

Comparing Freshwater Benthic Macroinvertebrate Communities in Forest and Urban Streams of the Coastal Ecological Region of Cameroon

Fils Mamert Onana^{1*}, Serge Hubert Zebaze Togouet², Antoine Arfao Tamsa³, Nectaire Lié Nyamsi Tchatcho¹, Siméon Tchakonte³, Ernest Koji⁴, Armel William Yemtsa Yemeli¹, Abigaëlle Natacha Sandrine Mouto Makong¹

¹Department of Aquatic Ecosystems Management, Institute of Fisheries and Aquatic Sciences, University of Douala, Douala, Cameroon

²Department of Animal Biology and Physiology, Faculty of Science, University of Yaoundé I, Yaoundé, Cameroon

³Microbiology and Biotechnology Laboratory, Saint Jerome Polytechnic Institute, Saint Jerome Catholic University of Douala, Douala, Cameroon

⁴Department of Animal Biology and Physiology, Faculty of Sciences, University of Douala, Douala, Cameroon

Email: *filsonana@yahoo.fr

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Abstract

In this study conducted in the coastal zone of Cameroon, biological indices and functional feeding groups of benthic macroinvertebrates were used to assess the health status of two urban streams. For a better diagnosis, two streams located in coastal forest zone were used as a reference. Benthic macroinvertebrates were sampled monthly over a 3-month period (from May to July 2017) in six urban stations and six forest stations. Measurements of the physicochemical variables were done simultaneously. Physicochemical analysis revealed that urban streams are strongly polluted with high content of decaying organic matters, while forest streams are slightly polluted as indicated by the Principal Component Analysis. Concerning benthic macroinvertebrates, urban streams are poorly diversified with the proliferation of taxa tolerant to water pollution and belonging to the functional feeding groups of collectors-gatherers. Inversely, forest streams are more diversified and dominated by sensitive taxa, most belonging to the functional feeding groups of predators and shredders. These marked differences between biological indices and feeding mode of benthic macroinvertebrates in forest and urban rivers confirm the reliability of benthic macroinvertebrates as good indicators of freshwater ecosystem in the coastal zone of Cameroon.

Keywords

Urban and Forest Streams, Benthic Macroinvertebrates, Water Pollution, Biological Indices, Functional Feeding Groups

1. Introduction

Assessment of the impacts of urbanization on rivers and streams involves the research and use of a wide range of physical, chemical, and biological indicators [1]. However, [2] recommend the use of biological communities at the expense of physicochemical variables which provide a punctual approximation of the quality of the environment. The benthic macroinvertebrates are metazoans that are widely represented in rivers and streams and constitute a good tool for this diagnosis [3]. Their preference for biological monitoring of rivers is justified for the following characteristics [2]: 1) they occupy a wide range of trophic levels and pollution tolerance, providing solid information for the interpretation of cumulative effects due to exposure to pollutants; 2) their sedentary life style make it possible to reflect the local conditions of the environment, and to give a significant image of the quality of the habitat over time.

In Cameroon, the use of benthic macroinvertebrates as bioindicators of the health status of rivers has expanded considerably in the last 15 years. However, most of the works on this group of organisms has been conducted in urban and forest streams in the South-Central Forest Ecological region with bimodal rainfall [4] [5] [6]. The data available for the coastal eco-zone with unimodal rainfall relate to only a few urban and peri-urban rivers in the industrial-port city of Douala [7] [8] [9]. To date and to our knowledge, no study has been conducted on the ecology of benthic macroinvertebrates of coastal forest streams in the unimodal rainfall ecological region. However, in order to understand the functioning of a biological system, it must be understood and interpreted according to its particular ecological situation and implicitly implies a reference model adapted to the ecological region considered [10].

The main objective of this study is to assess the impact of urban pollution during the rainy season on the diversity of benthic macroinvertebrates communities of two streams of the industrial-port city of Douala, as compared to the referential status of two other streams chosen in a natural forested river basin at Yabassi. The specific objectives of this study are: 1) to evaluate the physico-chemical quality of the waters of the forest and urban streams; 2) to determine the variation in the structure of benthic macroinvertebrates communities of naturally vegetated watersheds and urban watersheds using the biological indices and functional feeding groups; 3) to determine the main physicochemical variables that influence the distribution and the dynamic of benthic macroinvertebrates in the studied streams.

2. Materials and Methods

2.1. Study Area and Sampling Stations

The present study was conducted in the littoral region of Cameroon, which is subject to a unimodal equatorial climate of Guinean type and Cameroonian coastal sub-type, characterized by two seasons: a long rainy season of 9 months (March–November) and a short dry season of 3 months (December to February) [11]. Rainfalls are abundant and regular (2596–5328 mm). The air temperature is relatively high with a monthly average of 28°C. The streams chosen for study are situated in the localities of Douala and Yabassi. **Table 1** presents the characteristics of sampling stations.

The locality of Yabassi extends on a surface area of approximately 3080 km² located between 4°27' and 4°40' of latitude North and between 9°57' and 10°10' of longitude East. It has a population of about 14,685, representing a density of 4.77 inhabitants per km². Watersheds are covered more than 85% by a dense evergreen forest composed of big trees with an important canopy. In Yabassi, two streams namely Makono and Ndimia were chosen for the study (**Figure 1(a)**). Three sampling stations coded Mak1, Mak2 and Mak3 were positioned respectively in the upper, middle and lower sections of the Makono stream. In the Ndimia stream, three sampling stations were also chosen (Ndi1, Ndi2 and Ndi3) and located respectively in the upper, middle and lower sections of the stream (**Figure 1(a)**).

The city of Douala lies between 3°58' and 4°7' of latitude North and between 9°34' and 9°49' of longitude East. It covers a surface area of approximately 923 km² for an estimated population of about 2.8 million inhabitants, with a density of 3033.59 inhabitants per km². For this study, two streams were selected (Mboppi and Simbi) (**Figure 1(b)**). The Mboppi river basin is characterized by

Table 1. Characteristics of the study sites.

