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Research Article

Development of a Macroinvertebrate Multimetric Index for the Evaluation of the Ecological Quality of Lake Nokoué

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Abstract

Nowadays, new tools for assessing the biotic integrity of aquatic environments are used. In Benin, the Macroinvertebrate MultiMetric Lake Index (M3LI) was designed to reveal the current state of Lake Nokoué. The inventory was carried out in eight seasonal data collection campaigns from 2019 to 2021 using an Eckman type grab and a trouble net. The composition, diversity and different metrics were calculated. Thirty-nine metrics grouped into five categories were defined and subjected to selection using a PCA in order to identify the relevant metrics for calculating the index. In the lake, 83 taxa divided into 25 orders and 54 families representing 32,770 specimens were determined. Insects, Molluscs, Crustaceans and Annelids constituted the essential macrofauna which was numerically dominated by Gastropods, Crustaceans, Bivalves and Insects. Of the 5 food functional groups obtained, crushers and collector-gatherers were dominant. Ten metrics relevant and well explained by environmental variables were used to calculate M3LI. The M3LI calculated varied from 6.44 at the station near Dantokpa to 3.38 at the Cotonou channel station with fluctuating water quality between poor quality and good quality. These results clearly explain the responses of the living communities of the lake faced with the various stresses due to daily marine intrusion, the role of receptacle of different continental waters and the various anthropogenic activities plunging the environment into a hypereutrophic state. It is therefore urgent to take measures to restoration of this environment to allow living species to regain their balance of life. This index is also a departure for the establishment of a biomonitoring program for the restoration of the lake.

Keywords

Lake Nokoué, Benthos, Diversity, Bioindication, Ecological Status

1. Introduction

For several decades, the assessment of the health of aquatic ecosystems has been made through the use of biological indicators such as macroinvertebrates and through the calculation of biotic indices of macroinvertebrates [1, 2]. These indices for the most part take into account a single variable. Recently, the multimetric approach has emerged [3-6]. This

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approach integrates different biological measures (richness, composition, tolerance and trophic status) into a single value that can potentially reflect the impact of multiple anthropogenic pressures [7].

In Benin, since 2006, numerous studies on benthic macrofauna organisms have been carried out in aquatic ecosystems [8-12]. The methods used in this work to evaluate the integrity of these different environments are classic statistical methods which use classifications and/or ordinations. It is necessary to use cutting-edge software and more or less solid basic statistical training to better interpret the results of data analysis. Nowadays, researchers have seen the need to integrate biological tools that can better demonstrate what they experience in their own environment that we would like to qualify. These are bioindicators that demonstrate the spatial and temporal heterogeneity of different disturbances in the aquatic environment [9].

The work of Adandédjan, D. on the determinism of benthic macroinvertebrate populations in the Porto-Novo Lagoon and the coastal lagoon (South Benin) initially highlighted the indicator species of each of the environments studied and in a second step revealed the quality of these environments using quadratic indices [9]. This study by which had hoped in its perspectives, the development of biotic indices has until now had as continuity the inventory studies in the different ecosystems and the determination of the ecological quality of environments by multivariate methods. A first attempt in Benin led Gnohossou et al, 2015 to design a non-multimetric biotic index based on the presence/absence of indicator taxa at the different points of the stations sampled in the lake [13]. A first sketch of a Macroinvertebrate MultiMetric Lake Index (M3LI) was made by Sossou 2019 in Lake Ahémé through the BiOSEL project with the aim of establishing the design methodology based on multimetric approaches [14]. But this study was only a test because the sampling was only carried out over 4 months while the benthic organisms have variable populations depending on the hydrological seasons. It therefore seems necessary to capitalize on all these experiences in order to develop a valid multimetric index for the evaluation of the ecological quality of Lake Nokoué. To achieve this, we will determine the relevant metrics for the development of this multimetric index and rule on the ecological state of Lake Nokoué.

