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Diversity of benthic macroinvertebrates and biotic indices to evaluate water quality in Lake Sokotè (Côte d'Ivoire)

Fato Edouard Motchié, Yao Aristide Konan*, Bi Gouli Gooré, N'Doua Raphaël Etilé, Stanislas Silvain Yao

Laboratory of Hydrobiology and Water Ecotechnology, Department of Biosciences, University of Félix-Houphouet-Boigny, Abidjan, Côte d'Ivoire

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Abstract

Aquatic environments provide many ecosystem services to human people and their management requires a good knowledge of ecological status and biodiversity. The present study aimed to determine the structure of benthic macroinvertebrate assemblage in relation to the physicochemical quality of Lake Sokotè, in Bongouanou City (Côte d'Ivoire). Physico-chemical parameters were measured monthly from May 2017 to April 2018 and the benthic macrofauna was collected using a Van Veen grab on a total area of about 0.5m² per sample. Both macroinvertebrates and physico-chemical data were analysed according to seasonal variations and correlations. Physicochemical parameters analysis indicated low values of dissolved oxygen, pH and transparency and significant variations between the dry and rainy seasons ($p<0.05$). Thirty-five taxa of macroinvertebrate including annelids molluscs, insects and were identified in Lake Sokotè. Quantitative analysis of macroinvertebrate assemblage revealed that three families Tubificidae (annelids), Thiaridae (molluscs) and Chironomidae (insects) which are resistant taxa to pollution represent 95.34% of the total abundance. Number of taxa varied significantly according to seasons and diversity index were lower in all seasons. Diversity indices and physicochemical parameters revealed that Lake Sokotè is rich in organic matter and poor quality, and macroinvertebrates assemblages changed depending on seasonal variation of environmental variables.

***Corresponding Author:** Yao Aristide Konan ✉ ariskoya@yahoo.fr

Introduction

Biodiversity conservation has long been a priority for human populations. Sacred natural sites, forests, hills, river sections or other water bodies have survived for many years and continue to this day throughout the African region despite many pressures. Their objectives include the maintenance of ecosystem services, the provision of benefits to local communities, support for sustainable resource use, as places which have spiritual and/or cultural significance to one or more groups of people and biodiversity conservation (Anderson *et al.*, 2005).

Sokotè is a sacred lake located inside Bongouanou city and plays an important role in tourism and culture. However, it suffers from various sources of pollution, including domestic sewage from the surrounding human settlements and agricultural wastes from City. Indeed, during low water seasons, fish mortalities are regularly observed, giving off unpleasant odors. These activities and decomposition of fish can release organic matter into the environment and affect water quality (Jin-Kyung and Jong-Min, 2018). Quality of water may be changed due to different types of chemicals, biological and physical pollutants originating from different industrial and agricultural sources (Andhale and Zambare, 2012). Pollution of the aquatic environment is a major factor posing serious threat to the survival of aquatic organisms including fish, invertebrates, etc. So, it is appropriate to assess the biotic integrity of this ecosystem. Several methods are used, including biological indicators and chemical methods. Macroinvetebrates constitute an important component of biodiversity in lotic systems. They are diverse, have short generation times and are easily dispersed. As a group, macroinvertebrates are sensitive and respond to both natural and man-induced changes in their environment (Wallace and Webster, 1996; Barbour *et al.*, 1999).

Several techniques, protocols and indices have been developed to monitor stream quality using changes in species composition, diversity and functional organization of aquatic insects (Lenat, 1993). According to intermediate disturbance hypothesis (IDH) high species diversity in moderate disturbed ecosystems are attributed to co-existence of pioneer, stress-tolerant and ruderals species (Connell, 1978). However, there is no information of macroinvertebrates assemblage of Sokotè lake and aquatic environment quality. The present work aimed to investigate macroinvertebrate communities and water quality and in sacred Lake Sokotè. This study will determine water physico-chemical characteristics, describe macroinvertebrate composition and relate water quality to macroinvertebrate abundance and diversity index.