Stream	Sampling station	Latitude N	Longitude E	Altitude (m)	Stream width (m)	Stream depth (cm)	Current velocity (m/s)	Dominant Substrate
Makono	Mak1	04°25'32.43"	10°0'19.37"	69	1.50	20.20	0.52	Sand, gravel
	Mak2	04°25'3.36"	09°59'0.74"	38	2	75.30	0.38	Mud, Sand
	Mak3	04°25'35.27"	09°57'32.50"	24	2.50	45.80	0.24	Sand, gravel
Ndimia	Ndi1	04°27'9.20"	10°0'42.85"	70	1.80	8.70	0.61	Sand, gravel
	Ndi2	04°26'32.31"	09°59'20.43"	36	4.20	25.10	0.39	Sand, gravel
	Ndi3	04°26'8.97"	09°58'03.76"	34	7.40	30.50	0.21	Sand
Mboppi	M1	04°02'70"	09°42'23.17"	11	1.60	23	0.28	Sand
	M2	04°03'0.71"	09°42'28.53"	6	2.80	50.60	0.14	Mud
	M3	04°03'39.72"	09°42'17.67"	2	3.60	30.40	0.15	Mud
Simbi	S1	04°02'6.97"	09°44'38.16"	16	1.90	24.70	0.30	Sand
	S2	04°01'48.48"	09°44'20.10"	14	2.80	36.30	0.17	Mud, sand
	S3	04°01'5.02"	09°44'14.28"	7	4.10	20.70	0.15	Mud, Sand

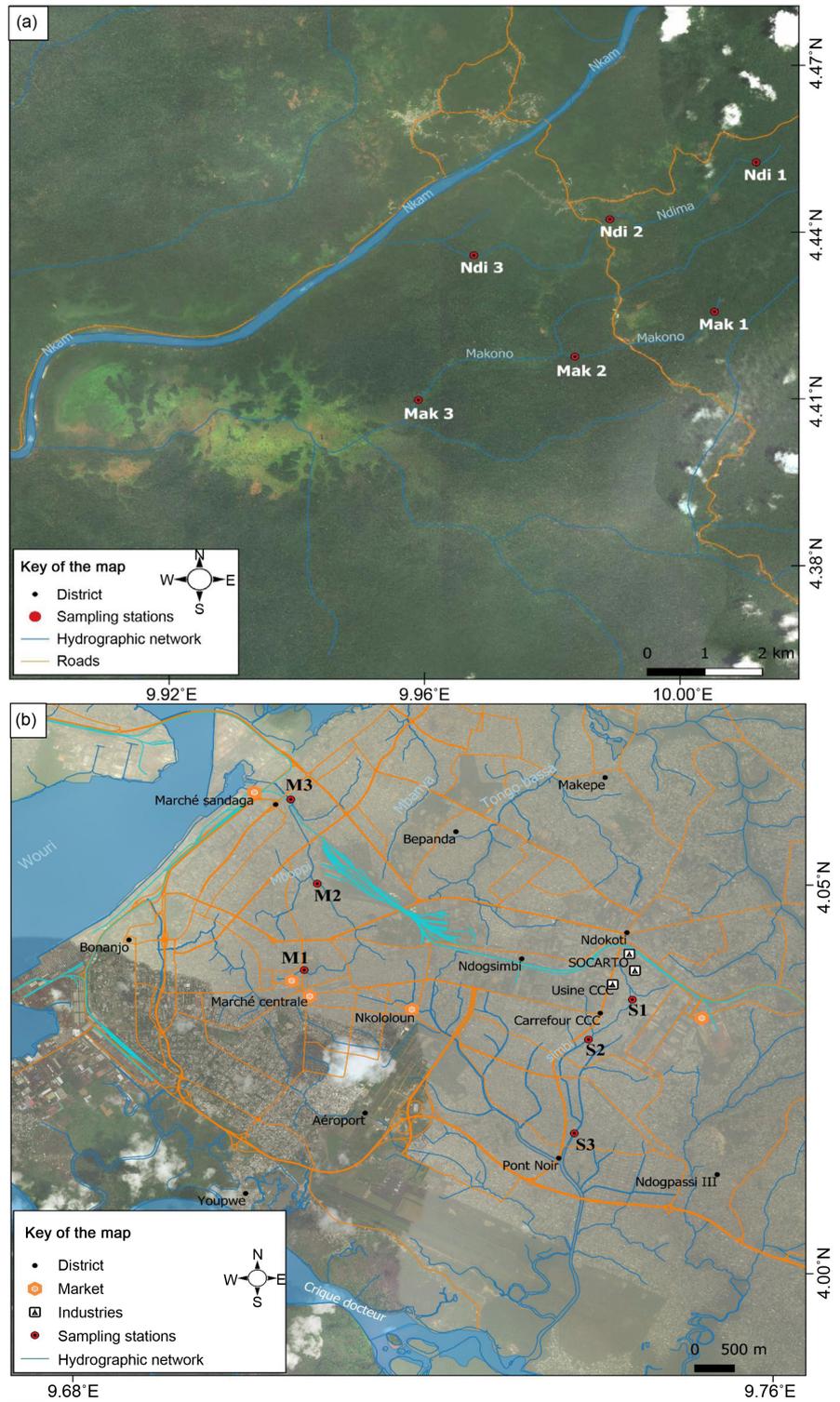


Figure 1. Hydrographic map of the study area showing sampling stations. Yabassi (a); Douala (b).

the presence of the biggest markets of the city of Douala (Congo market, Mboppi market, Nkololoun market, Central market, Sandaga market). Three sampling stations were positioned on the Mboppi stream: M1, M2 and M3 located respec-

tively in the upper, middle and lower sections of the stream (**Figure 1(b)**). The Simbi watershed is characterized by the presence of some industries whose effluent flows into the Simbi stream: Cameroon Chemical Complex (CCC), paper making industry (SOCARTO) and industries specialized in the Modeling of Synthetic Organic Products (SCIMPOS). Three sampling stations were positioned on the Simbi stream. Station S1 is located in the upstream, S2 is situated in the middle section of the stream and S3 positioned downstream.

