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Updating Benthic Macroinvertebrates Database of the Nokoué Lake in South Eastern Benin

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Abstract: ***The objective of this study was to update the existing database on the benthic macrofaunaof the Nokoué Lake. Seasonal sampling was conducted from March 2019 to February 2021 in 11 stations. Benthic fauna was collected with an Eckman grab, Surber net, and mesh screen. Taxonomic richness, estimated richness, occurrence, abundance, functional feeding groups were determined. Correspondence Factorial Analysis (CFA) and a Hierarchical Clustering (HCA) were performed to identify the different communities. The inventory indicated 83 taxa representing 32 770 specimens gathered into 54 families, 25 orders and 6 classes. The average predicted species richness was 85.88 ± 0.29 taxa without singletons and doubletons. Six classes of benthos were determined wuth crustaceans, the richest (23 taxa) and gastropods, the most abundant (58.4%). Three communities are formed with distinct taxa whose richnesses did not vary significantly between groups. The low number of constant taxa and the differentfunctional feeding groups are justified by the state of the environment, which is highly enriched in organic matter and its fragility due to its proximity to the ocean. It is urgent to rehabilitate the ecosystem in order to bring it back to life for an effective sustainability.***

Keywords: benthic fauna, inventory, update, Lake

1. Introduction

Lake Nokoué, a lagoon with high strategic stakes for the environment, is a victim of numerous natural and anthropic pressures. The natural pressures include the filling of Lake Nokoué following the rains, the erosion of the banks and the seasonal variations in the physico - chemical quality of the lake water. The pressures due to human activities, obviously concern the highly developed fluvialnavigation, the informal trade of hydrocarbons or adulterated gasoline, the inputs and pesticides from the agricultural zones located in the northern zones of the lake, without forgetting the fishing gears and techniques such as the acadja with its corollaries and the latrines installed on the lake (Mama, 2010; Sossou - Agbo, 2013). These different pressures usually encountered in all continental aquatic environments are constantly increasing under the effect of climate change, population growth, and the intensification of human activities. The direct consequences of these disturbances suffered by aquatic environments have direct repercussions on the living resources.

Indeed, the dynamics of all aquatic populations - primary producers, fish, and invertebrates - is controlled by the ecosystems' evolution that support them as well as by various recruitment strategies over time and space (Edia, 2008; Adandedjan, 2012). For each population, the available habitat conditions the biomass and the production that the ecosystem canlodge and that will be subjected to natural or anthropogenic predation (Edia, 2008; Adandedjan, 2012). Therefore, any modification of the ecosystem has repercussions on the entire trophic chain. In response to these disturbed situations, some species and populations show adaptations affecting growth or reproduction phenomena. Other species, in the same stressful situations, show thehighest adaptive capacities allowing them to develop at the detriment of less plastic species (Edia, 2008; Adandédjan, 2012). Therefore, it results a profound change in the biodiversity, the composition and the structure of the species communities that could be translated by in species substitutions, changes in size spectra and significant trophic changes (Adandedjan *et al*.2018).

As living aquatic communities, benthic macroinvertebrates are also under various environmental stresses, which can affect mostly their biodiversity and the species composition (N'goran, 1997). As essential links in the food web, these organisms are sensitive to any environmental change (Tachet *et al*., 2003). Their presence or absence as well as their composition testifies the quality of the ecosystem (Adandédjan, 2012; Tchatcho, 2014; Tchatcho*et al*., 2014; Kaboré *et al*., 2016; Gerami *et al*., 2016). Moreover, they are the most used in biomonitoring of aquatic environments (Adandédjan, 2012). Thus, knowledge of the richness and composition of benthic macroinvertebrates in Lake Nokoué is necessary to better understand the functioning of the environment face to natural and anthropogenic pressures especially in the context where the government through its Government Action Program (GAP), has decided to undertake a rehabilitation of Lake Nokoué by dredging and construction of infrastructure such as the Northern Bypass, recreational areas, etc.).

Various works have already been carried out on the benthic macrofauna of Lake Nokoué such as those of Gnohossou (2006) and those of Odountan and Abou (2016). These works had revealed inventories of the benthic fauna of the lake. The first true study on the benthic fauna of the lake by Gnohossou dates back more than 10 years; that of Odountan and Abou, although ther were recent, have focused attention on the use of these organisms as indicators of water quality as a complement to the study by Gnohossou. In this study, it is essential to update these different inventories in order to have a more complete database for the designing of an ecological quality index based on this group of animals. To do this, the present work aims to update the existing database of the benthic macrofauna in Lake Nokoué in the southern Benin. Thus, these data will serve as a basis for the evaluation of biodiversity after the rehabilitation of the lake and its surroundings, which will begin very soon, since the financing has already been voted. More specifically, it is a question of (i) inventorying the benthic macro invertebrates of the lake and characterizing the spatio - temporal distribution of the richness and abundance of the existing benthic fauna in the lake.

2. Methodology

2.1 Study environment

Located in the southeast of the Beninese lagoon system (6°25' N, 2°36' E) (Figure 1), Lake Nokoué lies between parallels 6°20' and 6°30' North and meridians 2°20' and 2°35'. It is considered the largest body of water in Benin and covers an area of 150 km2 (Niyonkuru and Lalèyè, 2010). With a length of 20 km in its east - western direction and a width of 11 km in its north - southern direction, it represents the largest lagoon water in the Republic of Benin and the most important from the point of view of its development. It is connected to the Porto - Novo Lagoon by the Totchè Channel and is supplied with fresh water by the Ouémé and the Sô Rivers (Niyonkuru and Lalèyè, 2010; Bossou, 2013). It also receives the influences of wastewater from Abomey - Calavi, rainwater collectors of Cotonou, and the Cotonou Channel through which seawater arrives (Mama, 2010).

The substratum of the lake has evolved over time as we notice different depths nowadays that varying from 0.43 m along the shores to less than 2 m along the banks during low water periods (Sossou - Agbo, 2013). The first work done in the lake by Gaillard, in 1908 did not encounter more than 2 m of depth. He explained this by the alluvial contributions of the Sô River, which has an obvious N - S flow.

Lake Nokoué shelters an abundant diversity of fauna and flora. Concerning fish, the number of species observed has varied considerably over the last 50 years. Gras (1961) indicated 87 species belonging to 43 families while Lalèyè (1995) reported 78 species belonging to 36 families. According to the work of Niyonkuru (2001), 50 species belonging to 46 genera divided into 33 families and 10 orders are known on Lake Nokoué. With respect to the benthic fauna, Gnohossou (2006) counted 76 taxa (genera/species) and Odoutan and Abou (2016), 66 taxa (genera/species).

The activities carried out on the water body and around the lake concern fishing, trade, agriculture, livestock, transportation of goods and people and tourism. These different activities allow the residents and their families to live but they pollute the lake directly or indirectly.