Material and methods

Study area

Sokotè is a sacred lake with an area of 15 000m^2 (Fig. 1) and located in the city of Bongouanou (Region of Moronou, Côte d'Ivoire). Fishing, swimming and several other anthropogenic activities are prohibited in this area. However, runoff from the watershed and domestic effluents are discharged into the aquatic environment. Rainfall is bimodal with long rains occurring during the months of April to July (RS1) and the short rains from October to November (RS2). Dry seasons occur between August and September (DS1) as well as December and March (DS2). The mean annual temperature ranges between 28 and 30°C.

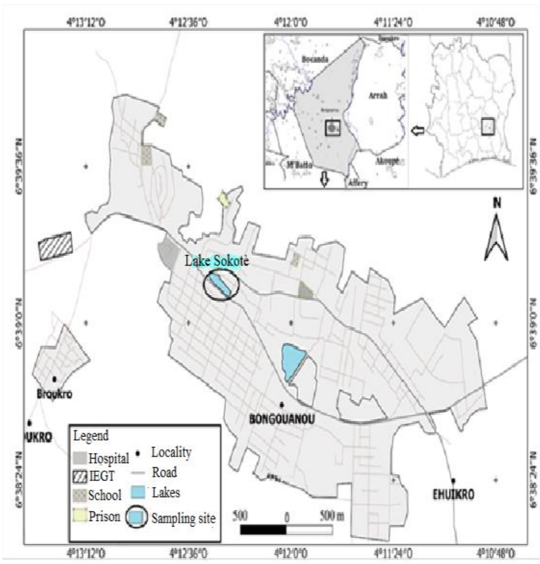

Fig. 1. Map of Bongouanou Department showing Lake Sokotè (Côte d'Ivoire).

Sampling

Physicochemical parameters of water were measured at different site in Lake Sokotè between April 2017 and March 2018. Temperature, dissolved oxygen, pH, conductivity and Transparency were measured in situ. In the laboratory, phosphate and nitrate levels were determined by colorimetry using spectrophotometer and the results expressed in µg/L.

Macroinvertebrates were sampled using a Van Veen Grab, 1m long and 14cm in diameter. Mud was obtained up to a depth of 10cm. It was first examined, all large (visible) invertebrates removed with forceps and put in specimen bottles containing 5% formalin. The remaining mud was loosened with more water, put in polythene bags and then preserved using 5% formalin. In the laboratory, the mud was washed through a 500µm sieve and all macroinvertebrates picked from the sieve. Macroinvertebrates were sorted, identified accordind to Elouard (1981), Moor and Day (2002) and Tachet *et al.* (2010) and counted at the Laboratory.

Data analysis and Statistics

Mann-Withney analysis were used to compare physico-chemical parameters values and invertebrates population between rainy and dry seasons. The level of statistical significance was maintained at 95% ($p < 0.05$). Macroinvertebrate diversity was calculated using biodiversity indices of the Hill's Family (Hill, 1973; Pielou, 1975): Species richness (total number of taxa present per season), Shannon–Wiener index (H'), Equitability (J), Eveness (E) and Simpson (S). Saprobic level of Lake Sokotè was evaluated by Shannon-Wiener index according to Staub *et al.* (1970) (Table 1).

Table 1. Classification of saprobity based on Shannon-Weaver's index (H') (Staub *et al.,* 1970).

H'	Saprobity
0 - 1	polysaprobic
1 - 2	α-mesosaprobic
2 - 3	β-mesosaprobic
3 - 4.5	oligosaprobic

Redundancy analysis (RDA) were used to identify environmental gradients and their relationships to the benthic community using CANOCO software (Ter Braak, 1986). It was performed taking into account the abundance of all taxa as biotic variable and the physico-chemical parameters.

Results

Physicochemical parameters

Temperature varied between 26.4°C and 28.1°C and the highest values were obtained in DS2 (Table 2). In contrast, oxygen showed higher values (68.8%) in rainy seasons and lowest values (8.4%) during dry seasons. Conductivity was very high, especially during DS2 (523.5 ± 257.9µS/cm) while transparency values were very low. Phosphate and Nitrate was higher in dry seasons (DS2) and don't change significantly between seasons. Mann-Withney test revealed oxygen, pH and transparency readings were only significantly different between RS1 and DS2. Fluctuations in environmental variables were most pronounced between RS1 and DS2 rather other seasons.