2.2. Physicochemical Analyzes

The measurements of the physicochemical parameters at each of the twelve sampling stations were done monthly, between 7 and 10 am, from May to July 2017. These measurements were conducted in accordance with standard methods described by [12]. Thus, a total of 36 measurements were carried out for each parameter (18 measurements in the 6 stations of the forest streams and 18 others in the 6 stations of the urban streams). Water temperature (T), pH, electrical conductivity (EC), and dissolved oxygen concentration (DO) were measured *in situ* using a portable multi-parameter HANNA HI 9829. For the parameters intended to be measured in the laboratory, samples of water were collected at each sampling point using pre-clean double-capped polyethylene bottle of 500 ml, and preserved in refrigerated conditions. Turbidity (Turb), water color (Col), Suspended Solids (SS), Orthophosphate (PO_4^{3-}), Ammonium (NH_4^+) and Nitrites (NO_2^-) were measured using a HACH DR/3900 spectrophotometer. To assess the organic pollution level, the Organic Pollution Index (OPI) was calculated according to the methodology described by [13] which is based on three ion concentrations (NH_4^+ , NO_2^- and PO_4^{3-}). For each parameter, 5 classes of contents having an ecological significance are defined (**Table 2**). The OPI corresponds to the arithmetic mean value of the class number of each parameter and the values obtained are apportioned into 5 levels of pollution (**Table 3**).

Table 2. Boundary of the Organic Pollution Index (OPI) classes.

Classes	Parameters		
	NH_4^+ (mg-N/l)	NO_2^- ($\mu\text{g-N/l}$)	PO_4^{3-} ($\mu\text{g-N/l}$)
5	<0.10	5	15
4	0.10 - 0.90	6 - 10	16 - 75
3	1 - 2.40	11 - 50	76 - 250
2	2.50 - 6	51 - 150	251 - 900
1	>6	>150	>900

Table 3. Classification of the pollution level according to the class values of the OPI.

OPI Class	1.00 - 1.90	2.00 - 2.90	3.00 - 3.90	4.00 - 4.50	4.60 - 5.00
Organic pollution level	Very high	High	Moderate	Low	Null

2.3. Sampling and Identification of Benthic Macroinvertebrates

Benthic macroinvertebrates samples were collected at each station using a long-handled kick net (30 cm × 30 cm side, 400- μ m mesh size and 45 cm of depth). All the available habitats within the study station including leaf packs, branches, macrophyte beds, sand, mud and rafts were sampled. Samplings were done in a 100-m stretch for each station, following protocols described by [14]. At each sampling station, 20 drags of the kick net were done in different micro-habitats, each corresponding to a surface area of 0.3 m² (30 cm × 100 cm), for a total sampled surface area of 6 m² per station. Each time, the benthic macroinvertebrates retained by the meshes of the net were sorted and collected using a pair of fine forceps, and then introduced into plastic bottles containing 70% alcohol. In the laboratory, all of the benthic macroinvertebrates at each sampling station were identified to the family taxonomic level and counted, using a Wild M5 stereomicroscope and appropriate taxonomic identification keys proposed by [15] [16] [17]. Recent research indicates that extensive identification up to the family provides a sufficient level of taxonomic resolution to detect responses of the communities studied to anthropogenic disturbances [18].

2.4. Benthic Macroinvertebrates Metrics and Indices

The diversity index of Shannon and Weaver (*H'*) and the Pielou's evenness index (*J*) were calculated from the taxonomic richness (*S*) and abundance (*TA*) of macroinvertebrates. These indices informed on the distribution of individuals within the taxa so as to compare the diversity of the communities of the different sampling stations [19]. The assumption is that undisturbed environments are characterized by high diversity or richness and an even distribution of individuals among the Taxa [20].

Seven benthic macroinvertebrate's metrics were calculated to analyze the community structure: taxonomic richness of the groups Ephemeroptera-Plecoptera-Trichoptera (*S-EPT*), Plecoptera-Odonata Ephemeroptera-Trichoptera (*S-POET*), relative abundance of the group EPT (%-EPT), relative abundance of Insecta (%-Ins), relative abundance of Diptera (%-Dip), relative abundance of Insecta Non Diptera (%-Ins-N-Dip), and relative abundance of Oligochaeta (%-Oligo). Significant changes in the value of these metrics can indicate environmental disturbances, including freshwater pollution and habitat degradation [18].

The adaptation of benthic macroinvertebrates to organic pollution was assessed through six metrics: relative abundance of taxa tolerant to pollution (%-To; tolerance score > 6), relative abundance of taxa sensitive to pollution (%-Into; tolerance score < 4), relative abundance of dominant taxon (%-Dom), Hilsenhoff index (FBI), Biological Monitoring Working Party (BMWP) and Average Score Per Taxon (ASPT). Indeed, the sensitivity and tolerance of indicator assemblages to a number of environmental characteristics, such as organic pollution, heavy metals, pesticides and eutrophication are known to differ among

taxa [21]. The tolerance score assigned to each organism in this study was taken from [22] [23].

Lastly, we assigned each taxon to one of the five functional feeding groups (FFGs): shredders (shr), scrapers (scr), collectors-gatherers (c-g), collectors-filterers (c-f) and predators (prd); based on the food habit descriptions in literature [16]-[24]. In fact, functional approach which the goal is to characterize ecosystem condition uses FFGs to describe ecosystem attributes in streams [24].

2.5. Statistical Analyses

A Principal Component Analysis (PCA) was performed on the physicochemical data set made up of 10 variables measured on the 36 water samples collected during the study. This PCA permitted us to identify firstly homogeneous groups having great physicochemical characteristic similarities, and secondly, characterizing each group according to the physicochemical variables measured. The purpose of this test was to discriminate samples from forest and urban sites according to pollution gradient. The normality test of Shapiro Wilk was carried out before comparing the biotic and abiotic parameters of forests and urban streams. In addition, the Man Whitney U-test was performed to search for significant differences between the physicochemical variables measured at forest and urban sites, and also between the benthic macroinvertebrates metrics values of these two groups of samples. Relationships between physicochemical variables and metrics obtained from benthic macroinvertebrates were determined using Spearman's correlation test and PCA. All the statistical analyses were compiled using the XLSTAT 2007 software.