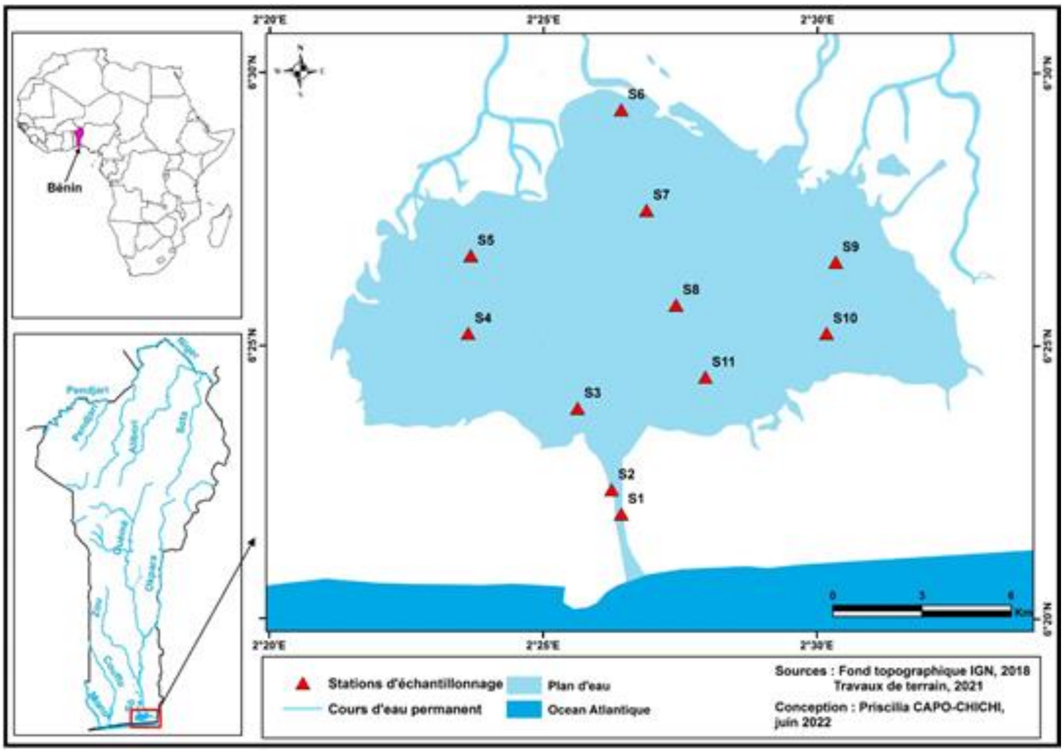


Figure 1. *Study environment and different stations sampled on Lake Nokoué.*

2. Material and Methods

2.1. Study Area

Located to the South-East of the Benin lagoon network (6°25' N, 2°36' E) (Figure 1), Lake Nokoué is between the parallels 6°20' and 6°30' North and the meridians 2°20' and 2°35'. It is considered the largest body of water in Benin and covers an area of 150 km^2 [15, 16]. With a length of 20 km in its East-West direction and a width of 11 km in its North-South direction, it represents the largest lagoon body of water in the Republic of Benin and the largest from the point of view of its development [17]. It is connected to the Porto-Novo Lagoon by the Totchè canal and is supplied with fresh water by the Ouémé river and the Sô river [16, 18]. It also receives the influences of wastewater coming from Abomey-Calavi, rainwater collectors from the city of Cotonou and the Cotonou channel through which sea water arrives [19].

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

2.2. Sampling Stations

A total of eleven (11) stations were selected for the study (Figure 1). Their positions were identified using a Global Positioning System (GPS). The criteria for choosing stations are accessibility, the development of human activities, the presence or absence of vegetation, proximity to a fishing gear or technique (Acadja, or others). Data collection was carried out over 2 years (March 2019 – February 2021) taking into account the four hydrological seasons which are: Short Dry Season, Little Rainy Season, Great Dry Season and Great Rainy Season.

2.3. Measurement of Physicochemical Data

Transparency was measured *in situ* at each sampling. In addition to this parameter, six (06) other parameters were measured in the laboratory from water samples at each station. These are: Nitrites ($NO2^-$), Nitrates ($NO3^-$), Ammonium ($NH4^+$), Phosphates ($PO4^{3-}$), Total Phosphorus (P-total) and Chlorophyll *a*.

2.4. Collection of Biological Data

Sampling of benthic macroinvertebrates was carried out using a multi-habitat approach [20, 21]. Two (2) tools have been used for this purpose. This is an Eckman grab and a surber net. At each station, 5 strokes of the grab and 1 stroke of the surber net were given. The collected organisms were collected in bocal containing 10% formalin.

In the laboratory, after cleaning to remove the conservation formalin, the organisms were sorted station by station under a binocular magnifying glass. The taxonomic determination was carried out down to the species level unless the identification keys do not allow it. The keys used are: Aquatic invertebrates of South African Rivers Version 2 [22]; Water beetles from Benin (Coleoptera: Haliplidae, Dytiscidae, Noteridae, Hydraenidae, Hydrochidae, Hydrophilidae, Gyrinidae, Elmidae) [23]; Inventory of aquatic insects in fish ponds in southern Côte d'Ivoire [24]; Guide to the identification of the main freshwater macroinvertebrates of Quebec [25]; Freshwater invertebrates [26]. After identification, the organisms were counted at each station and by species. Then they were preserved in 70% alcohol.

2.5. Statistical Processing

2.5.1. Calculating Metrics

Thirty-nine (39) metrics representing various aspects of benthic macroinvertebrate assemblages were identified and calculated per sampling station [27, 28]. These metrics can be grouped into five (05) categories: taxonomic richness metrics, composition metrics, tolerance metrics, diversity metrics, food functional group metrics.

Categorie 1: Taxonomic richness metrics

These are the metrics that define the number of taxa (families or genera/species) of a given taxonomic level. In the present work, twelve (12) richness metrics have defined and concern the total taxonomic richness S, the richness of Gastropods, the richness of Bivalves, the richness of Insects, the richness of Crustaceans, the richness of Oligochaeta, the richness of Neritidae, the richness of Thiaridae, the richness of Gammaridae, the richness of Chironomidae, the richness of Potamididae and the richness of Nereididae.

Categorie 2: Composition metrics

For a given group X belonging to a station, its composition metric is calculated by the expression of [29]:

$$\%X = \frac{Abundance\ of\ X}{Total\ abundance} * 100$$

Where the Abundance of X is the number of specimens of X collected at the given station.