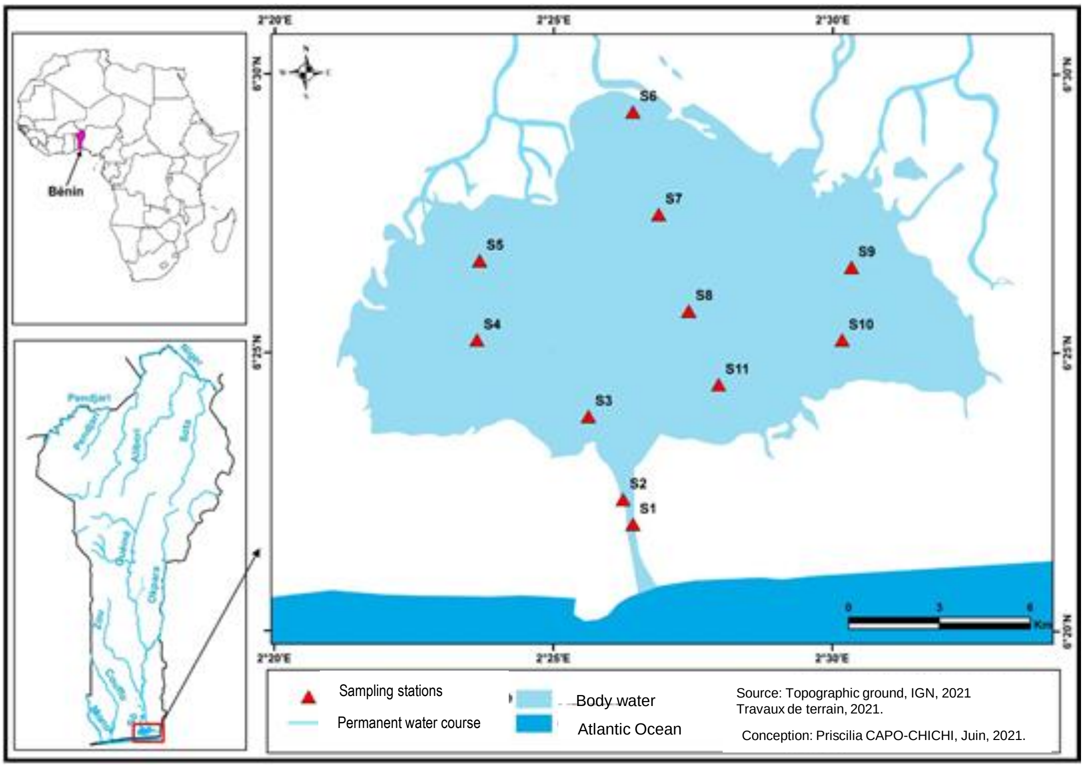

Figure 1: Study environment and different stations sampled on Lake Nokoué

2.2 Sampling stations

A total of eleven (11) stations were selected aand located using a Global Positioning System (GPS) for the study (Figure 1) during an exploratory visit in March 2019. The criteria for choosing the stations were accessibility, development of human activities, presence or absence of vegetation, proximity to a fishing gear or technique (Acadja, or others). Data collection was done over 2 years (March 2019 - February 2021) taking into account the four hydrological seasons that were: LowDry season (LDS): mid - July to mid - September; Low Rainy Season (LRS): mid - September to mid - November; Great Dry Season (GDS): mid - November to mid - February, Great Rainy Season (GRS): mid - February to mid - July.

2.3 Macroinvertebrates 'Sampling

2.3.1 Field works

Sampling of benthic macroinvertebrates was conducted using a multi - habitat approach (Moisan and Pelletier, 2011). Several tools such as an Eckman - type bucket, a surber net and sieves with mesh sizes ranging from 500 µm to 1 mm were used. At each station, 5 grab shots and 1 surber net shot were given. Floating solids and roots of surface macrophytes were collected and rinsed through the sieves for organism sampling. Organisms were collected in jars containing 10% formalin.

2.3.2 Laboratory works

In the laboratory, after cleaning to remove the preservative formalin, the organisms were sorted station by station under a binocular microscope. Organisms were separated according to their morphological appearance and grouped by class, order and family. The taxonomic determination was made up to the species level unless the identification keys did not allow it. The keys used are Iconographic catalog of aquatic insects of Ivory Coast (Dejoux *et al*, 1981); Water beetles from Benin (Coleoptera: Haliplidae, Dytiscidae, Noteridae, Hydraenidae, Hydrochidae, Hydrophilidae, Gyrinidae, Elmidae) (Van Vondel, 2005); Freshwater Snails of Africa and their medical importance (Brown, 1980); freshwater invertebrates (Tachet *et al*., 2006); Fauna of France, wandering polychaetes (Fauvel, 1923) and Aquatic flora and fauna of Sahelo - Sudanian Africa (Durand and Lévêque, 1981).

During this identification phase, not only were the organisms determined, but they were also counted by species at each station and by sampling. Then, the organisms were preserved in 70% alcohol. A collection of specimens was kept in the Laboratory of Hydrobiology and Aquaculture.

2.3.3 Data analysis and statistical treatments

2.3.3.1 Data analysis

a) **Richness obtained and estimated richness**: the taxonomic richness or number of taxa obtained (S) was determined globally and by station/sampling. To ensure that the sampling was complete, the theoretical richness of the benthic macrofauna of the lake was estimated. Four richness estimators, Chao1, ACE, Jacknife1, and bootstrap were used using EstimateS software. The Spatial - seasonal variations of the taxonomic richness of the macrofauna obtained were represented.
b) **Taxon frequency**: the percentage of occurrence that informs on the habitat preferences of a given species was determined according to Dajoz (2000), and Adandédjan (2012) as follows: $F = Fi \times 100/Ft$, where: Fi = number of records containing species i; Ft = total number of records obtained. Based on the value of F, four groups of species are distinguished: constant species ($F \geq 50\%$); incidental species ($25\% \leq F < 50\%$); accidental species ($F < 25\%$) and rare species ($F < 5\%$).
c) **Abundance N and Relative Abundance Nr**: Abundance, the number of individuals (N) of a taxon (species, genus, family, and so on.) and the Relative abundance (Nr), the percentage of the number of individuals of a taxon (species, genus, family, etc.) from a station/season to the total number of individuals of all taxa from all stations/seasons were détermined. The Spatial - seasonal variations of the abundance/relative abundance of the fauna obtained were represented.
d) **Functional Feeding Groups (FFGs):** the trophic classifications of Cummins and Klug (1979) and Cummins and Wilzbach (1985) that defined five functional food groups (collectors, filter feeders, scrapers, grinders, and predators) were used to characterize benthic communities. Spatial and seasonal variations in the different FFG were expressed.

2.3.3.2. Statistical processing

All analyses were performed using Statistica version 6.0 software.

Different communities of the benthic macrofauna

Correspondence Factorial Analysis (CFA) was performed using the presence - absence matrix of taxa which had at least 5% occurrence at a station. Table 1 below provides the list of the animals'names codes used for this analysis. A Hierarchical Classification Analysis (HCA) was used to group the 11 stations based on their degree of similarity. The binary index was used for presence/absence data (Borg and Groenen, 1997) and the Euclidean distance was used (Dufrêne, 1992). The Ward method was used as an aggregation criterion. The result of this analysis is presented as a dendrogram.