3. Results

3.1. Physicochemical Quality of Water

Except for orthophosphates, the values of pH, temperature, electrical conductivity, color, Suspended Solids, turbidity, ammonia and nitrite were significantly lower ($P < 0.01$) at the forest stations compared those recorded in the urban stations. Inversely, the highest values of dissolved oxygen were recorded at the forest stations, while the urban stations showed very high oxygen content (**Table 4**). Moreover, the organic pollution level of the water was moderate at the forest sites ($OPI = 3.41 \pm 0.54$) whereas in the urban area it was high ($OPI = 2.11 \pm 0.58$) (**Table 4**).

The PCA carried out with the physicochemical parameters data set shows that the first two axes F1 (58.36%) and F2 (18.21%) accounted for 76.57% of the total variance (**Figure 2**). The distribution of the 36 water samples on factorial plane of the PCA allowed to discriminate the sampling sites into two groups (**Figure 2(b)**): Group A, consisting of all the samples collected from the Makono and Ndima streams which are located in a forested zone (Yabassi) and which are characterized by good oxygenation of water and low concentrations of organic matter (high OPI) (**Figure 2(a)**). Group B, regrouping the samples collected

Table 4. Mean and standard deviation (SD) values of the physicochemical variables at each sampling station of forest and urban streams.

Parameters	Forest streams							Urban streams						
	Mak1 (n = 3)	Mak2 (n = 3)	Mak3 (n = 3)	Ndi1 (n = 3)	Ndi2 (n = 3)	Ndi3 (n = 3)	Means ± SD (n = 18)	M1 (n = 3)	M2 (n = 3)	M3 (n = 3)	S1 (n = 3)	S2 (n = 3)	S3 (n = 3)	Means ± SD (n = 18)
T (°C)	21.27 ± 1.10	19.17 ± 0.76	18.33 ± 0.58	20 ± 10	20.43 ± 0.51	19.73 ± 1.57	19.82 ± 1.26^a	26.33 ± 1.76	26.43 ± 1.29	26.57 ± 1.40	26 ± 1.00	26.27 ± 1.61	26.17 ± 2.02	26.29 ± 1.32^b
pH	5.85 ± 0.14	6.68 ± 0.03	6.83 ± 0.02	6.91 ± 0.45	7.06 ± 0.59	7.21 ± 0.36	6.76 ± 0.53^a	7.25 ± 0.12	7.18 ± 0.14	7.21 ± 0.16	6.93 ± 0.10	7.79 ± 1.49	7.03 ± 0.27	7.23 ± 0.60^b
DO (%)	37.03 ± 4.57	41.50 ± 9.56	38.70 ± 5.66	64.97 ± 1.25	63.73 ± 2.24	62.53 ± 2.41	51.41 ± 13.48^a	26.03 ± 5.35	30.4 ± 1.65	32.5 ± 0.17	29.07 ± 2.34	29.73 ± 4.47	28.07 ± 10.47	29.30 ± 4.88^b
EC (µS/cm)	35.33 ± 2.31	36.67 ± 2.52	34.67 ± 4.16	21.30 ± 5.89	23.07 ± 1.27	24.27 ± 2.68	29.22 ± 7.23^a	799.67 ± 770.70	701.67 ± 620.77	732.9 ± 695.96	383.43 ± 387.62	2345.67 ± 3693.20	1172.13 ± 1502.17	1022.58 ± 1577.46^b
Col (Pt.Co)	8.67 ± 3.51	27 ± 6.56	33.33 ± 12.50	15 ± 5.00	31.67 ± 30.55	26 ± 20.07	23.61 ± 16.39^a	610.67 ± 205.18	549.33 ± 153.66	366 ± 129.98	129.67 ± 30.09	794.67 ± 791.62	555 ± 428.77	500.89 ± 388.64^b
SS (mg/l)	0.33 ± 0.58	2.33 ± 3.21	6 ± 50.29	2.67 ± 2.08	14 ± 9.16	9 ± 7.21	5.72 ± 6.62^a	99 ± 19.16	80.67 ± 28.38	55.33 ± 38.73	13 ± 4.58	77.67 ± 71.51	80 ± 53.03	67.61 ± 45.29^b
Turb (NTU)	8.25 ± 3.38	9.86 ± 16.84	11.73 ± 20.32	1.33 ± 1.15	1.33 ± 1.15	2.33 ± 1.53	5.81 ± 10.16^a	82 ± 26.91	101 ± 20.07	61 ± 25.36	24.33 ± 9.07	138.33 ± 147.01	90.33 ± 90.17	82.83 ± 70.83^b
NH ₄ ⁺ (mg/l)	0.53 ± 0.58	0.75 ± 0.82	0.9 ± 0.69	0.07 ± 0.01	0.13 ± 0.14	0.56 ± 0.32	0.49 ± 0.54^a	5.85 ± 4.33	11.51 ± 9.25	6.42 ± 5.45	1.65 ± 1.45	1.96 ± 1.29	3.43 ± 2.38	5.14 ± 5.37^b
NO ₂ ⁻ (mg/l)	0.01 ± 0.001	0.003 ± 0.003	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.02	0.04 ± 0.03	0.01 ± 0.02^a	0.06 ± 0.02	0.04 ± 0.00	0.03 ± 0.01	0.32 ± 0.33	0.65 ± 1.07	0.07 ± 0.04	0.20 ± 0.45^b
PO ₄ ³⁻ (mg/l)	0.70 ± 0.81	0.57 ± 0.82	0.32 ± 0.28	1.16 ± 0.93	1.17 ± 0.60	0.82 ± 0.66	0.79 ± 0.68^a	2.50 ± 1.13	3.50 ± 2.12	1.08 ± 0.95	0.82 ± 0.59	0.69 ± 1.01	1.30 ± 0.78	1.65 ± 1.45^a
IPO	3.22 ± 0.77	3.78 ± 0.51	3.67 ± 0.34	3.56 ± 0.20	3.22 ± 0.19	3 ± 0.88	3.41 ± 0.54^a	1.56 ± 0.19	1.78 ± 0.19	2.33 ± 0.58	2.11 ± 0.69	2.78 ± 0.69	2.11 ± 0.38	2.11 ± 0.58^b

Mann Whitney tests were used to evaluate differences among the two groups of streams (forest streams and urban streams). The values followed by the superscript (a, b) for a given physicochemical parameter indicate that this parameter is significantly different between forest and urban streams (P < 0.01).

from the Simbi and Mboppi streams, located in Douala. These urban sampling sites have very poor water quality with higher values of water color, turbid, ions content, and important organic matter load.

