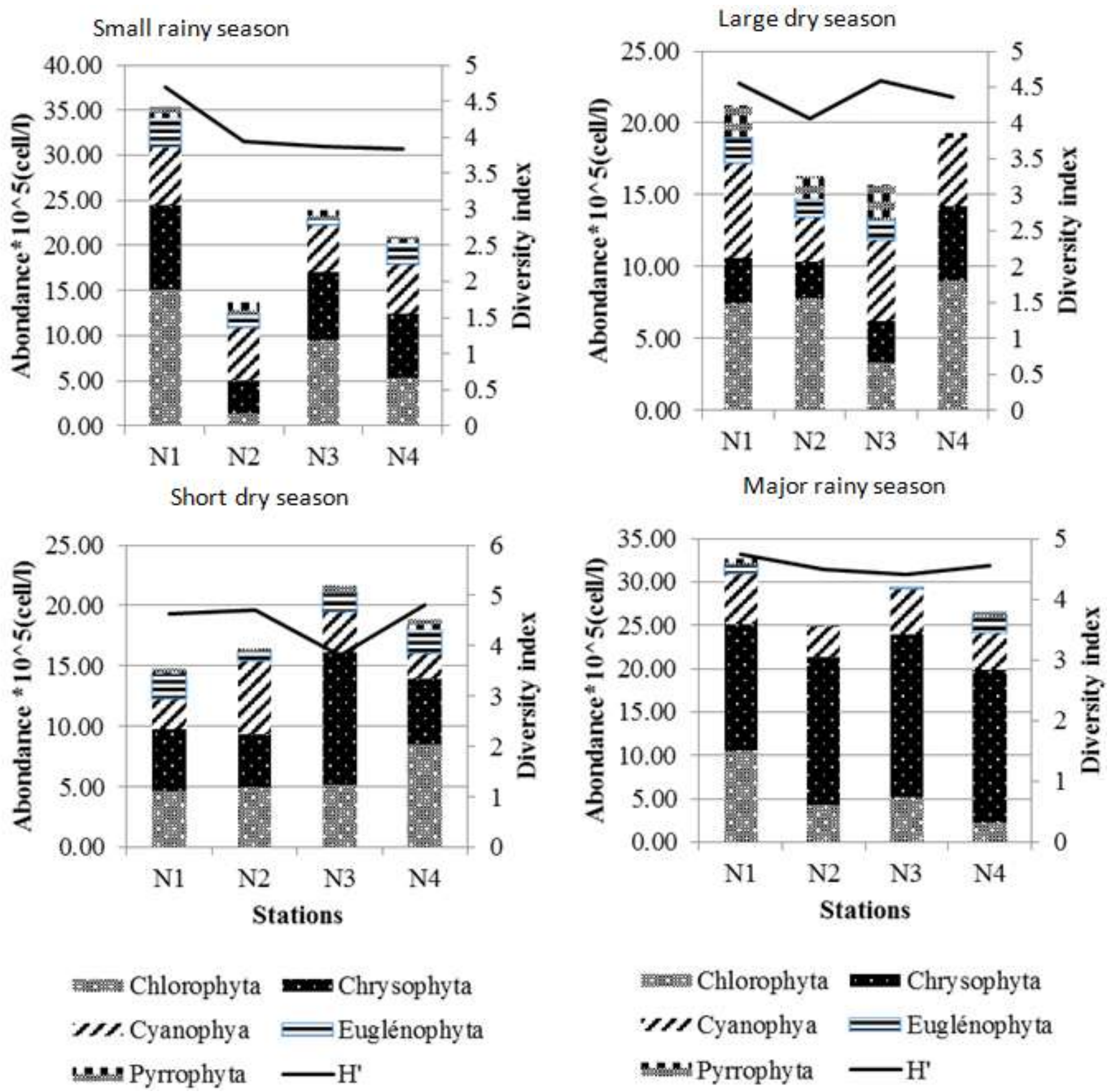

Figure 3. Seasonal variation in the abundance of phytoplankton groups and specific diversity index in the Nyong estuary During SRS,

and N2 with 3.98×105 cell/l and 1.66×10^5 cell/l respectively. However at station N4, it was the *Closterium aciculare* species (Chlorophyta) that was dominated with 1.66×10^5 cell/l. During this season, the Pyrrophyta group (6.72×10^5 cell/l) was more abundant than the Euglenophyta group (4.53×10^5 cell/l)which was absent at station N4.