Sixteen (16) composition metrics were retained. These are: the percentage of Molluscs, the percentage of Gastropods, the percentage of Crustaceans, the percentage of Insects, the percentage of Oligochaetes, the percentage of Worms, the percentage of Diptera, the percentage of Neritidae, the percentage of Thiaridae, the percentage of Gammaridae, the percentage of Nereididae, the percentage of Chironomidae, the percentage of Potamididae, the percentage of Ostreidae, the percentage of Sphaeridae and the percentage of Balanidae.

Categorie 3: Tolerance Metrics

Three (03) tolerance metrics were retained and are: the Ephemeroptera-Coleoptera index, the Hilsenhoff Biotic Index and the percentage of intolerant taxa.

Categorie 4: diversity metrics

Three (03) diversity metrics were retained and are: Shannon index, Margalef index and Simpson index.

Categories 5: food functional group metrics

Five (05) food functional group were retained. There are: percentage of Grinders, percentage of Filter-Collectors, percentage of Collectors-Gatherers, percentage of Scrapers and percentage of Predators.

2.5.2. Standardization of Metrics

The normalized value of a variable is obtained by dividing the value of the variable at a given station by the largest value of this variable obtained for all the stations sampled in the lake. Values positively associated with a healthy ecosystem were normalized by dividing them by the maximum reached. For variables that are negatively associated with a healthy ecosystem such as the percentage of Oligochaetes, the reciprocal (1-x) of the value is divided by the maximum of the reciprocal values [30, 31].

2.5.3. Pre-selection of Metrics

Spearman correlation between normalized metrics and the seven environmental parameters (Transparency, Ammonium, Nitrites, Nitrates, Phosphates, Total Phosphorus and Chlorophyll a) was performed. Only metrics with a significant correlation ($p < 0.05$) were pre-selected.

2.5.4. Selection of Metrics

It was carried out using a Principal Component Analysis (PCA) according to [9]. The PCA module allows you to create a factorial space from a set of variables, and show how to interpret its dimensions and project variables and individuals into this factorial space. The base used is composed of x (rows) stations and y (columns) preselected metrics. Metrics with a factorial weight greater than 0.6 on axes 1 and 2 were selected for the calculation of the index.

2.5.5. Construction of the Macroinvertebrate Multimetric Lake Index (M3LI)

The calculation of the M3LI is based on the metrics selected at the end of the PCA. Its value at each station is the sum of the selected metrics.

3. Results

3.1. Metrics Calculation

Thirty-nine (39) metrics were calculated and the results recorded in Table 1 below.

***Table 1**. Metric calculation results.*

METRICS	Codes	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Taxonomic richness	RTAX	43	42	43	46	42	46	49	36	44	41	42
Gastropod richness	RGAS	8	10	7	9	12	10	14	9	10	8	9
Bivalves richness	RBIV	10	11	10	9	7	8	6	6	9	9	10
Insects richness	RINS	5	8	4	5	7	6	8	6	7	4	6
Crustaceans richness	RCRU	15	8	14	17	10	13	14	8	11	11	10
Oligochaeta richness	ROLI	1	1	1	1	2	2	2	1	1	2	1
Neritidae richness	RNER	2	4	1	2	5	4	6	1	2	2	3
Thiaridae richness	RTHI	3	3	2	2	2	3	3	3	3	2	2
Gammaridae richness	RGAM	2	2	2	2	2	2	2	0	2	2	2
Chironomidae richness	RCHI	1	1	1	1	2	1	0	0	1	2	2
Potamididae richness	RPTA	2	2	2	2	2	2	2	2	2	2	2
Nereididae richness	RNEA	2	1	3	2	2	2	1	2	3	3	2
Percentage Molluscs	PMOL	69.09	93.2	57.68	61.52	90.01	88.52	81.45	89.46	87.97	87.46	77.60
Percentage Gastropods	PGAS	54.57	87	34.28	50.57	83.99	84.39	78.16	83.42	82.82	83.54	57.23
Percentage Crustaceans	PCRU	20.32	3.36	22.53	30.5	6.11	5.29	13.47	4.10	8.26	8.93	11.38
Percentage Insects	PINS	4.86	1.85	5.75	0.92	2.46	4.22	2.81	3.22	2.81	0.20	5.9
Percentage Oligochaeta	POLI	36.71	7.59	36.71	48.1	7.59	24.05	20.25	26.58	12.66	16.46	8.86
Percentage Worms	PVER	3.63	1.4	12.5	4.99	1.3	1.12	1.85	2.39	0.67	3.04	4.64
Percentage Diptera	PDIP	2.90	0.77	1.73	0.27	1.01	0.94	0.64	0.24	0.46	0.17	3.08
Percentage Neritidae	PNER	1.45	0.45	1.37	1.52	2.66	6.19	6.35	0.12	0.46	0.43	1.33
Percentage Thiaridae	PTHI	33.24	26.10	10.17	33.93	43.07	31.85	60.5	36.74	59.29	51.72	8.36