3.2. Benthic Macroinvertebrates Communities' Structure

Considering spatial distribution of the taxonomic richness, 36 families divided into 4 classes (Crustacea Gastropoda, Insecta, Oligochaeta) and 12 orders were collected in the forest sites, while in the urban area, only 16 families belonging to 4 classes (Achaeta, Oligochaeta, Gastropoda, Insecta) and 7 orders were identified. In the forest streams, the most represented orders are Ephemeroptera and Odonata, with 6 families each. They are followed by the Hemiptera and Coleoptera with 5 families each. Moreover, Plecoptera of the family Perlidae and Trichoptera of the family Hydropsychidae are present in the two forest streams. In urban streams, Ephemeroptera, Plecoptera, Trichoptera and Odonata are absent

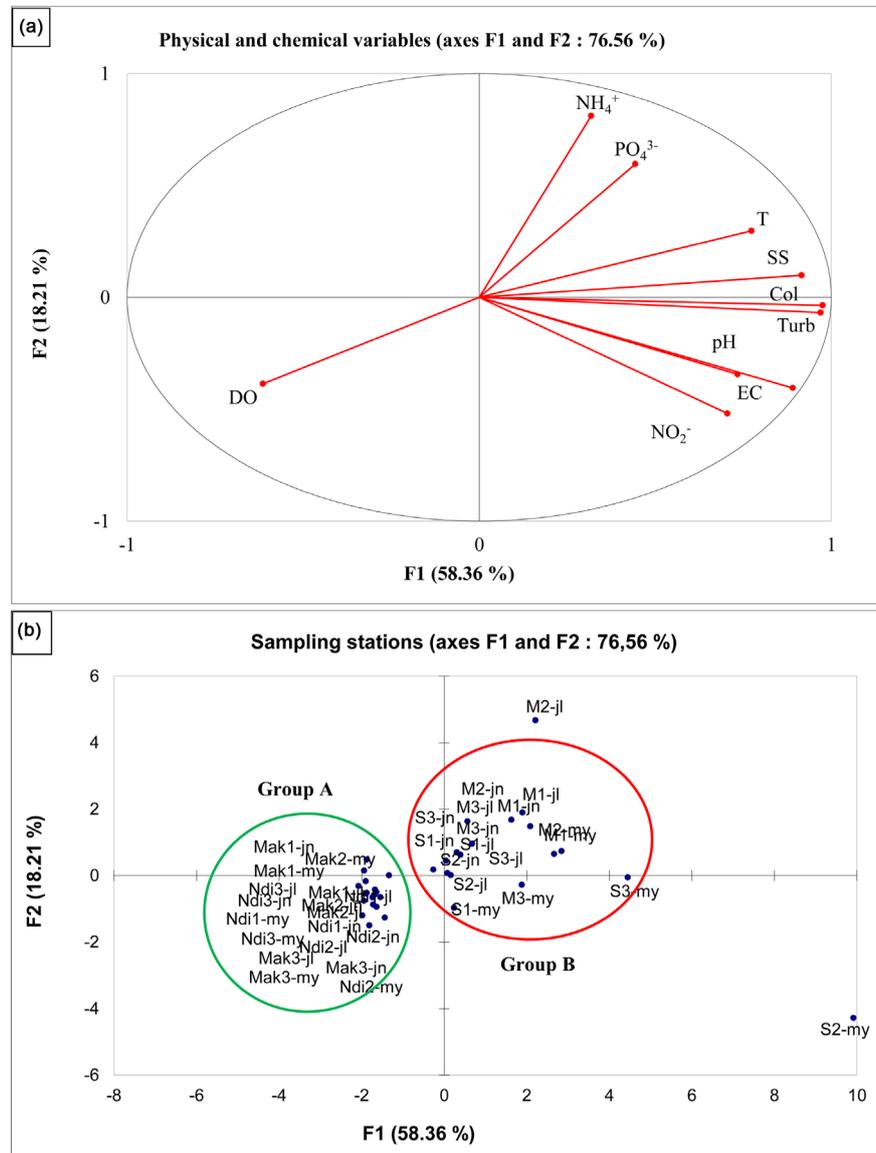


Figure 2. Projections of the physicochemical variables of water samples collected on the plane of the first two axes of the PCA. Correlation circle (a) and grouping of stations into two classes based on their physicochemical characteristics (b); where my, jn et jl represent respectively sampling months May, June and July.

while Diptera, Haplotoxida and Basommatophora are the most represented orders with 5, 4 and 4 families respectively. Similarly, Decapoda crustaceans are absent in urban streams while in forest streams, they were present and represented by 4 families. In addition, the average number of family (S), the S-EPT and S-POET metric values were significantly higher ($P < 0.01$) in forest stream than those recorded in urban stations (Table 5).

As regards the abundances, the Mboppi and Simbi urban streams despite their low taxonomic richness (16 families), have the highest abundance with 750 individuals. This could be due to the proliferation of pollution-resistant taxa such as Physidae (48.80%), Lymnaeidae (20.53%) and Chironomidae (13.20%), which

Table 5. Values of the metrics used to describe the benthic macroinvertebrates communities' structure and to measure the pollution tolerance.