Table 1: Acronyms for taxa used in the multivariate analysis

Taxons	Codes	Taxons	Codess	Taxons	Codes
Amphinomidae ind	Amphi	*Melita* sp.	Melit	*Macrobrachium vollenhovenii*	Mavol
Anadara senilis	Ansen	*Mesovelia mulsanti*	Memul	*Excirolana latipes*	Exlat
Anadara sp.	Ansp.	*Mytilus edulis*	Myedu	*Exosphaeroma* sp.	Exosp
Anthura sp.	Anthu	*Naucoris* sp.	Nauco	*Ficopomatus enigmatus*	Fieni
Balanus sp.	Balan	*Nereis diversicolor*	Nediv	*Gammarus pulex*	Gapul
Brachydontes exustus	Brexu	*Nereis* sp.	Nerei	*Gammarus* sp.	Gamma
Brachydontes sp.	Brach	*Neritina afra*	Neafr	*Glycera alba*	Glalb
Bulinus forkasli	Bufor	*Neritina clenchi*	Necle	*Glycera* sp.	Glyce
Callinectes amnicola	Caamn	*Neritina glabrata*	Negla	*Grandidierella africana*	Grand
Ceriagrion sp.	Ceria	*Neritina natalensis*	Nenat	Hydrophilidae ind	Hydro
Chaoborus sp.	Chaob	*Neritina* sp.	Nerit	*Lestes* sp	Lestes
Cirolana sp.	Cirol	*Neritina virginea*	Nevir	*Libellula* sp	Libe

Clibanarius sp.	Cliba
Cloeon sp.	Cloeo
Corbula sp.	Corbu
Corbula trigona	Cotri
Crangnon crangnon	Crang
Crassostrea gasar	Craga
Culex sp.	Culex
Cyathura sp.	Cyath
Dixa sp.	Dixas
Dreissena sp	Dreis
Enchytraeidae ind	Enchy
Pseudagrion sp.	Pseud

Pachygrapsus sp.	Pachy
Pachymelania aurita	Paaur
Pachymelania quadriseriata	Paqua
Pachymelania sp.	Pachy
Panopeus africanus	Paafr
Penaeus sp.	Penae
Perinereis cultrifera	Pecul
Photis sp.	Photi
Pisidium sp.	Pisid
Polypedilum deletum	Podel
Polypedilum laterale	Polat
Protodrilus sp.	Proto

Littorina africana	Liafr
Tagelus adansonii	Taada
Tanais dulongi	Tadul
Tellina sp	Tellin
Thais coronata	Thcor
Tubifex sp	Tubif
Tympanotonus fuscatus	Tyfus
Tympanotonus fuscatus radula	Tyrad
Macrobrachium sp.	Macro
Sesarma angolense	Seang
Sesarma sp.	Sesar
Sphaerium sp.	Sphae

- Comparison tests

To test the spatial and/or seasonal variability of macroinvertebrate richness and relative abundance/ abundance, the Kruskal - Wallis test was used. Also the Mann - Whitney test was applied to confirm the differences obtained between stations and/or seasons taken in pairs.

3. Results

3.1 Composition of the benthic macrofauna collected

The different taxa of benthic macroinvertebrates collected during the study and classified in the different taxonomic groups were presented in Table 2. In total, 83 taxa (genera and species) were inventoried. These taxa are grouped into 54 families, 25 orders, 6 classes and 3 phyla, namely Molluscs, Arthropods and Annelids representing 6 classes (Bivalves and Gastropods for Molluscs; Crustacea and Insects for Arthropods and then for Annelids, Oligochaetes and Polychaetes) were obtained (Table 2).

With 5 orders, 17 families and 19 genera, the Crustacean class was the most represented class with 23 species, or 27.71% of the total richness (Table 2 and Figure 2). This class was followed by the gastropoda with 18 species (i. e.21.68%), 8 families and 3 orders. Insects (13 families and 17 species), Bivalvia (7 orders, 10 families and 15 species) and Polychaeta (4 orders, 5 families and 5 genera) and Oligochaetes (1 order, 2 families and 2 genera) were also found in the lake.

Table 2: List of macroinvertebrates collected in the study environment

Family	Species	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	F (%)
MOLLUSCS													
BIVALVIA													
Arcoida													
Arcoidae	*Anadara senilis* (Linnaeus, 1758)	*	*	*		*	*			*	*	*	**26, 13**
	Anadara sp. Gray, 1847		*	*	*	*						*	**6, 81**
Cardiida													
Solecurtidae	*Tagelus adansonii* (Bosc, 1801)	*	*	*	*		*				*	*	**14, 77**
Myoida													
Corbulidae	*Corbula trigona* Hinds, 1843	*	*	*	*	*	*	*	*	*	*	*	**63, 63**
	Corbula sp. Bruguière, 1797		*							*	*	*	**4, 54**
Dreissenidae	*Dreissena* sp. Van Beneden, 1835		*			*			*	*			**9, 09**
	Dreissena polymorpha (Pallas, 1771)		*					*					**2, 27**
Mytilida													
Mytilidae	*Mytilus edulis* Linnaeus, 1758	*	*	*	*	*	*	*	*	*	*	*	**32, 95**
	Brachydontes sp. Gray, 1847	*		*			*						**4, 54**
	Brachydontes exustus (Linnaeus, 1758)	*		*	*		*					*	**10, 22**
Ostreoida													
Ostreidae	*Crassostrea gasar* (Deshayes, 1830)	*	*	*	*	*	*	*	*	*	*	*	**45, 45**
Pectinida													
Pectinidae	*Pecten* sp. Müller, 1776								*		*		**2, 27**
Veneroida													
Sphaeridae	*Pisidium* sp. Pfeiffer, 1821	*	*	*	*	*	*	*	*	*	*	*	**57, 95**
	Sphaerium sp. Scopoli, 1777	*		*	*			*		*		*	**9, 09**
Tellinidae	*Tellina* sp. Linnaeus, 1758	*	*	*	*					*	*		**10, 22**
GASTROPOAa													
Basommatophora													
Neritidae	*Neritina glabrata* Sowerby, 1849	*	*		*	*	*	*	*	*	*	*	**31, 81**
	Neritina afra Sowerby, 1841		*			*	*	*				*	**13, 63**
	Neritina clenchi (Russell, 1940)					*		*					**4, 54**
	Neritina natalensis Reeve, 1845		*			*	*	*					**9, 09**
	Neritina sp. Rafinesque, 1815	*	*	*	*	*	*	*		*	*	*	**29, 54**
	Neritina virginea (Linnaeus, 1758)							*					**5, 68**
Planorbidae	*Bulinus forskali* (Ehrenberg, 1831)	*			*	*				*	*		**6, 81**