METRICS	Codes	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Percentage Gammaridae	PGAM	4.28	0.83	7.12	5.58	0.83	1.88	1.59	0.00	1.88	0.26	1.33
Pourcentage Nereididae	PNEI	2.98	0.64	10.4	3.09	0.85	0.49	0.69	0.40	0.38	1.96	2.96
Percentage Chironomidae	PCHI	0.00	0.83	1.22	0.11	0.12	1.39	0.66	0.00	0.00	0.00	0.00
Percentage Potamididae	PPTA	19.81	60.7	21.32	14.15	36.99	46.38	11.17	46.48	22.91	31.16	47.68
Percentage Ostreidae	POST	5.01	4	16.9	1.27	3.09	0.54	1.33	9.07	1.34	1.32	10.48
Percentage Sphaeridae	PSPH	2.61[M]	0.46	1.96	7.54	0.24	1.8	0.53	1.48	0.76	0.91	1.87
Percentage Balanidae	PBAL	4.14	0.28	0.62	8.26	3.4	0.67	5.73	2.84	3.98	5.48	7.32
EC index	EC	0	0	0	0	2	0	0	1	1	1	1
Percentage of intolerant taxa	PTTS	2.33	2.38	0.00	0.00	0.00	0.00	2.04	2.78	2.27	0.00	2.38
Hilsenhoff Biotic Index	FBI	7.14	7.71	6.64	6.96	7.64	7.71	7.49	7.75	7.61	7.62	7.09
Shannon Index	ISHA	2.93	1.64	2.85	2.66	1.94	1.89	2.05	1.97	1.82	1.94	2.46
Simpson Index	ISIM	0.09	0.36	0.09	0.15	0.23	0.29	0.27	0.23	0.29	0.22	0.16
Margalef Index	IMAR	5.81	4.67	5.42	5.86	4.69	5.71	5.71	4.35	5.16	4.78	5.37
Percentage Grinders	PBRO	40.93	47.30	32.86	38.54	46.76	47.6	45.24	46.19	47.20	45.84	40.20
Percentage filter-collectors	PFCO	9.21	3.32	17.2	6.90	3.23	2.23	1.83	3.28	4.95	2.13	12.70
Percentage Collectors-Gatherers	PCRA	35.22	46.6	25.25	33.35	46.26	45.67	43.96	45.31	45.66	45.46	37.41
Percentage Scrapers	PRAC	7.55	0.47	10.9	11.02	0.99	1.48	3.46	0.69	1.30	1.75	1.74
Percentage Predators	PPRE	7.09	2.25	13.7	10.20	2.76	3.03	5.51	4.53	0.89	4.82	7.96

3.2. Standardized Metric Values

Wide variations are observed for standardized metric values (Table 2). For example: EC index [0-1]; number of intolerant taxa [0-1]; Insect richness [0.5-1]; Crustacean percentage [0.47-1].

Table 2. *Standardized metric values.*

METRICS	CODES	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Taxonomic richness	RTAX	0.88	0.86	0.88	0.94	0.86	0.94	1.00	0.73	0.90	0.84	0.86
Gastropod richness	RGAS	0.57	0.71	0.50	0.64	0.86	0.71	1.00	0.64	0.71	0.57	0.64
Bivalves richness	RBIV	0.91	1.00	0.91	0.82	0.64	0.73	0.55	0.55	0.82	0.82	0.91
Insects richness	RINS	0.63	1.00	0.50	0.63	0.88	0.75	1.00	0.75	0.88	0.50	0.75
Crustaceans richness	RCRU	0.88	0.47	0.82	1.00	0.59	0.76	0.82	0.47	0.65	0.65	0.59
Oligochaeta richness	ROLI	0.50	0.50	0.50	0.50	1.00	1.00	1.00	0.50	0.50	1.00	0.50
Neritidae richness	RNER	0.33	0.67	0.17	0.33	0.83	0.67	1.00	0.17	0.33	0.33	0.50
Thiaridae richness	RTHI	1.00	1.00	0.67	0.67	0.67	1.00	1.00	1.00	1.00	0.67	0.67
Gammaridae richness	RGAM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00
Chironomidae richness	RCHI	0.50	0.50	0.50	0.50	1.00	0.50	0.00	0.00	0.50	1.00	1.00
Potamididae richness	RPTA	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