During the SDS, the seasonal mean of the total phytoplankton cell abundance was 14.33×10^5±10.32×10^5cell/l. The groups of chrysophyta and chlorophyta were the most abundant with 36.04% and 32.51% respectively. Chrysophyta was dominant at station N3 with 10.94×105 cell/l, while Chlorophyta dominated at station N4. At station N2, Cyanophyta dominated with 6.08×105 cell/l, with the majority of species of the genus *Gomphosphaeria*. At station N3, *Tetraspora gelatinosa* species (Chlorophyta) ranked first with 1.50×105 cell/l. The proportions of Euglenophyta ranged from 0.78×105 cell/l to 2.08×105 cell/l and they were present at all stations. This last group dominated in N4 with the genus *Trachelomonas* (2.25×105 cell/l).

The highest phytoplankton abundance was observed during the MRS (22.70×10^5 ± 27.01×10^5 cell/l). Chrysophyta group appears to be dominant at all stations with a percentage abundance of 60.03%, followed by Cyanophyta (18.63×10^5 cell/l) and Chlorophyta (22.25×10^5 cell/l) divisions. The most widespread genus of chrysophyta in all stations was the *Nitszchia* genus.

The group of Euglenophyta (3.13×10^5 cell/l), were absent in N2, and Pyrrophyta (1.38×10^5 cell/l) and were the least represented in N3

Correlation analysis

A strong positive correlation was obtained between the abundance and dissolved oxygen concentration (r = 0.95, P <0.001), between the Shannon-Weaver index and dissolved oxygen (r =0.69, P <0.05), which would reflect the high oxygen production (respiration) linked to the abundance and the specific diversity of the estuary. The strong negative correlation observed between nutrients and abundance confirms this strong microalgae production, which is accompanied by a decline in nitrate (NO_3^-, r = -0.72, P <0.05) and nitrite (NO_2^-, r = -0.56, P <0.05) concentrations. Between ammonium and abundance a positive correlation was observed (r = 0.41, P <0.05).

DISCUSSION

A permanent monitoring of physicochemical parameters in aquatic ecosystems provides information on the health status of the environment (Sargaonkar and Deshpande, 2003). In this study, the combination of these variables with phytoplankton made it possible to diagnose the quality of Nyong estuarine waters. Water temperature at the Nyong estuary was high, and follows the atmospheric evolution. It is high in the dry season and low during the rainy seasons.

The average value of pH higher or equal to 7 during the dry seasons or the small rainy season indicates that water bodies of the estuary are made up mainly of basic marine water. These estuarine water bodies have a pH of less than 7 but close to neutrality in the rainy season due to the influence of freshwater from rivers. The increase in conductivity in the dry season is explained by the mineralization of these hydro-systems when the tidal flow prevails over the flow of freshwater.

Nutrients concentrations value obtained during this study were low compared to those of the Douala, Wouri and Dibamba estuaries. For instance, in the study area, and during the rainy and dry seasons respectively, ammonium, nitrate and phosphate concentrations respectively varied in the ranges (0,74 ; 1,18) mg/l, (0,27 ; 1,38) mg/l and (0,67 ; 0,80) mg/l on one hand, and (1,16 ; 1,24) mg/l, (1,08 ; 1,42) mg/land (0,36 ; 1,90) mg/l on the other hand, respectively during the rainy and the dry seasons. Whereas especially in the Douala estuary, previous ammonium, nitrate and phosphate concentrations respectively varied in the ranges (108,8 ; 118,6) mg/l, (107,5 ; 129,9) mg/l and (0,04 ; 0,38) mg/l during the wet seasons, and (42 ; 57,5) mg/l, (31 ; 44) mg/l and (0,03 ; 0,04) mg/l during the dry seasons (Fonge et al., 2013).

Unlike the Douala estuary where ammonium concentrations were high in the rainy season due to urban drainage load in the effluent, it is during the dry seasons that the highest values were observed in the Nyong. In the Nyong estuary, nutrients are both from agro-industrial effluents and organic matters decomposition. During rainy seasons, significant freshwater inputs would dilute chemical concentrations at thresholds considered limiting for the growth of some microalgae (Akoma et al., 2008).

Guildford and Hecky (2000) reported that, the ratio N/P in marine and continental area covert the same class of values, and could allow to predict any modification in phytoplankton composition. Ratio is influenced by the morphology of the environment. Actually, the residence time and depth of the estuary affects the availability of nitrogen and phosphorus, which would become limiting nutrient for the production of phytoplankton (Le Gall, 2012). N/P ratio value obtained in the course of this study presented intra-seasonal (during the Short and the Large Dry Seasons) and inter-seasonal variations. But globally, results indicated that the Nyong Estuarine waters were phosphorus-deficient during the LDS (N/P>33) (McDowell et al., 2009) and nitrogen-deficient during the SDS. This contrasts with observations made during the rainy seasons, where nitrogen- and phosphorus were both deficient. However, rainy seasons were the richest in terms of abundance and diversity of phytoplankton.