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	Bulinus sp. Müller, 1781							*	*			*	**3, 40**
	Biomphalaria sp. Preston, 1910		*					*	*				**3, 40**
Mesogastropoda													
Ampullariidae	*Lanistes varicus* (Müller, 1774)					*					*		**2, 27**
Bithyniidae	*Gabbiella candida* Mandahl - Barth, 1968					*				*			**2, 27**
Littorinidae	*Littorina africana* (Krauss, 1847)			*	*			*	*	*		*	**6, 81**
Potamididae	*Tympanotonus fuscatus radula* (Linné, 1758)	*	*	*	*	*	*	*	*	*	*	*	**77, 27**
	Tympanotonus fuscatus (Linnaeus, 1758)	*	*	*	*	*	*	*	*	*	*	*	**52, 27**
Thiaridae	*Pachymelania* sp. Smith, 1893	*	*	*	*	*	*	*	*	*	*	*	**44, 31**
	Pachymelania aurita (Müller, 1774)	*	*	*	*	*	*	*	*	*	*	*	**82, 95**
	Pachymelania quadriseriata Gray, 1831	*	*				*	*	*	*			**18, 18**
Neogastropoda													
Muricidae	*Thais coronata* (Lamarck, 1816)			*	*		*						**4, 54**
ARTHROPODS													
CRUSTACEAN													
Amphipods													
Aoridae	*Grandidierella africana*Schellenberg, 1936	*	*	*	*	*	*	*	*	*	*	*	**60, 22**
Gammaridae	*Gammarus pulex* (Linnaeus, 1758)	*	*	*	*	*	*	*		*	*	*	**27, 27**
	Gammarus sp. Fabricius, 1775	*	*	*	*	*	*	*		*	*	*	**28, 40**
Melitidae	*Melita* sp. Leach, 1814					*	*	*	*	*	*	*	**9, 09**
Photidae	*Photis* sp. Kroyer, 1842	*			*			*	*				**5, 68**
Cirripeds													
Balanidae	*Balanus* sp. Da Costa, 1778	*	*	*	*	*	*	*	*	*	*	*	**59, 09**
Decapods													
Crangnonidae	*Crangnon crangnon* (Linnaeus, 1758)	*		*	*								**4, 54**
Diogenidae	*Clibanarius* sp. Dana, 1852	*	*	*	*		*	*		*	*	*	**22, 72**
Grapsidae	*Pachygrapsus* sp. Randall, 1839	*		*	*		*		*			*	**10, 22**
Paleomonidae	*Macrobrachium vollenhovenii* (Herklots, 1857)					*	*			*	*		**9, 09**
	Macrobrachium sp. Bate, 1868		*	*				*		*	*		**5, 68**
Panopeidae	*Panopeus africanus* Milne - Edwards, 1867	*		*	*	*	*	*		*	*	*	**23, 86**
Penaeidae	*Penaeus* sp. Fabricius, 1798	*			*			*	*				**10, 22**
Portunidae	*Callinectes amnicola* (Rochebrune, 1883)	*			*		*						**7, 95**
Sesarmidae	*Sesarma* sp. Say, 1817	*			*	*	*			*		*	**7, 95**
	Sesarma angolense De Brito Capello, 1865						*				*		**4, 54**
Isopods													
Anthuridae	*Anthura* sp. Leach, 1814	*		*	*								**5, 68**
	Cyathura sp. Norman & Stebbing, 1886		*	*	*								**4, 54**
Cirolanidae	*Excirolana latipes* (Barnard, 1914)				*			*	*		*		**4, 54**
	Excirolana sp. Richardson, 1912	*						*					**3, 40**
	Cirolana sp. Leach, 1818			*	*				*				**4, 54**
Sphaeromatidae	*Exosphaeroma* sp. Stebbing, 1900			*		*	*	*		*			**6, 81**
Tanaidacea													
Tanaidae	*Tanais dulongi* (Audouin, 1826)	*	*	*	*	*		*				*	**19, 31**
INSECTS													
Coleoptera													
Hydrophilidae	*indéterminé*					*			*		*		**4, 54**
Diptera													
Ceratopogonidae	*indéterminé*		*							*	*		**3, 40**
Chaoboridae	*Chaoborus* sp. Lichtenstein, 1800		*			*		*					**4, 54**
Chironomidae	*Einfeldia* sp. Kieffer, 1924					*							**2, 27**
	Chironomus formosipennis kieffer 1908				*	*					*		**3, 40**
	Polypedilum deletum Goetghebuer, 1936			*						*		*	**5, 68**
	Polypedilum laterale Goetghebuer, 1936	*	*				*				*	*	**5, 68**
Culicidae	*Culex* sp. Linnaeus, 1758	*	*		*		*	*	*	*		*	**14, 77**
Dixidae	*Dixa* sp. Meigen, 1818	*	*					*	*	*		*	**7, 95**
Ephemeroptera													
Baetidae	*Cloeon* sp. Leach, 1815					*				*		*	**6, 81**
Hémiptera													
Ranatridae	*Ranatra linearis* (Linnaeus, 1758)		*					*					**3, 40**
Mesovelidae	*Mesovelia mulsanti* White, 1879			*	*			*					**4, 54**
Naucoridae	*Naucoris* sp. Geoffroy, 1762		*			*	*						**5, 68**
Odonata													
Coenagriidae	*Pseudagrion* sp. Selys, 1876			*		*		*					**5, 68**
	Ceriagrion sp. Selys, 1876			*			*		*				**6, 81**
Lestidae	*Lestes* sp. Leach, 1815	*	*		*		*	*	*	*			**11, 36**
Libellulidae	*Libellula* sp. Linnaeus, 1758	*			*		*	*	*	*		*	**12, 5**
ANNELIDS													

OLIGOCHAETA													
Haplotaxida													
Tubificidae	*Tubifex* sp. Lamarck, 1816					*	*	*			*		**4, 54**
Enchytraeidae	*indéterminé*	*	*	*	*	*	*	*	*	*	*	*	**43, 18**
POLYCHAETES													
Canalipalpata													
Protodrilidae	*Protodrilus* sp. Hatschek, 1881	*		*			*	*					**5, 68**
Sabellida													
Serpulidae	*Ficopomatus enigmatus* (Fauvel, 1923)		*	*	*	*	*	*	*	*	*	*	**44, 31**
Phyllodocida													
Nereididae	*Nereis diversicolor* (Müller, 1776)	*	*	*	*	*	*	*	*	*	*	*	**53, 40**
	Nereis sp. Linnaeus, 1758	*		*	*	*				*	*		**7, 95**
	Perinereis cultrifera (Grube, 1840)			*			*		*	*	*	*	**11, 36**
Glyceridae	*Glycera* sp. Savigny, 1818		*	*	*		*		*		*	*	**13, 63**
	Glycera alba (Müller, 1776)				*		*	*	*	*	*	*	**10, 22**
Amphinomida													
Amphinomidae	*indéterminé*	*	*	*		*	*	*	*	*	*	*	**20, 45**
	Total par station	**43**	**42**	**43**	**46**	**42**	**46**	**49**	**36**	**44**	**41**	**42**	
	Total général						**83**						

Legend: *= presence of the species, F= percentage of occurrence.

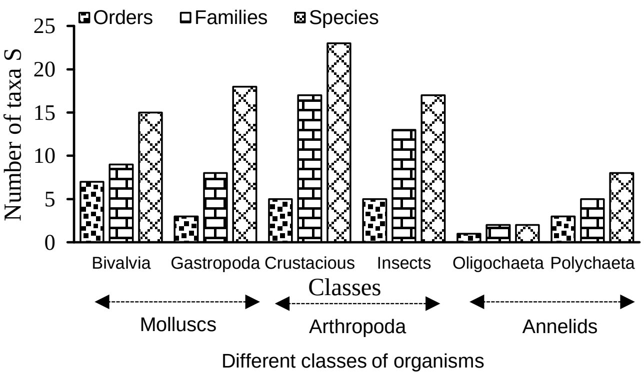

Figure 2: Composition of différent groups of benthic macrofauna collected.

3.2 Estimation of the invertebrates richness

Four estimators were used to predict the taxonomic richness of the lake in benthic macrofauna (Figure 3). This study made it possible to have the curves of singletons and doubletons allowing to realize the perfection of the inventory (Figure 4). The different grphs showed that there was no singleton or doubleton at the end of the sampling (Figure 4).

With 33 taxa collected during the study, the specific richness of the molluscs increased significantly from the first (e_1) to the third (e_{1-3}) samplingsto stabilize from the 4th; e1 - 3he richness varying from 27 to 33 taxa (Figure 3). The predicted species richness for molluscs was 33± 0 for ACE, 33± 0 for Chao1, 35.91 ± 1.15 for Jack1 and 34.13 ± 0 for Bootstrap. Thus, the average predicted specific richness was 34.01 ± 0.29 taxa of molluscs; thus, 95.64% of mollusc taxa are currently collected.