METRICS	CODES	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Nereididae richness	RNEA	0.67	0.33	1.00	0.67	0.67	0.67	0.33	0.67	1.00	1.00	0.67
Percentage Molluscs	PMOL	0.74	1.00	0.66	0.66	0.96	0.95	0.87	0.96	0.94	0.94	0.83
Percentage Gastropods	PGAS	0.63	1.00	0.39	0.58	0.96	0.97	0.90	0.96	0.95	0.96	0.66
Percentage Crustaceans	PCRU	0.67	0.11	0.74	1.00	0.20	0.17	0.44	0.13	0.27	0.29	0.37
Percentage Insects	PINS	0.81	0.31	0.96	0.15	0.41	0.71	0.47	0.54	0.47	0.03	1.00
Percentage Oligochaeta	POLI	0.76	0.14	0.76	1.00	0.14	0.49	0.41	0.54	0.25	0.33	0.17
Percentage Worms	PVER	0.29	0.11	1.00	0.40	0.10	0.09	0.15	0.19	0.05	0.24	0.37
Percentage Diptera	PDIP	0.94	0.25	0.56	0.09	0.33	0.31	0.21	0.08	0.15	0.06	1.00
Percentage Neritidae	PNER	0.24	0.42	0.97	1.00	0.02	0.07	0.07	0.21	1.00	0.00	0.04
Percentage Thiaridae	PTHI	0.56	0.71	0.53	1.00	0.61	0.98	0.85	0.14	1.00	0.00	0.01
Percentage Gammaridae	PGAM	1.00	0.15	0.34	0.28	0.00	0.34	0.05	0.24	1.00	0.00	0.18
Pourcentage Nereididae	PNEI	1.00	0.27	0.16	0.22	0.13	0.12	0.64	0.96	1.00	0.00	0.32
Percentage Chironomidae	PCHI	0.00	0.60	0.49	0.08	0.09	1.00	0.48	0.00	0.00	0.00	0.00
Percentage Potamididae	PPTA	0.33	1.00	0.35	0.23	0.61	0.76	0.18	0.77	0.38	0.51	0.78
Percentage Ostreidae	POST	0.30	0.24	1.00	0.08	0.18	0.03	0.08	0.54	0.08	0.08	0.62
Percentage Sphaeridae	PSPH	0.35	0.06	0.26	1.00	0.03	0.24	0.07	0.20	0.10	0.12	0.25
Percentage Balanidae	PBAL	0.50	0.03	0.08	1.00	0.41	0.08	0.69	0.34	0.48	0.66	0.89
EC index	EC	0	0	0	0	1	0	0	0.5	0.5	0.5	0.5
Percentage of intolerant taxa	PTTS	0.84	0.86	0.00	0.00	0.00	0.00	0.73	1.00	0.82	0.00	0.86
Hilsenhoff Biotic Index	FBI	0.92	1.00	0.86	0.90	0.99	1.00	0.97	1.00	0.98	0.98	0.92
Shannon Index	ISHA	0.41	0.54	0.56	0.79	0.66	0.44	0.49	0.66	0.62	1.00	0.53
Simpson Index	ISIM	0.25	1.00	0.26	0.42	0.63	0.11	0.25	0.64	0.80	0.60	0.43
Margalef Index	IMAR	0.99	0.80	0.92	1.00	0.80	0.97	0.97	0.74	0.88	0.82	0.92
Percentage Grinders	PBRO	0.86	0.99	0.69	0.81	0.98	1.00	0.95	0.97	0.99	0.96	0.84
Percentage filter-collectors	PFCO	0.53	0.19	1.00	0.40	0.19	0.13	0.11	0.19	0.29	0.12	0.74
Percentage Collectors-Gatherers	PCRA	0.75	1.00	0.54	0.71	0.99	0.98	0.94	0.97	0.98	0.97	0.80
Percentage Scrapers	PRAC	0.69	0.04	0.99	1.00	0.09	0.13	0.31	0.06	0.12	0.16	0.16
Percentage Predators	PPRE	0.52	0.16	1.00	0.74	0.20	0.22	0.40	0.33	0.07	0.35	0.58

3.3. Metric Preselection

Table 3 shows the results of Spearman's correlation test between standardized metrics and environmental variables. Of the thirty-nine (39) metrics calculated, fourteen (14) were significantly correlated ($p < 0.05$) with physico-chemical parameters such as transparency (Transp), nitrates ($NO3^-$), nitrites ($NO2^-$), ammonium ($NH4^+$), phosphates ($PO4^{3-}$), total phosphorus (P-total) and Chlorophyll *a* (Chlorop *a*)

The metrics concerned as follows:

1. Gastropods richness (RGAS);
2. Thiaridae richness (RTHI);
3. Nereididae richness (RNEA);
4. Shannon index (ISHA);
5. Simpson index (ISIM);
6. Percentage Molluscs (PMOL);
7. Percentage Gastropods (PGAS);
8. Pourcentage Chironomidae (PCHI);
9. Percentage Grinders (PBRO);
10. Percentage intolerant Taxa (PTTS);
11. Percentage Collectors-Gratherers (PCRA)
12. Percentage Predators (PPRE);
13. Percentage worms (PVER)

14. Percentage Balanidae (PBAL).

Table 3. *Results of correlation test between standardized metrics and environmental parameters. (In bold, metrics significantly correlated with parameters).*

Codes	Transp	$NO3^-$	$NO2^-$	$NH4^+$	$PO4^{3-}$	P-total	Chlorop a
PTTS	0.31	0.13	-0.32	0.34	0.70	0.03	-0.01
RGAS	-0.15	0.18	-0.03	-0.28	-0.22	-0.62	-0.26
RTHI	-0.23	-0.17	-0.12	0.00	0.46	-0.64	-0.46
RNEA	-0.15	-0.04	0.64	0.35	0.21	0.47	0.33
ISHA	0.61	-0.16	-0.16	-0.09	-0.16	0.50	-0.17
ISIM	-0.49	0.21	-0.01	-0.07	0.14	-0.65	-0.06
PMOL	-0.33	0.31	0.15	-0.14	0.14	-0.64	0.05
PGAS	-0.48	0.13	0.02	-0.13	0.07	-0.66	0.07
PCHI	-0.54	0.37	-0.16	-0.82	-0.66	-0.57	-0.07
PBRO	-0.56	0.06	0.15	-0.10	0.21	-0.75	-0.15
PCRA	-0.54	0.20	0.12	-0.14	0.05	-0.68	0.10
PPRE	0.51	-0.15	-0.31	-0.01	-0.24	0.65	0.00
PVER	0.50	-0.03	-0.37	0.00	-0.29	0.65	0.16
PBAL	0.65	-0.58	-0.22	0.55	0.02	0.61	-0.19