Metrics	Forest rivers							Urban rivers						
	Mak1	Mak2	Mak3	Ndi1	Ndi2	Ndi3	Means ± SD (n = 6)	M1	M2	M3	S1	S2	S3	Means ± SD (n = 6)
Community structure Index														
S	16	13	9	15	16	17	14.33 ± 2.94^a	7	10	6	8	7	11	8.17 ± 1.94^b
TA	125	139	104	73	83	101	104.16 ± 724.81^a	62	252	23	255	86	72	125 ± 101.72^a
S-EPT	1	4	2	1	4	1	2.17 ± 1.47^a	0	0	0	0	0	0	0^b
S-POET	5	5	3	5	7	6	5.17 ± 1.33^a	0	0	0	0	0	0	0^b
H'	2.43	2.63	2.23	3.28	3.20	3.31	2.85 ± 0.47^a	2.43	1.55	2.02	1.548	1.71	3.14	2.07 ± 0.62^b
J	0.61	0.71	0.71	0.84	0.80	0.81	0.75 ± 0.08^a	0.86	0.47	0.78	0.52	0.61	0.91	0.69 ± 0.19^a
%-EPT	0.80	36.69	4.81	1.37	14.46	3.96	10.35 ± 13.81^a	0.00	0.00	0.00	0.00	0.00	0.00	0.00^b
%-Ins	21.60	46.04	22.12	54.79	45.78	58.42	41.46 ± 15.96^a	43.55	2.78	17.39	37.65	13.95	29.17	24.08 ± 15.43^a
%-Ins-N-Dip	20.80	45.32	22.12	54.79	45.78	58.42	41.21 ± 16.12^a	0.00	0.39	0.00	1.57	4.65	5.56	2.03 ± 2.48^b
%-Dip	0.80	0.72	0.00	0.00	0.00	0.00	0.25 ± 0.39^a	43.55	2.38	17.39	36.08	9.30	23.61	22.05 ± 15.70^b
%-Oligo	0.80	0.72	0.00	0.00	0.00	0.00	0.25 ± 0.39^a	6.45	4.37	4.35	3.92	2.33	34.72	9.36 ± 12.50^b
Pollution tolerance Index														
%-To	1.60	0.00	3.85	27.40	24.10	13.86	11.80 ± 11.87^a	66.13	57.1	65.22	92.94	68.6	52.78	67.14 ± 13.99^b
%-Into	6.40	34.53	6.73	1.37	24.10	10.89	14.00 ± 12.68^a	0.00	0.00	0.00	0.00	0.00	0.00	0.00^b
%-Dom	55.20	30.20	50.00	26.03	34.94	29.70	37.68 ± 12.01^a	25.81	54.4	43.48	55.29	55.81	20.83	42.60 ± 15.69^a
FBI	5.59	4.22	5.54	6.44	5.51	5.28	5.43 ± 0.71^a	8.10	7.13	7.61	7.82	7.35	7.24	7.54 ± 0.37^b
FMWP	77.00	57.00	44.00	81.00	74.00	92.00	70.83 ± 17.38^a	54.00	68.00	47.00	54.00	54.00	80.00	59.52 ± 12.16^a
ASPT	4.81	4.38	4.89	5.40	4.63	5.41	4.92 ± 0.42^a	7.71	6.80	7.83	6.75	7.71	7.27	7.35 ± 0.48^b

Mann Whitney tests were used to evaluate differences among the two groups of streams (forest streams and urban streams). The values followed by the superscript (a, b) for a given metric indicate that this metric is significantly different between forest and urban streams ($P < 0.01$).

account for 82.53% of the total abundance in urban streams. In the forest streams, a total abundance of 625 individuals was registered. The Desmocaridae (17.12%), Thiaridae (15.36%), Lymnaeidae (10.24%) and Atyidae (10.24%) are the most represented benthic macroinvertebrate families in forest streams. Also, pollution-sensitive taxa are significantly represented with Perlidae (8.64%), Gyrinidae (7.68%), and Gomphidae (2.72%). In addition, Statistical analyses revealed that, metric values such as %-EPT and %-Ins-N-Dip, were significantly higher ($P < 0.01$) in forested streams than in urban streams (Table 5). Inversely, the %-Dip and %-Oligo indices showed significantly lower values ($P < 0.01$) in forested streams as compared to urban streams.

The Shannon and Weaver diversity index (H') revealed a significantly higher diversity ($P < 0.05$) in forested streams (2.85 ± 0.47 bits/ind.), whereas in urban streams subjected to anthropogenic disturbances, lowest values of diversity in-

dex were noted (2.07 ± 0.62 bits/ind) (Table 5). Although indicating, a better distribution of individuals within different taxa in forest (0.75 ± 0.08) and urban (0.69 ± 0.19) stations, the Pielou evenness index (J) did not vary significantly ($P > 0.05$) (Table 5). The %-Into and FMWP indices measuring sensitivity of taxa to pollution were higher in forest streams than in urban ones. For %-To and FBI, the values recorded in urban streams are significantly high ($P < 0.05$) than those registered in forested sites (Table 5). In addition, the FBI revealed that forest streams waters are of medium quality with fairly substantial organic pollution ($FBI = 5.43 \pm 0.71$) whereas waters from urban streams are of very poor quality with severe organic pollution ($FBI = 7.54 \pm 0.37$).

Regarding FFGs, in the forest streams, predators and shredders are the most represented with 38.04% and 30.02% of relative abundances respectively (Figure 3). The collectors-gatherers and the scrapers represent 16.18% and 15.40% of the total abundance respectively. The collectors-filterers are very poorly represented with 0.36% of individuals. In urban streams, macroinvertebrates are dominated by collectors-gatherers, which constitute 82.15% of the population. However, we also find collectors-filterers, predators and shredders which respectively account for 12.85%, 4.80% and 0.20% of macroinvertebrates.