Table 2. Some physical and chemical parameters (with mean and standard deviation) of Lake Sokoté measured during April 2018 and March 2019. RS1 and RS2 = first and second rainy season; DS1 and DS2 = first and second dry season.

Parameters	Seasons				Mann-Withney
	RS1	DS1	RS2	DS2	RS1xDS2
Temperature (°C)	27,4±1,5	26,4±1,1	27,6±1,1	28,1±2,6	-
Oxygen (%)	68,8±16,4	36,3±15,9	43,7±5,3	8,4±6,3	p<0.05
pH	7,7±0,72	7,0±0,3	6,9±0,4	6,7±0,2	p<0.05
Conductivity (µS/cm)	326,3±74,7	414,5±21,9	445,8±47,7	523,5±257,9	-
Transparency (m)	0,2±0,02	0,2±0,05	0,1±0,01	0,1±0,04	p<0.05
Phosphate (µg/l)	29,6±21,3	31,6±10,6	25,3±1,7	71,83±41,35	p<0.05
Nitrate (µg/l)	17,2±6,8	10,7±4,4	12,5±3,2	27,4±21,5	-

Macroinvertebrates assemblage and Diversity

A total of 35 taxa of macroinvertebrates (annelids, gasteropods and insects) belonging 23 families were collected from Lake Sokotè (Table 3). Annelids, gastropods and insects are represented by 11.43%, 22.86%) and (67.71%) taxa, respectively. Number of taxa has varied according to seasons. The higher number of taxa (28) were recorded during rainy seasons compared to 24 in dry seasons. In Oligochaetes, only one taxa, *Tubifex* sp., was sampled in all seasons, while in molluscs, *B. pfeifferi* and

M. tuberculata was more frequent. Among Insects, only Chironomidae appear in all seasons while Odonates, Heteroptera and Coleoptera are less frequent. Other Diptera group, Ephemeroptera, Odonats, Heteroptera and Coleoptera were present but not frequent. Low population of Achateta were recorded in RS1. There is a significant difference between invertebrates population in RS1-DS1 (p=0.003) and RS1-RS2 (p=0.020). The five most abundant taxa (relative abundance >1%) were *Melanoides tuberculata* (52.72%), Tubifex sp. (20.25%), *Chironomus formosipennis* (18.67%), *Polypedilum* sp. (3.32%) and Culex sp. (1,98%) belonging to Tubificidae (Oligochatea), Thiaridae (Gasteropoda) and chironomidae (Diptera). These 3 families Tubicifidae, Thiaridae and Chrironomidae represent 95.34% of total abundance of benthic macroinvertebrates in Lake Sokotè.

Table 3. Taxa collected in Lake Sokotè with their relative abundance (percentage of the total number of individuals) per season. Marked '–' means absence. RS = rainy season; DS = dry season.