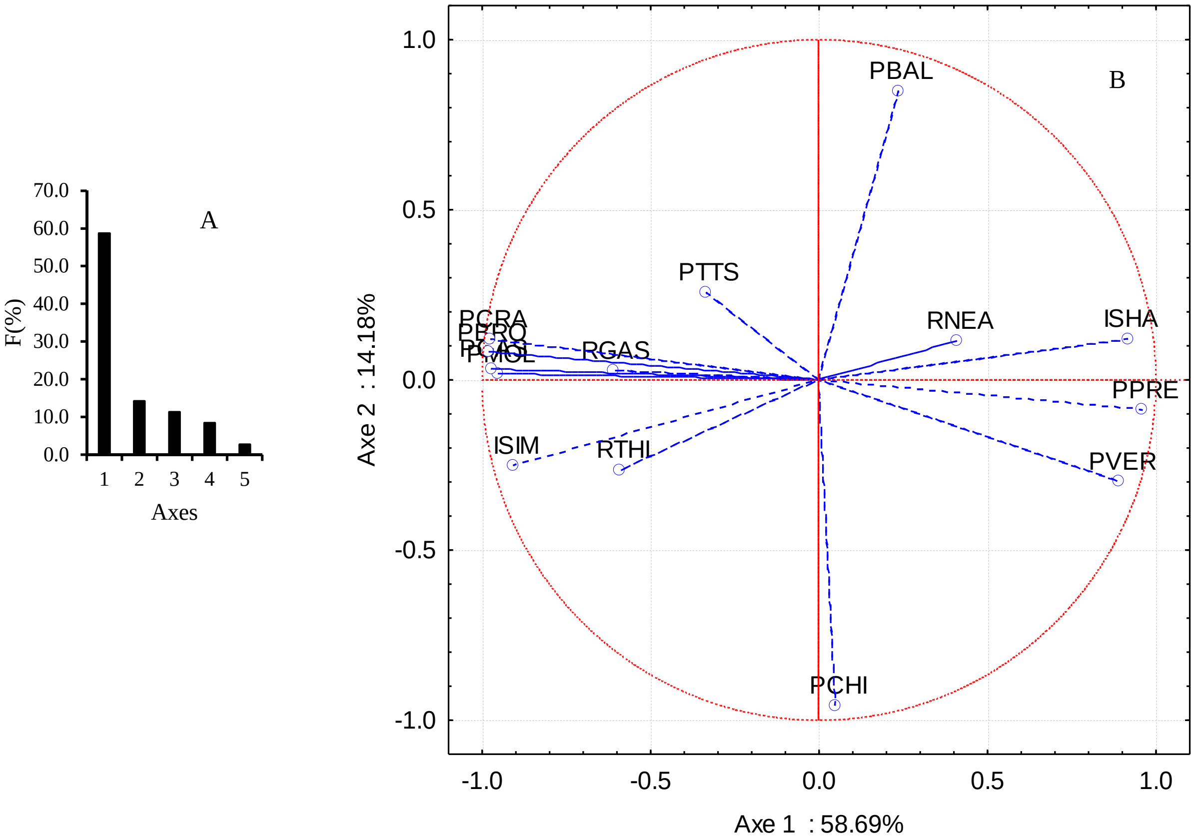
3.4. Metric Selection

The Principal Component Analysis (PCA) performed with the 14 pre-selected metrics showed that 72.9% of the total inertia of the data is expressed by the first two axes of the analysis (Figure 2A). These two axes were used to express the PCA results. Ten variables proved to be more discriminating, with a factor weight greater than 0.6 (Table 4): Shannon Index or ISHA; Simpson Index or ISIM; Percentage of Molluscs or PMOL; Percentage of Gastropods or PGAS; Percentage of Chironomidae or PCHI; Percentage of Grinders or PBRO; Percentage of Collectors-Gatherers or PCRA; Percentage of Predators or PPRE; Percentage of Worms or PVER; and Percentage of Balanidae or PBAL.

Table 4. *Variable selection based on factor weights. (Factor weights of the most discriminating variables in bold).*

Codes	Axe 1	Axe 2
PTTS	-0.34	0.26
RGAS	-0.59	0.03
RTHI	-0.59	-0.26
RNEA	0.41	0.12
ISHA	0.92	0.12
ISIM	-0.91	-0.25
PMOL	-0.95	0.02
PGAS	-0.97	0.03
PCHI	0.05	-0.96

Codes	Axe 1	Axe 2
PBRO	-0.98	0.08
PCRA	-0.98	0.12
PPRE	0.96	-0.09
PVER	0.89	-0.30
PBAL	0.24	0.85



A = Eigenvalues of factorial axes; B = Correlation circles.