The crustacean richness accumulation curve showed a clear increase from the first sampling (e_1) with 18 taxa to the fourth (e_4) before reaching a horizontal asymptote for 3 estimators (ACE, Chao 1 and Bootstrap); the fourth estimator, Jack 1 indicated at the 8th sampling a slight growth (Figure 3). However, the richness predicted by ACE was 23± 0, for Chao1, 23± 0; for Jack1, 26 ± 2.78 and finally for Bootstrap, 24.44 ± 1.84. The maximum richness predicted for the lake in crustaceans was 24 ± 1.15 taxa, which allowed us to deduce that 97.14% of the lake's crustaceans were sampled during this study.

For the entomofauna whose richness obtained during this study was 17 taxa, the curve of the estimators for the insect fauna indicated a growth from the 1st sampling (e_1) where 10 taxa were obtained until the third (e_{1-3}) to stabilize from the 4th (e_{1-4}) (Figure 3). The predicted wealth was 17 ± 0 for ACE, 17 ± 0 for Chao1, 18.61 ± 0 for Jack1, 17.88 for Bootstrap. The average predicted species richness is 17.62 taxa; the level of perfection of this present inventory in insect larvae is therefore 96.61%.

As for the ringed worms whose harvested richness was 10 taxa. Figure 3 showed growth from the 1st sampling (e_1) where 9 taxa were collected up to the 2nd (e_{1-2}). This predicted richness was 10 ± 0 for ACE, 10 ± 0 for Chao1, 10.68 ± 0 for Jack1 and 10.31 ± 0 for Bootstrap. The average species richness predicted is 10.25 worm taxa. The inventory perfection rate was 97.65%.

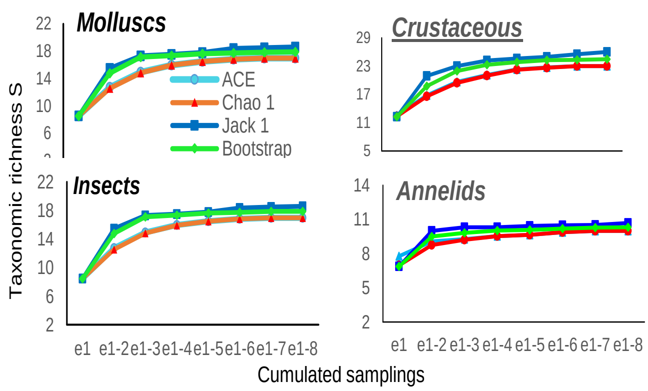

Figure 3: Accumulation curves of the taxa of the major groups of the benthic macrofauna of Lake Nokoué and of the species richness estimators (ACE, Chao1, Jack1 and Bootstrap).

Legend: e1= sample from the first campaign (season); e1 - n= sum of samples from the first campaign to the nth campaign (n varying from 2 to 8).

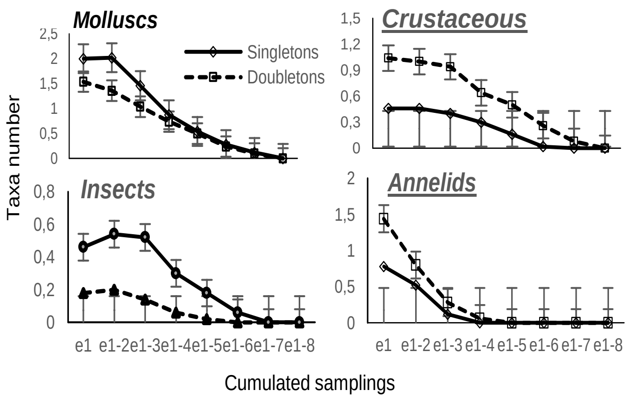

Figure 4: Curves of singletons and doubletons in the samples of the large groups of benthic macrofauna from the eight successively cumulated samplings of Lake Nokoué.

e1= sample from the first campaign; e1 - n = cumulated samples from the first campaign to the nth campaign (n varying from 2 to 8).

3.3 Habitat preferences of collected taxa

The frequency of observation of the different taxa in their preferred habitats was determined from the presence - absence matrix. The results are shown in Table 4 below. In total, only 8 taxa, or 9.63% of the total richness obtained were constant. Also, 10 other taxa (12.04% of the wealth collected) were incidental. Finally, 78.33% of the taxa were accidental with 48 rare species.

Table 4: Classification of benthic taxa from Lake Nokoué based on their consistency.

Constant taxa	Accessory taxa	Accidental/rare taxa
Balanus sp. (59, 09%)	*Anadara senilis* (26, 13%)	*Panopeus africanus* (23, 86%)
Corbula trigona (63, 63%)	*Crassostrea gasar* (45, 45%)	*Clibanarius* sp. (22, 72%)
Grandidierella africana (60, 22%)	*Enchy ind* (43, 18%)	*Amphinomidae ind* (20, 45%)
Nereis diversicolor (53, 40%)	*Ficopomatus enigmatus* (44, 31%)	*Tanais dulongi* (19, 31%)
Pachymelania aurita (82, 95%)	*Gammarus pulex* (27, 27%)	*Pachymelania quadriseriata* (18, 18%)
Pisidium sp. (57, 95%)	*Gammarus* sp. (28, 40%)	*Culex* sp. (14, 77%)
Tympanotonus fuscatus (52, 27%)	*Mytilus edulis* (32, 95%)	*Neritina afra* (13, 63%)
Tympanotonus fuscatus radula (77, 27%)	*Neritina glabrata* (31, 81%)	*Glycera* sp. (13, 63%)
	Neritina sp. (29, 54%)	*Lestes* sp. (11, 36%)
	Pachymelania sp. (44, 31%)	*Perinereis cultrifera* (11, 36%)

N. B: Only accidental or rare taxa with a frequency equal to at least 11% have been represented in this table.

3.5 Spatial and seasonal variations in the taxonomic richness of the fauna collected

Figures 5 a and b below presented the spatial seasonnal variations in the richness of the benthic fauna obtained during the 2 years. The taxonomic richness varied from 5 to 31 taxa respectively at stations S4 and S5 then at S3 (Figure 5). These different variations observed were not significant. ($p>0.05$).

In general, over the study period, the analyzes showed that the number of species varied significantly ($p < 0.05$) during the seasons. The taxonomic richness obtained between seasons fluctuated from 12 taxa in the Great Dry Season (GDS) to 31 taxa in the Sreat Rainy Season (GRS) (Figure 6). The specific richness during the GSP was clearly higher than those obtained during the GDS and the LDS. Similarly, the number of species during the LRS was significantly higher than that obtained during the LDS. This was not the case for the richness obtained during the GDS and LDS on the one hand, and GRS and LRS on the other hand.

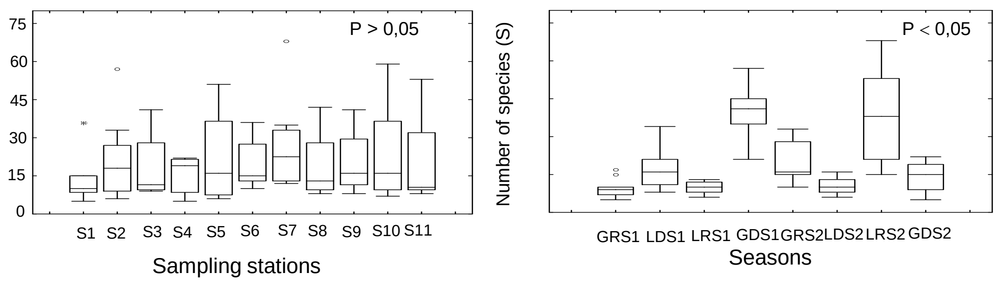

Figure 5: Spatial (A) and seasonnal (B) variations of taxonomic richness.