Family	Taxa	Code	RS1	DS1	RS2	DS2
Tubificidae	*Tubifex* sp.	Tub	5.98	3.86	5.75	4.66
Lumbriculidae	*Lumbriculus* sp.	Lum	0.01	–	–	–
Glossiphoniidae	*Haementeria costata*	Hae	0.02	–	0.01	0.01
	Hemiclepsis marginata	Hem	0.09	–	0.02	–
Bulinidae	*Bulinus forskalii*	Bul	0.01	–	–	–
	Bulinus truncatus	But	0.01	0.01	–	–
Planorbidae	*Biomphalaria pfeifferi*	Bio	0.16	0.07	0.05	0.25
	Helisoma sp.	Hel	–	–	0.01	–
	Gyraulus sp.	Gyr	0.32	0.01	–	–
Pilidae	*Pila africana*	Pil	0.01	–	–	–
	Pila ovata	Pio	–	0.01	–	0.06
Thiaridae	*Melanoides tuberculata*	Mel	26.14	12.3	3.34	10.94
Beatidae	*Baetis* sp.	Bae	0.19	–	0.01	0.21
Ceonagrionidae	*Ischnura* sp.	Isc	0.01	–	–	–
	Pseudagrion punctum	Pse	0.03	–	–	0.01
Cordulidae	*Epitheca bimaculata*	Epi	0.05	–	–	–
	Somatochlora sp.	Som	0.07	–	–	–
	Somatochlora flavomaculata	Sof	0.01	–	–	–
Notonectidae	*Anisops* sp.	Ani	0.02	–	0.02	0.03
Belostomatidae	*Diplonychus*	Dip	0.03	–	–	0.21
Nepidae	*Ranatra linearis*	Ran	0.01	–	–	0.02
Hydrophilidae	*Laccobius* sp.	Lab	0.01	–	–	–
	Helochares sp.	Her	0.01	–	–	0.01
Chrysomilidae	*Pyrralta* sp.	Pyr	–	–	–	0.01
Dystiscidae	*Laccophilus lutuosus*	Lac	–	–	–	0.03
	Laccophilus sp.	Las	–	–	–	0.01
Ceratopogonidae	*Ceratopogon* sp.	Cer	0.03	–	–	–
Chironomidae	*Chironomus formosipennis*	Chi	9.40	2.41	5.25	1.61
	Nilodorum fractilobus	Nil	0.27	0.03	0.07	0.01
	Polypedilum sp.	Pol	3.25	0.01	0.03	0.03
Culicidae	*Culex* sp.	Cul	–	–	–	1.98
Ephydridae	*Hydrellia* sp.	Hyd	0.01	–	–	0.05
Limoniidae	*Hexatoma* sp.	Hex	–	–	0.03	–
Stratiomyidae	*Odontomyia* sp.	Odo	0.01	–	–	0.25
Syrphidae	*Eristalis* sp	Eri	–	–	–	0.15

Biodiversity indices varied between seasons (Table 4). Dominance had lower values in rainy season and only the comparison between RS1 and DS2 indicated significant differences. The highest Shannon's index was observed at DS2 (1.42±0.04) and the DS1-DS2 comparisons were significant. Shannon's index was less than 1 only in DS1 and more than 1 in other seasons. For the Eveness and Simpson indices, only the RS1-DSA and DS1-RS2 comparisons were significant. Equitability increased from RS1 to DS2 and differences were significant for RS1-RS2 comparison.

Seasonal Correlation between macroinvertebrates and abiotic parameters

Redundancy analysis has determined that five environmental variables, conductivity, transparency, pH and dissolved oxygen and phosphate levels strongly influenced distribution of benthic macroinvertebrates in lake Sokotè. Two groups of macroinvertebrates are distinguished according to axis I and II (Fig. 2).

Table 4. Biodiversity indices (mean ± SE) according to seasons in Lake Sokotè for annual period (April 2017-March 2018). RS = rainy season; DS = dry season.

Indices	RS1	DS1	RS2	DS2	Mann-Withney Comparison	Mann-Withney p value
Dominance (D)	0.38 ±0.01	0.49± 0.02	0.34± 0.01	0.35± 0.01	RS2-DS1	0.027
Shannon (H')	1.28± 0.03	0.92± 0.03	1.18± 0.03	1.42± 0.04	DS2-DS1	0.013
Equitability (J)	0.39 ±0.01	0.42± 0.01	0.47± 0.01	0.47± 0.01	RS1-RS2	0.039
Evenness (E)	0.13± 0.01	0.28± 0.01	0.27± 0.01	0.20± 0.01	RS1-DS1	0.027
Simpson (S)	0.62 ±0.01	0.51± 0.02	0.66± 0.01	0.65± 0.01	RS2-DS1	0.027

RS = rainy season; DS = dry season; Cond = Conductivity; O2 = Dissolved oxygen; Temp = Temperature; Transp = Transparency; PO_4^{3-} = Phosphate; NO^{3-} = Nitrate.