3.3. Relationship between Benthic Macroinvertebrates Metrics and Physicochemical Water Quality

The PCA based on the physicochemical variables and the benthic macroinvertebrates metrics showed that the first two axes (F1, F2) account for 67.60% of the total variance (Figure 4). The distribution of the observations according to the factorial plane 1 - 2 discriminates two groups. The group I is consisted of physicochemical parameters such as nitrites, ammonium, orthophosphates, color, SS, turbidity, pH and temperature, which are positively and significantly correlated to %-Dip, %-Oligo, %-To, FBI and ASPT. It may be thought that benthic

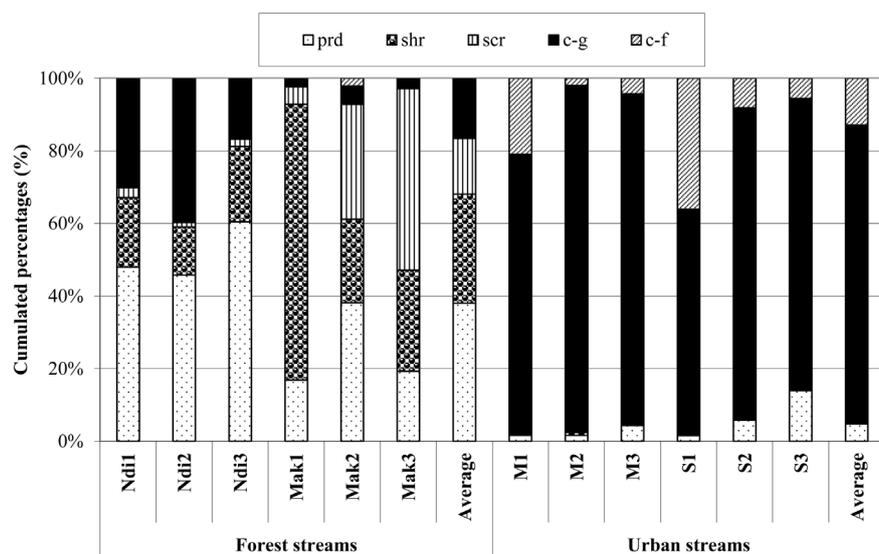


Figure 3. Functional feeding groups identified during study period.

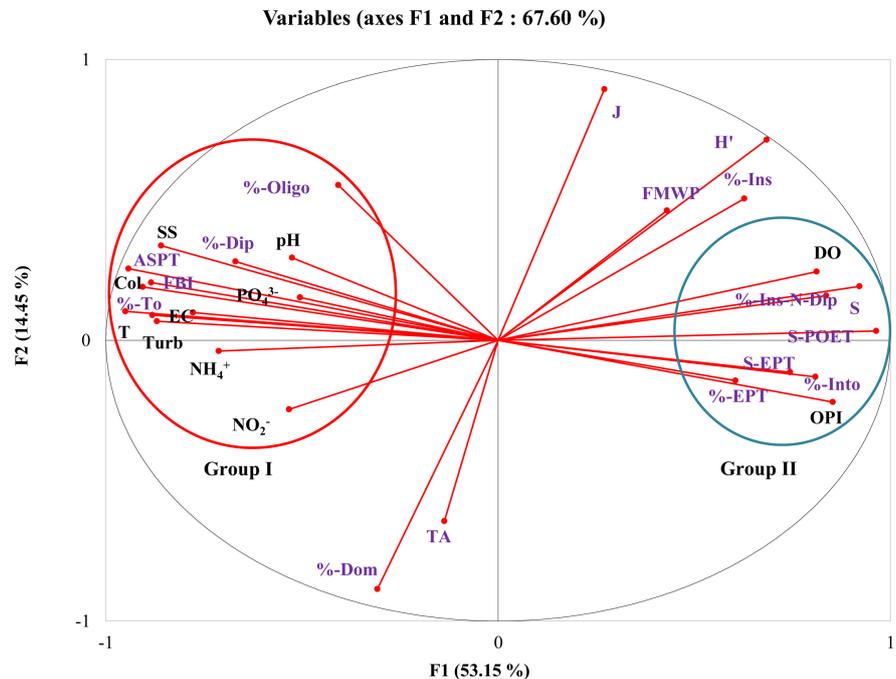


Figure 4. Correlations circle between physicochemical variables and benthic macroinvertebrates metrics from the first two axes (axis 1 horizontal and axis 2 vertical) of the PCA.

macroinvertebrates individuals belonging to the orders of Diptera, Oligochaeta and all other individuals belonging to pollution-tolerant families (tolerance score > 6) proliferate in very turbid waters, with high temperature and heavy organic matter load, characteristics of urban streams located in Douala. This is confirmed by the positive and significant correlations between metrics such as %-Dip, %-Oligo, %-To, FBI and ASPT and environmental variables such as temperature, electrical conductivity, color, turbidity, SS, nitrites, ammonium and orthophosphates (Table 6). Inversely, the group II, gathered metrics such as %-Ins-N-Dip, %-Into, %-EPT, S, S-EPT and S-POET which are positively and significantly correlated with dissolved oxygen and OPI (Figure 4), indicating low organic matter load in the forest streams of Yabassi. Similarly, the Spearman correlation matrix revealed that the installation and the proliferation of non-Dipterans insects, EPT, POET and all other sensitive individuals (tolerance score < 4) are favored in well oxygenated water with low organic matter concentration (Table 6).

4. Discussion

Analysis of environmental variables revealed different water quality profiles for forest and urban sites. In the city of Douala, the combined action of domestic, urban and industrial solid wastes and wastewaters discharged into the streams studied (Mboppi and Simbi) is at the origin of water quality degradation. These wastes mainly come from industries (CCC, SOCARTO, SCIMPOS), unstructured shopping centers (Congo market, Central market, Nkololoun market,

Table 6. Spearman's correlation coefficient between the physicochemical variables and the benthic macro-invertebrates metrics.