3.6 Abundance and relative abundance of the different taxa collected

A total of 32770 individuals of benthic macroinvertebrates were collected from the environment during the study. Table 6 below shows the breakdown of this workforce by station. Stations S2 and S5 gathering respectively 5295 and 5073 individuals (i. e.16.16 and 15.48% relative abundance) of benthos were the most abundant stations. On the other hand, four (04) stations with less than 2000 specimens were the least abundant during the study. These are the S1 stations (1378 individuals); S11 (1723 individuals), S4 (1845 individuals) and S3 (1966 individuals).

Of the three phyla harvested, molluscs were the majority, thus totaling 27475 MIB specimens, or 84% of the total abundance (Figure 7 (A)). Then come the Arthropods and then the Annelids constituting respectively 13% and 3% of the total number.

As for the different MIB classes recorded, gastropods were the most predominant (Figure 7 (B)), thus representing 76.12% (i. e.24, 206 individuals) of the total abundance collected. Crustaceans (10.07% relative abundance, or 3299 specimens) and Bivalves (7.75% relative abundance, or 2373 specimens) followed. Insects and Polychaetes gathered 2.77% and 2.73% of the workforce. Oligochaetes are in traces, 0.59% of the workforce.

Table 6: Summary of numbers (in individuals) of MIBs by station

	Sampling stations										
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
N (ind)	1378	5295	1966	1845	5073	2229	3778	2515	3451	3517	1723
Nr (%)	4.21	16.16	6.00	5.63	15.48	6.80	11.53	7.67	10.53	10.73	5.26

Legend: N is the number of individuals or the abundance and Nr the relative abundance (in %).

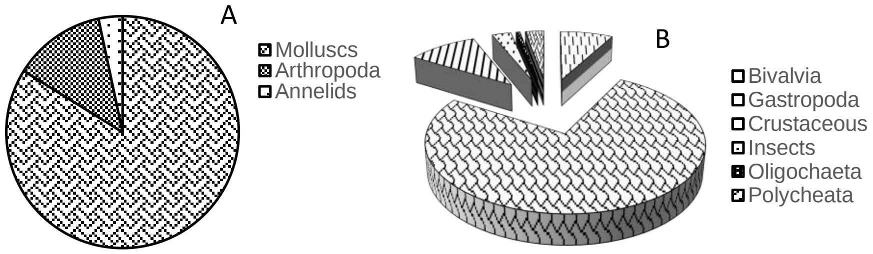

Figure 7: Relative abundances of the different MIB phyla (A); and the different classes of MIBs collected.

3.7 Spatial and seasonnal variations in the abundances of taxa identified

Spatially, the absolute abundances N varied from 52 individuals at station S4 to 1781 individuals at station S5 (Figure 8A). Spatial variations in abundances were not significant (KW - test: p>0.05). In general, only two MIB families were main (Nr>5%); there were the Thiaridae and the Potamididae, molluscs gastropoda whose numbers collected were respectively for all the stations, 12781 (39.23%) and 11319 specimensbb (34.74%).

On the whole lake, 4 species were main, namely *Tympanotonus fuscatus radula* (N=9633 specimens, Nr=29.40%), *Pachymelania aurita* (N=9364 specimens, Nr=28.64%), *Pachymelania* sp. (N=3165 specimens, Nr=9.66%) and *Tympanotonus fuscatus* (N=1686 specimens, Nr=5.15%). Three (03) other species, *Crassostrea gasar*, *Balanus* sp. And *Grandidierella africana* were also preponderant with relative abundances of 3.57, 3.55 and 2.21% respectively.

The figure 9B has illustrated the seasonnal variations of the taxa abundances (N). N fluctuated significantly (KW - test: p<0.001) from 52 individuals in the GRS to 2, 865 individuals in the LDS (Figure 9). Indeed, the abundances of taxa obtained during the first year of collection are significantly different (KW - test: p<0.001) from those obtained during the second year for the same seasons. Also, the abundances of taxa during GRS and GDS of the same year on the one hand, and during the GRS and LRS, were not significantly the same.

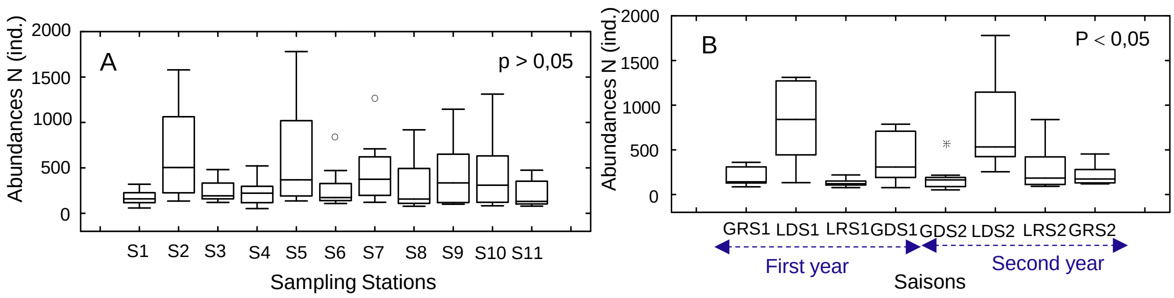

Figure 8: Spatial (A) and seasonnal (B) variations of the abundances of organisms.

3.9 Functional Feeding Groups (FFG) and their variations in the lake

Five FFG have been identified in the lake (Figure 9). Therewere collector - gatherers, filter - collectors, scrapers, grinders and predators. Collectors - gatherers and grinders constituted the main FFG of the macroinvertebrates (MIB) collected in the lake representing 51% of the taxonomic richness. Filter collectors with 14% were the latest group.

In the ecosystem, grinders and collector - gatherers were predominant at all stations/seasons. Their maximum abundance was obtained at station S2 in which totalised 4700 specimens or 47.30% of its abundance; it was the station S3 that collected the minimum number, i. e.877 specimens. Filter - collectors were more numerous at stations S2 (19.64%), S1 (18.87%), S11 (18.52%) and S10 (17.31%). As for scrapers, station S4 presented the highest richness, i. e.24.14% of its fauna Finally, predators represented less than 20% of the taxonomic richness of most stations, but they are still well present at stations S3, S6 and S8.

Their relative abundances varied from 44.98% at the GRS to 46.06% at the LDS for the grinders then from 43.46% at the GRS to 43.04% at the PSS for the collectors. Scrapers, filter feeders and predators were in the minority in all seasons. Filter feeders and predators were richer during the GDS (22% of the season richness). Finally, the scrapers with 17% of the richness of the taxa were richer during the GRS.

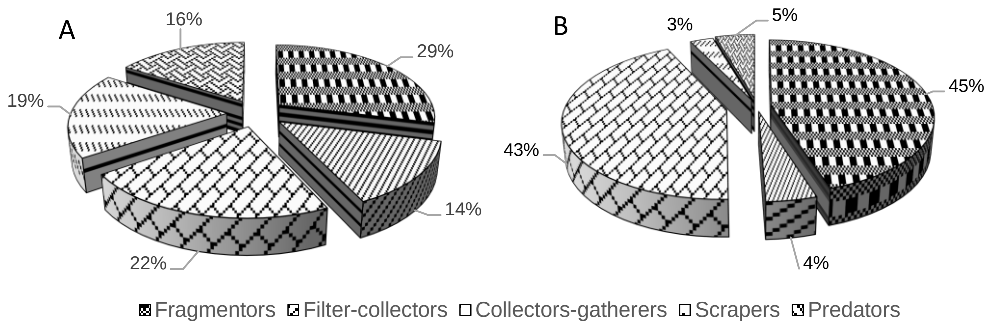

Figure 9: Taxonomic richness (A) and Relative Abundance (B) of the different functional feeding groups.