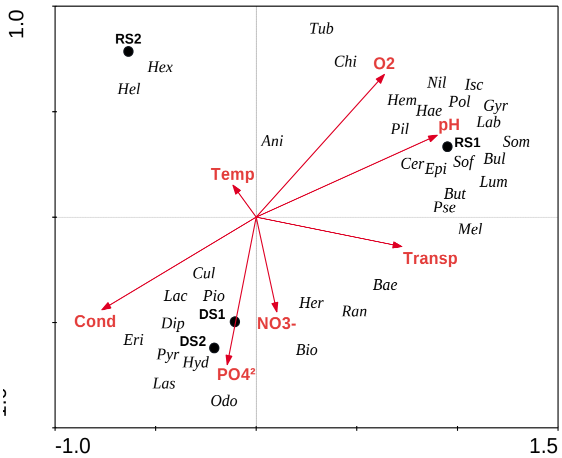

Fig. 2. Redundancy analysis triplot (RDA) of macroinvertebrates abundance data constrained by environmental parameters and seasons in Lake Sokotè. Taxa codes are given in Table 3.

The first group includes *Odontomyia* sp. *Eristalis* sp., *Pyrralta* sp., *Hydrellia* sp., *Diplonychus* sp., *Laccophilus* sp., *Culex* sp., *Laccophilus* sp., *Pila ovata*, *Biomphalaria pfeifferi*, *Helochares* sp., *Ranata linearis*, *Baetis* sp. and it is correlated by conductivity, Phosphate (PO_4^{3-}) and transparency during dry seasons. The second group is composed of *Melanoides tuberculata, pseudagrion punctum, Bulinus truncatus, lumbriculus sp., Epitheca bimaculata, Ceratopogon sp., Somatochlora flavomaculata, Bulinus forskalii, Laccobius sp., Gyraulus sp., Polypedilum sp., Haementeria costata, Pila africana, Ischnura sp., Hemiclepsis marginata, Chironomus formosipennis, Tubifex sp.* and correlated by dissolved oxygen and pH in first rainy season (RS1).

Discussion

The present study showed that seasonal variations in physico-chemical parameters were marked mainly between long rainy season (RS1) and long dry season (DS2). Only dissolved oxygen, pH, transparency and phosphate level showed significant difference between rainy and dry seasons. These variations resulted in a decrease in values of parameters in DS2. This could be related to lower water level and low renewal of the lake water. In fact, Sokotè Lake regularly receives sewage from homes and rainwater. These rainwaters ensure the renewal of the lake's water during rainy season. The high level of dissolved oxygen may therefore be due to turbidity and a significant dissolution of atmospheric oxygen in the water (Secondat, 1952). On the other hand, the absence of water renewal during dry seasons will lead to an increase in quantity of organic matter in the environment and influence physicochemical parameters. Several authors have reported that poor land and sewage use practices contribute to a considerable amount of non-native material in aquatic systems and a decrease of transparency (Ometo *et al.*, 2000). Bacterial decomposition of organic matter would be at the origin of undersaturation of lake in oxygen during dry seasons (Eblin *et al.*, 2014). According to Aniyikaiye *et al.* (2019), the relatively lowest pH in dry season can be attributed to the discharge of effluents which loaded with a large amount of organic acids. Similar observations have been reported by Fofana *et al.* (2019) in Lake Kaby and other tropical waters (Leveque *et al.*, 1983; Harrison, 1987 and Hansen *et al.*, 1998).

A total of 35 taxa were collected in Lake Sokotè and divided into dominant groups such as Annelids (11%), Molluscs (23%) and Insects (66%). The qualitative composition of macroinvertebrates population is similar to most of the Lake environments (Ceesay *et al.*, 2019). The number of species obtained in this study is relatively low compared to Lake Obazuwa (46 taxa) which is strictly bounded by laws restricting human activities such as farming, laundering and bathing (Olomukoro and Oviojie, 2015). Two species of crustaceans have been collected from this lake while they are absent in this study. This difference in taxonomic structure may be related to the quality of the water. In fact, crustaceans generally live in running waters where the environmental conditions are favorable for their development (Celik *et al.*, 2010).