Figure 2. *Principal Component Analysis.*

3.5. Construction of Macroinvertebrates MultiMetric Lac Index (M3LI)

The Macroinvertebrates MultiMetric Lake Index (M3LI) is the sum of ten selected metrics: Shannon Index (ISHA); Simpson Index (ISIM); Percentage of Molluscs (PMOL); Percentage of Gastropods (PGAS); Percentage of Chironomidae (PCHI); Percentage of Grinders (PBRO); Percentage of Collectors-Gatherers (PCRA); Percentage of Predators (PPRE); Percentage of Worms (PVER) and Percentage of Balanidae (PBAL).

3.6. Macroinvertebrates MultiMetric Lake Index (M3LI) Values

Index values were calculated for each station and presented in Table 5. The Multimetric Macroinvertebrate Lake Index obtained at each station shows that the lowest value (3.38) was obtained at station S1 and the highest (6.44) at station S2.

Table 5. *Macroinvertebrates Multimetric Lake Index values at sampled stations.*

Stations	ISHA	ISIM	PMOL	PGAS	PCHI	PBRO	PCRA	PPRE	PVER	PBAL	IM2L
S1	0.41	0.25	0.74	0.63	0	0.56	0.45	0.22	0.09	0.03	3.38
S2	0.54	1	1	0.82	0.45	0.82	0.71	0.16	0.11	0.03	6.44
S3	0.56	0.26	0.62	0.31	0.78	0.49	0.44	0.57	1	0.08	5.11
S4	0.79	0.42	0.66	0.48	0.08	0.71	0.71	0.74	0.4	1	5.99
S5	0.66	0.63	0.96	0.96	0.09	0.98	0.91	0.2	0.1	0.41	5.9
S6	0.44	0.51	0.85	0.87	1	0.76	0.68	0.12	0.09	0.08	5.4
S7	0.49	0.25	0.87	0.76	0.28	0.75	0.44	0.4	0.31	0.29	4.84
S8	0.66	0.64	0.96	0.96	0	0.97	0.97	0.33	0.09	0.34	5.92
S9	0.62	0.8	0.94	0.95	0	0.99	0.98	0.07	0.05	0.48	5.88
S10	1	0.6	0.94	0.86	0	0.96	0.56	0.35	0.24	0.46	5.97
S11	0.53	0.43	0.83	0.66	0	0.84	0.8	0.58	0.37	0.69	5.73

3.7. Ecological Classes of M3LI

The minimum and maximum limits of the M3LI have been determined by taking into account the final number of metrics used to calculate the index. The index ranges from 0 to 10, depending on the number of metrics used in the calculation. Five ecological quality classes have thus been defined for the Multimetric Lake Index (M3LI):

M3LI between [8-10]: Very good ecological quality
M3LI included [6-8]: Good ecological quality
M3LI included [4-6]: Medium ecological quality
M3LI included [2-4]: Mediocre ecological quality
M3LI included [0-2]: Poor ecological quality.
The corresponding color scales are: (Figure 3).

IM2L index quality classes	Color scales	Water quality
[8-10]		Very good
[6-8]		Good
[4-6]		Medium
[2-4]		Mediocre
[0-2]		Poor

Figure 3. *Color scales.*

3.8. Ecological Quality of Lake Nokoué

Figure 4 shows the water quality of Lake Nokoué at its various stations. The map in Figure 5 shows the lake's ecological status at various points. Lake Nokoué is therefore in an average state of pollution.

Stations	M3LI	Water quality	Color codes
S1	3.38	Mediocre	
S2	6.44	Good	
S3	5.11	Medium	
S4	5.99	Medium	
S5	5.9	Medium	
S6	5.4	Medium	
S7	4.84	Medium	
S8	5.92	Medium	
S9	5.88	Medium	
S10	5.97	Medium	
S11	5.73	Medium	

Figure 4. *Lake Nokoué water quality.*

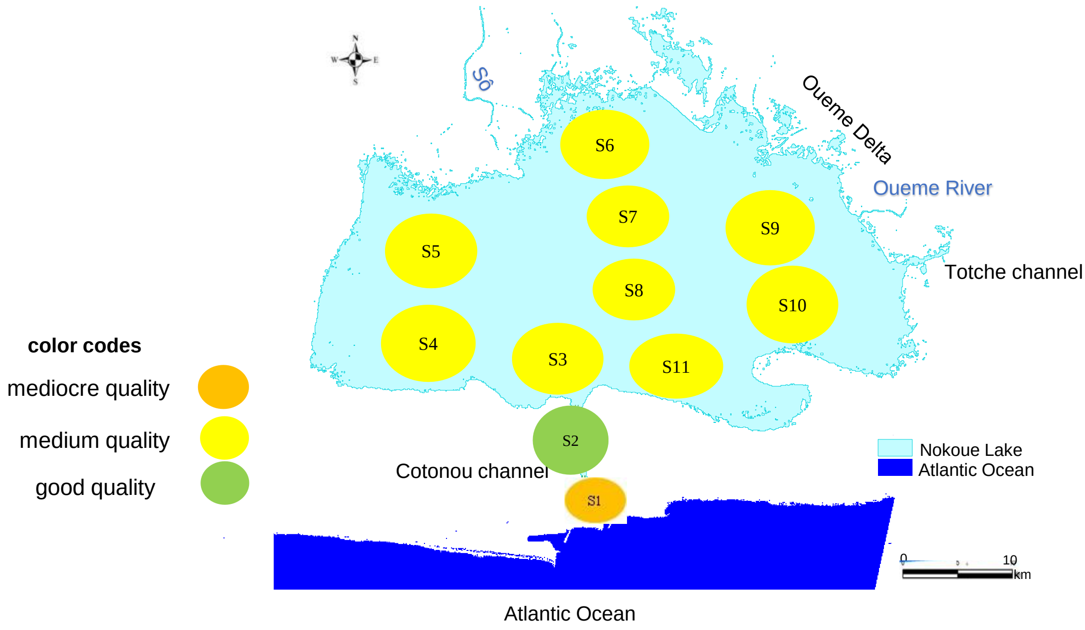


Figure 5. *Map showing station status after calculation of the index of biotic integrity.*