3.10 Distribution of organisms

A Factorial Correspondence Analysis (FCA) was performed with a matrix composed of eleven (11) stations and 72 taxa. Only taxa appearing in at least 5% of the samples were used for analysis. The results showed that the first two axes explained 52.70% (F1 (31.76% and F2 (20.94%) of the total variability of the information (Figure 10A). The analysis revealed that the stations had a large number of taxa of the macrofauna in common but are still different by a limited number of taxa which are characteristic of each of them. Two large communities are found in the lake; positively at the axis F1, gastropoda molluscs *Neritina*, bivalvia such as *Corbula*, *Melitina* and some insects such as *Naucoris* sp. formed a first community. Negatively to the F1 axis, arthropodA composed of isopoda crustaceans (*Anthura* sp.), decapoda (*Pachygrapsus*sp.; *Callinectesamnicola*, etc.), amphipoda (*Grandidierella* sp.) and worms such as the Polychaeta*Glycera*, and the insect larvae were grouped into a second community (Figure 10B). For the second axis, F2, worm, insect larvae such as *Chironomus*, associated with some crustaceans are positively correlated to this axis while negatively, we find molluscs such as *Bulinus*, *Biomphalaria*, *Littorina* associated with insect larvae such as *Libellula*sp., *Culex* and *Dixa* (Figure 10B).

Figure 11 below has presented the dendrogram corresponding to this classification analysis based on the presence - absence of the organisms. Three groups of stations were obtained. Group I consisted of stations S7 and S8; Group II was formedby stations S2, S5; S6, S9, S10 and S11. The third Group III was finally made up of the stations S1, S3 and S4. Overall, taxonomic richness was the same from one group to another (Kruskhal - Wallis test, $p > 0.05$) (Figure 13).

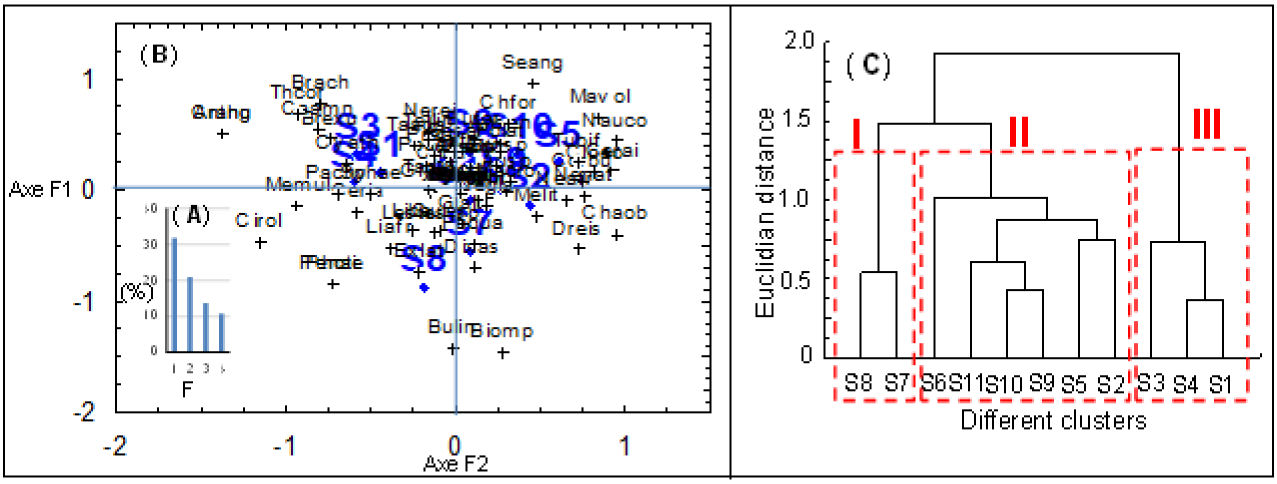

Figure 11: Factorial Correspondances Analysis based on the presence - absence of taxa. A) = histogram of proper values of axis; B = Factorial map and C) = Dendrogram summarizing the faunal similarities between the sampling stations. (S1, S2, S3, S4, S5, S6, S7, S8, S9, S10 and S11 are the station codes; I, II and III represent the groups)

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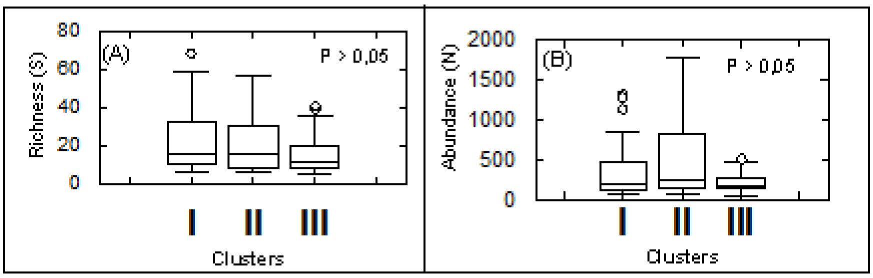

Figure 12: Differences in taxonomic richness (A) and abundance (B) between groups

4. Discussion

The study of benthic macroinvertebrates carried out over the period from March 2019 to February 2021 made it possible to collect 83 taxa divided into 6 classes, 25 orders, 54 families and 83 taxa. This richness is higher than those obtained by other authors for this lake. Indeed, the work of Gnohossou (2006) has registered 76 taxa. Odountan and Abou (2016) found of 66 taxa in the same lake. Also, Gnohossou (2006) has identified 2 Molluscs, 23 Arthropods and 2 Annelids which were not seen neither in the present, nor by Odountan and Abou (2016). Odountan and Abou (2016) who collected 13 Arthropods which were not obtained in the present study or in that of Gnohossou (2006). Eight (8) Molluscs, 10 Arthropods, and 2 Annelids were obtained in this study that were never quoted in the previous sudies. The differences observed in subsequent studies are probably due to the sampling methods, the types of habitats surveyed and the sampling equipment used. Indeed Gnohossou (2006) sampled benthic macroinvertebrates in 5 lake stations; Odountan and Abou (2016) in 8 stations while in the present study we identified 11 sampling stations, so more habitats were surveyed in this study. Regarding the collection of organisms, Gnohossou (2006) used a grab and artificial substrates to determine the composition of the lake in benthic fauna. Odountan and Abou (2016) used a kick net and also sampled the root of the aquatic vegetation like *Eichornia crassipes*. Also, in the present study, varied methods used for sampling helped to increase the sampling effort that undoubtedly, contributed to the results obtained.

These results obtained were confirmed by the estimates of the theoretical maximum richness. In fact, the results of these analyzes showed that there are neither singletons nor doubletons at the end of the sampling. However, the persistence of these species in the samples shows that there are taxa to be discovered, which is not the case for the present study. In addition, Molluscs were collected at 97.14%; Crustaceans at 97.14%; entomofauna at 96.61% and worms at 97.65%. This suggests that there were any species left to sample.