Furthermore, the results indicated that Thiaridae (*M. tuberculata*), Chrinomidae (*C. formosipennis*, *N. fractilobus* and *Polypedilum* sp.) and Tubificidae (*Tubifex* sp.) were the most abundant and collected in all seasons. High frequency and abundance of these organisms is linked to their ability to live in unfavorable conditions. Indeed, several authors have revealed that Tubificidae and Chironomidae are pollution-tolerant family and indicators of eutrophic environments (Barbour *et al.*, 1999; Rashid and Pandit, 2014). For example, in Lake Nilnag showing signs of eutrophication, these two families of macroinvertebrates were very abundant (Siraj *et al.*, 2010). According to Rashid and Pandit (2014), the lakes having soft bottom sediments are characterised by annelids either as dominant group or an important contributor to the macrobenthic fauna. The molluscs of the family Thiaridae are also known as being pollutant resistant organisms (Moisan and Pelletier, 2008). Indeed, Mollusca and Oligochaeta showed no habitat restrictions as they occurred in abundance in all stations of lake Obazuwa (Olomukoro and Oviojie, 2015). This resistance to pollution then justifies their abundance in the environment.

Seasonal changes in macroinvertebrates species composition were observed in Lake Sokotè. The highest taxonomic richness was obtained during rainy seasons (27 taxa in RS1 against 21 taxa in DS2). Some taxa only appeared in our collections in rainy seasons (RS1). These are, among others, *Lumbriculus* sp., *Bulinus forskalii*, *Pila africana*, *Ichnura* sp., *Epitheca bimaculata*, *Somatochlora flavomaculata, Somatochlora* sp., *Laccobius* sp. and *Ceratopogon* sp. Their presence only in rainy season might indicate their sensitivity to pollution. Canonical redundancy analysis has shown that these taxa are correlated with dissolved oxygen and pH. Indeed, during rainy seasons, Dissolved oxygen level increases in the aquatic environment and the acidity decreases, which favors their development. These results are confirmed by the work of Moisan and Pelletier (2008) which indicates that Cordulidae, Hydrophilidae and ceratopogonidae have an average tolerance to pollution. However, other taxa such as *Odontomya* sp., *Culex* sp., *Diplonochus* sp. were abundant in dry seasons and correlated with conductivity, phosphates, Nitrate and transparency. During these seasons, high values of these parameters make the environment unfavorable for the survival of several species. Thus, these species can be considered as resistant to pollution.

The present study indicated low diversity of Shannon, Equitability, Eveness and Simpson indexes. Shannon diversity index varied slightly between 0.92 and 1.42 depending on the season and reflects an aquatic environment whose integrity varies between the polysaprobic and α-mesosaprobic state (Staub *et al.*, 1970) which means that Lake Sokotè is very rich in organic matter. According to several authors, low values of diversity index reflect poorly diversified communities with a low degree of organization and unbalanced ecosystem (Amanieu et Lassere, 1982; Dajoz, 2006). Similar results indicated that in lake Donghu-China, a low species diversity of macroinvertebrates was observed in highly eutrophic areas measured in terms of species number, diversity index and k-dominant curves (Gong and Xie, 2001). The abundance of organic matter in the lake is confirmed by the low dissolved oxygen level (less than 10%) during the dry seasons because their decomposition requires great consumption by decomposers. The poor quality of water is also confirmed by high abundance of pollutant-resistant taxa (more than 95%) and the absence of pollutant-sensitive taxa such as Trichoptera and Plecoptera (Rosenberg and Resh, 1996; Moisan and Pelletier, 2008). High enrichment in organic matter could reflect a state of eutrophication and can justify the death of several fish in Lake Sokotè generally during periods of low water.

Conclusion

This study showed that Lake Sokoté housed a relatively low richness of benthic macroinvertebrates influenced by the seasonal variability of several physico-chemical parameters. The abundance of pollutant-resistant taxa, low oxygenation and acid character of water environment tend to show a pollution and eutrophication state of the lake.

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