As observed by Jiyalalram (1991) in the Mahi estuary in India and Nwankwo (1998) in the Epe lagoon in Nigeria, highest phytoplankton abundance (H'= 4.55) and diversity (113.50×10^5 cell/l) were recorded during the Major Rainy Season (MRS) on the Nyong estuary. The large population of phytoplankton corresponding to low nutrient values in the rainy seasons could also indicate high consumption rate. These seasons were marked by low dispersal of species (homogeneity), which means that enrichment would favor the development of some species at particular stations.

Distribution, composition and diversity of phytoplankton organisms in the estuary are influenced by nutrient concentrations that fluctuate from season to season, depending on location and physical nature of the environment. This has an impact on the quality of the ecosystem, as biodiversity differs from changes in ecosystems. Microalgae growth depends on the ability of the organism to adapt to ecological changes and interactions between variables (Reid, 1961; Fonge et al., 2012).

The Chlorophyta group was the most abundant during the short rainy season at the Nyong estuary. This abundance (31.33x105 cell/l) compared to other groups of micro-algae was in line with other works which showed that rivers of Cameroon (Nyong included) are richer in Chlorophyta species (Nguetsop et al., 2009; Mama et al., 2016).The limnohalin character of the estuary (mean salinity<5‰) justifies that fresh waters prevail over marine waters (Ayissi, 2014).The dominance of the genus *Closterium* (Chlorophyta) with 2.75×10^5 cell/l, and species *Botryococcus braunii* (Chlorophyta) with 3.98×10^5 cell/l and *Calothrix brevissima* (1.88×10^5 cell/l) and the presence of Cyanophyta group indicates an excess of nutrients in the environment which is the major characteristic of eutrophic ecosystems.

These findings correlate with those of Hans et al. (2001) which state that in tropical waters the excessive presence of Chlorophyta accompanied by Cyanophyta occurs when the environment has important nutritional conditions. The values of the Redfield ratio (greater than 16) obtained during the rainy seasons and the large dry season reflect the enrichment of the medium in nitrogen ion to the detriment of the phosphate ion. The average temperature of 27°C and the basic pH of the estuarine water confirm this eutrophic character of the River Nyong mouth. These results were similar to the findings of Ryding and Rast (1989) which state that Cyanophyta grows particularly well in eutrophic, alkaline environments and in lukewarm water.

The Chrysophyta group was dominant in quantity on Nyong (38.50%), mainly the class of Diatomophyceae of the genus *Nitszchia* and also the genus *Ophiocytium* of the class Xanthophyceae. This group is mainly found in freshwater, but some species have developed abilities to live in brackish and marine waters. Several species of Diatoms have been identified in Cameroon estuaries such as *Chaetoceros testissimus*, *Nitzschia closterium*, *Diatomavulgare* sp., *Trachyneis* sp. and *Coscinodiscus* sp. (Folack et al., 1991).

The adaptability of some of these species to brackish water makes them toxic (Yupeng et al., 2006). This constitutes a constraint for the practice of aquaculture activities in estuaries (Hans, 2001). The alkaline environment and temperature of the Nyong estuarine waters favor the presence of these species in the environment. This is in agreement with the work of Wetzel (1983) which showed that *Nitszchia* sp. are oligotrophic species. Similar results were found in the estuaries of Dibamba and Douala (Fonge et al., 2012).

Given the revealed importance of the Campo-Nyong estuarine system, particularly the Nyong estuary for its useful nursery role in fisheries and aquaculture development, a permanent monitoring of the evolution of physico-chemical and biological parameters, would allow a better management of this mangrove estuary. Moreover, as the Nyong estuary is part of the Douala-Edea reserve, these findings could be the baseline for the development of aquaculture activities and ecotourism. The WQI calculated on the basis of a greater number of variables would give better information on the health of the environment. Combined with biological indicators, this would allow a good management of the estuarine hydrosystem.

CONCLUSION

Fluctuations in the composition and abundance of phytoplankton groups are significant in the Nyong estuary. From the combination of environmental variables to abundance and phytoplankton diversity, the Nyong estuary contains, according to seasons, phytoplankton species indicating an oligotrophic and eutrophic state. The WQI used here indicates that Nyong water fluctuates from good to bad. These different states correspond to periods when the biological index indicates polluted or moderately polluted water. In conclusion, the combination of environmental variables and biological indicators allows complementarity in assessment of the quality of aquatic ecosystems. This knowledge is fundamentally important to understand the estuary dynamic and predict future changes.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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