This inventory provided 83 taxa (genera/species). This richness obtained is much lower than that obtained by in the lagoon of Porto - Novo Adandédjan (2012); 150 taxa (genera and species) then 182 taxa (genera and species) in the coastal lagoon. Six (06) classes of macroinvertebrates which are gastropoda, bivalvia, crustaceans, insects, polychaeta and oligochaeta have been identified in the lake. And the highest richness of this composition was provided by gastropoda (19 species) and crustaceans (22 species) respectively while the results of Gnohossou (2006) already indicated 3 essential classes of its fauna, the gastropods (12 taxa), crustaceans (17 taxa) and insects (38 taxa). These results suggest that the lake is getting poorer day by day, a consequence of the level of pollution in the environment.

The differences between the different inventories could be explained by the instability of the lake Nokoué due to its proximity with the Atlantic Ocean. Lake Nokoué is directly connected to the Atlantic Ocean by the Cotonou Channel. This communication, added to the effects of the natural flooding of the Ouémé and Sô rivers, causes very significant seasonal variations (Gnohossou, 2006). To these seasonal fluctuations are added the effects of the hydrology of the environment. Indeed, the lake undergoes the influences of the tides in its southern part because of its connection with the sea. The marine intrusion favors marine and estuarine species such as certain molluscs (*Tympanotonus fuscatus radula*,. . . and bivalvia) and crustaceans which showed high richness during the study. This richness testifies to the resistance of these groups of MIB to support high variations of salinity, especially in the environment. Also, the northern part of the lake is connected to the Sô and Ouémé rivers which promotes the continental species in the lake. This confirms that estuaries would present a little diversified but very rich benthofauna (Barnes, 1974). These results had similiritywith those obtained in the lagoons environments in other countries such as in Côte d'Ivoire with the studies of Kouadio *et al*., (2011; 2018) respectively in the Ebrié lagoon and the Grand - Lahou lagoon. (Ivory Coast); of Lamptey and Armah (2008) in the Keta lagoon (Ghana) and even outside West Africa with Bazaïri *et al*., (2003) in the Merja Zerga lagoon (Morocco).

The spatial variations of the richness and numbers of the fauna observed were not significant (Kruskal - Wallis test: $p>0.05$) whereas their seasonal variations were, i. e. $p<0.05$. And gastropoda molluscs and crustaceans, essentially fragmentors, collector - gatherers and grazers, which constituted the essential of the taxonomic composition of each station and or season with stations located in the southern zone of the lake enriched in crustaceans and those located close to continental water sources enriched with molluscs. The highest richness and abundance of these zoological groupes were related to the enrichment of the lake by organic matters that serve as foods for the animals. The position of the lake near the big market of the country, favored it to be subjected to intense anthropogenic activities added to the natural distubances that polluted the environment. This lake also served as a collector of all wastes and discharges coming from not only the market but also from riverine villages by runoff, spills and from agricultural zones by the washing of pepticides risidues especially during the rains. The lake is highly enriched in organic matter, food for grinders, scrapers and collector - gatherers that represent the major groups of molluscs and crustaceans (Adandédjan, 2012).

The important quantity of organic matted lodded in this ecosystem explain tthe abundance of a few families such as the Neritidae, the Thiaridae and the Potamididae. A lot of accidental or rare species were inventoried. These results corrobodated those obtained in the lagoons of Porto - Novo and Ouidah and Grand - Popo by Adandédjan (2012, 2018). This observation highlights the presence of large quantities of organic matter and the existence of aquatic plants on which the gastropods feed because, according to Adandédjan *et al.* (2012), these factors would contribute to increasing the heterogeneity of habitats, which influences the composition of benthic communities. Thus, the high abundance of Gastropods, Crustaceans and Bivalves within the lake to the detriment of other species, is then easily justified by the favorable abiotic conditions which present themselves to these opportunistic groups. All the activities done in and around this lake strongly influence aquatic fauna including benthic macroinvertebrates causing severe variations in their structure. According to Rosenberg and Resh (1993) and Adandédjan (2018), these invertebrates have different sensitivities to pollution. Some are polluo - sensitive, they disappear most rapidly from the environment; it is the case of Plecoptera and Ephemeroptera that were not found during the study. The same authors explained that when the pollutant load becomes excessive, several taxa disappear from the ecosystem while those that resist, the pollutant - tolerant, become more abundant.

The same observations were made by Foto *et al*. (2010) who attributed to anthropization, the emergence of Molluscs in the waterways of the Mfoundi basin in Cameroon. According to Moisan and Pelletier (2008), when the environment is disturbed or when environmental conditions become unfavourable, the most sensitive organisms struggle to survive, and therefore decrease in favor of the most resistant. Numerous studies have shown that the main sensitive taxa can decrease with the decline in water quality, which is mainly caused by human activities (Flores and Zafaralla, 2012; Elias *et al*., 2014; Morris *et al*., 2014). To this end, the insects which constitute, in general, a group very sensitive to organic pollution (Azrina *et al*., 2006), regress in the environment because of the high organic load of the sediments. In such a weakened environment, the succession of processions of organisms is assured and with the amount of stress induced, the environment can only contain accidental or rare species. These results were also confirmed in the work of Adandédjan (2012) where very few constant taxa were identified in the coastal lagoon.

The biotic typology carried out revealed three large communities on the basis of presence - absence within the lake. The dendrogram obtained after the HCA indicated that the stations forming the clusters I and II were the most polluted as regarding the species they contained. These species such as *Chironomus*, *Biomphalaria*, *Littorina* associated with insect larvae such as *Libellula*, *Culex* and *Dixa* are polluo - tolerant taxa found in environments enriched with organic matter. Stations S1, S3 and S4 forming group III are the least polluted. Indeed, the stations of groups I and II include the stations of Dantokpa (S2), Ganvié (S5), Aguégué (S9), Tchonvi (S10), Gbakpodji (S11), Houédogbadji (S6), Center Houédogbadji (S7) and Dékanmey (S8) come from agglomerations with high densities of the riparian population where anthropogenic actions are strong and permanent. Moreover, the variations between the taxonomic richness and the abundance of the different groups are not significant (Kruskal - Wallis test: $p>0.05$). These results could be explained by the heterogeneity observed in the stand. In fact, the different groups formed are not all different because the taxa are too scattered in the environment, which also justifies the high number of accidental or rare taxa in the lake due to its instability. The lake is in perpetual fluctuation because by its southern part, the tides bring marine taxa into the environment but the permanent flow to the north from the Rivers Sô and Ouémé send the taxa back. The species are too scatterd in the lake. Those that can no longer survive tend to disappear from the environment. The agglutination of taxa close to the origin of the axes of the CFA map is justified because in the lake, there is no station that is not subjected to disturbances.

5. Conclusion

Lagoon ecosystems are highly productive environments for aquatic fauna. This study has identified 83 taxa of invertebrates in Lake Nokoué in southern Benin, divided into 54 families, 25 orders and 6 classes representing 32 770 individuals. Molluscs were the major taxa obtained representing 84% of the total abundance. They were followed by Arthropodaand Annelids with respectively 13% and 3% of the total abundance. The state of the environment highly enriched in organic matter following intense anthropogenic activities and its fragility due to its proximity to the ocean justified the composition of the different functional feeding groups dominated by the collector - gatherers and the fragmentors; and the numerous accidental and/or rare taxa in the ecosystem. Lake Nokoué is very disturbed as shown the results. A development of the lake is necessary to allow it to regain its integrity and to promote its certain sustainability. Through this study, we constitute a consistent data basis that could lead us to do robust analysis to confirm the results obtained in ordor to make suggestions to decision makers for different interventions in sight of the lake durability.

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