4. Discussion

The most important phase in the construction of the multimetric index is the search for the appropriate metrics. Karr and Chu, 1999 defines a metric as a calculated measure that describes certain aspects of a biological community such as its structure, its functioning or any other biological characteristic [32]. In this study, thirty-nine (39) metrics were calculated. These metrics relate to tolerance, richness, abundance, diversity and functional food groups to take into account all the functionalities linked to the zoological group used. By comparing the number of metrics used to those of other authors in the sub-region such as [33], seventeen (17) for the construction of a multimetric index for evaluating the ecological quality of the region's waters West Cameroon; [27] used 46 metrics (metrics measuring food tolerance, richness, composition and functional group); [28] used 39 metrics (richness, composition, food functional group and tolerance measurement metrics); [34], calculated 29 (metrics of absolute taxonomic abundance, relative taxonomic abundance, taxonomic richness and diversity indices), etc. we can say that the number of metrics in this analysis is largely sufficient or representative.

Ten (10) selected metrics served as the basis for the development of the Multimetric Macroinvertebrate Lake Index (M3LI), which are the Shannon Index; the Simpson Index; the Percentage of Molluscs; the Percentage of Gastropods; the Percentage of Chironomidae; the Percentage of Grinders; the Percentage of Collectors-Gatherers; the Percentage of Predators; the Percentage of Worms and the percentage of Balanidae. These metrics are representative and meet the design standards of a biotic integrity index if we can align with the European standard used by all the aforementioned African countries because in Africa, there is none.

The Multimetric Macroinvertebrate Lake Index determined varied from 3.28 at station S1 of the Cotonou channel to 6.44 at station S2 near Dantokpa. As for the others, the index value is between 4.84 and 5.99; Only station S2 showed during the study a good ecological status according to the scale that we defined and corresponding to a low level of pollution. In fact, during the sampling period, this station suffered an eviction of the numerous populations who lived there and carried out large-scale anthropogenic activities such as domestic and industrial landfills, landings from surrounding villages, and trade especially in gasoline, and fishing with all the various gears, etc. This is a development program for water bodies in South Benin underway in Benin and appearing in the Government Action Program (PAG). Operations to liberate the banks of Lake Nokoué and the Cotonou channel began under the supervision of security forces in June 2020 where several hangars were destroyed this Tuesday, over a long distance. This development has worked in favor of this station which breathes as well as possible. But the physicochemical study carried out indicated that all the stations are hyperheutrophic. Note that the chemical analysis gives a specific image of the ecological state of the environment; however, this result is not in contradiction with the biological analysis. This is where monitoring of the station is necessary to preserve the sustainability of the development, and therefore of the lake.

The S1 station with the lowest index value is the one which receives the water discharged directly and permanently into the channel by pipes installed by a restaurant on the west side of the channel. The taxa collected are all pollutant-resistant taxa because the water directly discharged into the lake is not treated; they are full of nutrients which sediment and whose degradation consumes the oxygen available in the water. This is a heavily polluted station. Along the same lines, the other stations are in an ecological state of average quality which, in the more or less short term, may disintegrate. Indeed, these stations are those located on the outskirts of numerous riverside villages such as the villages of Sainte Cécile, Gbèjromèdé, Ménontin and Abomey-Calavi where the population density is very high, the pollution level increases from West to East and from station S2 towards the north of the lake. This observation could be explained by the fact that the northern zone of the lake receives permanent runoff water from rains and rivers. These waters are full of fertilizers and pesticides leached from the agricultural areas around the lake. It is also in these areas that numerous fishing gear have been installed. Operations to remove these devices were carried out during the study but remained without follow-up; which means that these machines have returned today.

5. Conclusion

In short, the index (M3LI) designed made it possible to determine the ecological quality of Lake Nokoué. Its values obtained varied from 3.28 to 6.44 thus placing the lake between poor ecological quality and good with most of its stations in average ecological status. This so-called global approach to indicating water quality will find its meaning in monitoring the various developments undertaken or planned for the restoration of Lake Nokoué and adjacent ecosystems. The use of the index on all aquatic ecosystems in Benin will make it possible to better validate the robustness of the index. However, the determination of a reference station is necessary to better establish the comparisons.

Abbreviations

BiOSEL	BIodiversity And Anthropic Pressures On Living Resources Aquatic Of Estuarian And Lagoon Systems Of South BENIN
GPS	Global Positioning System
M3LI	Macroinvertebrate MultiMetric Lake Index
PAG	Government Action Program
PCA	Principal Component Analysis

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Conflicts of Interest

The authors declare no conflicts of interest.

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