Variables	Metrics												
	S	S-EPT	S-POET	H'	%-EPT	%-Ins	%-Ins-N-Dip	%-Dip	%-Oligo	%-To	%-Into	FBI	ASPT
T	-0.62*	-0.85**	-0.75**	NS	-0.88**	-0.63*	-0.86**	0.75**	0.82**	0.74**	-0.85**	0.79**	0.82**
pH	NS	-0.59*	NS	NS	NS	NS	NS	NS	NS	0.69*	NS	NS	0.78**
DO	0.67*	0.82**	0.88**	0.62	0.83**	NS	0.83**	-0.94**	-0.90**	-0.66*	0.80**	-0.80**	-0.69*
EC	-0.72*	-0.78**	-0.86**	NS	-0.77**	-0.61*	-0.79**	0.84**	0.86**	0.60*	-0.75**	0.67*	0.76**
Col	-0.78**	-0.72*	-0.82**	NS	-0.7*	NS	-0.73**	0.70*	0.73**	0.74**	-0.74**	0.69*	0.77**
SS	NS	-0.72*	-0.67*	NS	-0.7*	NS	-0.66*	0.62*	0.72*	0.72*	-0.70*	0.65*	0.77**
Turb	-0.73**	-0.79**	-0.90**	-0.7	-0.78**	-0.74**	-0.78**	0.73**	0.81**	0.61*	-0.78**	0.64*	0.74**
NH ₄ ⁺	-0.76**	-0.77**	-0.88**	-0.67	-0.75**	-0.65*	-0.87**	0.73**	0.84**	0.58*	-0.75**	0.64*	0.78**
NO ₂ ⁻	NS	-0.81**	-0.73**	NS	-0.77**	NS	NS	0.65*	0.58*	0.85**	-0.77**	0.70*	0.76**
PO ₄ ³⁻	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
OPI	0.48*	0.86**	0.71*	NS	0.86**	NS	0.74**	-0.79**	-0.82**	-0.79**	0.82**	-0.78**	-0.78**

Significant correlation (*: $P < 0.05$; **: $P < 0.01$); NS: non-significant correlation.

Mboppi market, Sandaga market), households and traditional toilets of the spontaneous habitats. The resulting aerobic degradation of organic matter is responsible of the hypoxic condition of these waters [25]. As regards forest streams, they showed a better water quality due to the presence of riparian vegetation. In fact, the important riparian forest limits the exposure of the streams to solar rays, which considerably reduces the temperature of the water. It also reduces soils erosion and indirectly the amount of nutrients and organic matter loaded in the streams [26]. The values of parameters indicating organic matter load (nitrites, ammonium and phosphates) are lower in forest streams; however, these parameters revealed through the OPI, a moderate organic pollution of water. [27] has attributed such a situation in the forest zone, principally due to the degradation of the litter coming from the riparian vegetation.

Concerning forest streams of Yabassi, there was a numerical preponderance and taxonomic richness of sensitive taxa which includes Decapoda (Atiyidae, Desmocarididae) and non-Dipterans Insects (Leptophlebiidae, Baetidae, Potamanthidae, Ephemerellidae, Perlidae, Hydropsychidae, Veliidae, Gomphidae, Gyrinidae, Noteidae, Hydrophilidae, Chrysomelidae). Their preponderance would be related to the good oxygenation of the forest streams. The positive and significant correlations between S-EPT, S-POET, %-EPT, %-POET, %-Ins-N-Dip and the high concentrations of dissolved oxygen in forest streams confirm this observation. This numerical and taxonomic preponderance of Decapoda and non-Dipterans Insects found in the forest streams as compared to their low richness and abundance in the urban streams could reveal a state of advanced degradation of the Mboppi and Simbi stations. [28] showed that taxonomic richness particularly that of aquatic insects can be a good indicator of the influence of anthropogenic disturbances on rivers. Indeed, [16] indicate that aquatic

insects are highly sensitive to pollution and/or habitat modification, resulting in their disappearance in a disturbed environment. Moreover, the virtual absence of EPT orders in urban stations confirms their great degradation.

In a study conducted in the United States, [29] indicate that EPT taxa are among the most sensitive benthic macroinvertebrates and therefore their species richness decreases drastically with the urbanization of watersheds. Our results are in line with those of [30] who showed that a decrease in the number of EPT taxonomic richness in human impacted streams is clearly related to changes in water quality and habitat suitability. For freshwater Decapoda, it is recognized that these organisms proliferate in well-oxygenated waters [16] [31]. In addition, the great prominence of the Decapoda order would also be related to their belonging to the functional feeding groups of shredders and to the presence of large amounts of litter in forest streams. They find an important part of their food resources in the litter. [32] showed that macroinvertebrates associated with litter in Guinea's rivers were largely dominated by shredder Decapoda.

The proliferation of Physidae, Lymnaeidae and Chironomidae in the urban streams of the city of Douala is explained by the fact that these waters systems are subjected to heavy organic matter load. To live in such disturbed environments, these organisms have developed special adaptations. Indeed, [33] showed that Physidae and Lymnaeidae have a rudimentary lung through which they breathe atmospheric air and thus can live in hypoxic aquatic environments. Moreover, their rapid maturation and their ability to self-fertilize in difficult conditions are also at the origin of their important development [34]. As for Chironomidae, studies by [35] [36] have shown that these organisms have adapted to hypoxic media with the hemoglobin in their hemolymph which allows them to store oxygen in the cuticle when it is abundant in the medium and to release it when its concentration becomes low. Furthermore, Chironomidae have what appears to be finger-like "gills" at the posterior ends of their bodies, which are actually involved in osmoregulation and permitted them to live in polluted waters with high ionic concentrations [8]. In addition, the high abundance of Physidae, Lymnaeidae and Chironomidae is related to their feeding mode; indeed, they are collectors-gatherers and proliferate in turbid aquatic milieu with important decaying organic matters load [24]. This is primarily due to various anthropogenic pollution sources found in the rivers basins of Douala township.

5. Conclusion

In this study, the set of benthic macroinvertebrates metrics and FFGs used to describe the health status of the watersheds reveals very poor water quality and poor diversity of benthic macroinvertebrates in urban streams. On the other hand, these metrics and FFGs have highlighted better water quality and high biodiversity in Yabassi forest streams. The benthic macroinvertebrates communities encountered in the studied streams showed different sensitivities to en-

vironmental conditions, confirming the reliability of benthic macroinvertebrates in assessing disturbances in streams of the coastal ecological region of Cameroon.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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