

Research Article

Distribution of Benthic Macroinvertebrates in Some Rivers of the Ntem Basin in Southern Cameroon

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Abstract

Water is an essential yet scarce commodity for human life due to its many uses. Depending on their condition, bodies of water can improve or degrade living conditions. The Mvila watershed in southern Cameroon, which experienced archaic urbanization coupled with incivism and urban disorder, was the site of a study examining the relationship between the ecology of benthic macroinvertebrates and abiotic parameters. This study was conducted monthly from December 2018 to December 2019. It involved sampling benthic macroinvertebrates and collecting water samples using standard methods. For the most part, the physicochemical parameters remained within the standards prescribed by the water quality grid. Throughout the study, the Sounou stream had the highest abundance of benthic macroinvertebrates, followed by the Lo'o and Bengo streams. For the trophic groups, predators were the most abundant, while filter feeders were the least abundant. Canonical correspondence analysis revealed that certain physicochemical parameters had a negative influence on benthic macroinvertebrate taxa, while others had a positive impact on them. The parameters that negatively influenced them were temperature, pH, and conductivity, while the parameters that positively influenced them were suspended solids, colour, and turbidity. Finally, Shannon and Weaver's diversity indices and Pielou's evenness indicate a rich and diverse living environment with an equal distribution of organisms among the studied rivers. In conclusion, some environmental factors, such as temperature, pH, conductivity, and dissolved oxygen, influence the diversity and distribution of macroinvertebrates.

Keywords

Ecology, Benthic Macroinvertebrates, Watershed, Taxa

1. Introduction

The water molecule is the most widely distributed substance on Earth's surface [1]. Despite its abundance, clean drinking water remains scarce for populations with limited ac-

cess to it. Water is essential for ecological and economic reasons, as it is indispensable for agriculture, transportation, domestic consumption, and many other purposes [2]. Thus, rivers can significantly contribute to the economic development

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of local communities and environmental change through various farming activities [3, 4]. However, agricultural activities in river areas generally harm the ecology of macrobenthic organisms, especially benthic macrofauna [5]. These activities can lead to soil erosion, increased solute runoff, elevated physicochemical parameters, and subsequent water pollution, which damages plants and animals [6]. Nowadays, waterways in developing countries are often littered with trash, which contributes to pollution [7]. This study utilized benthic macroinvertebrates, which are organisms without a backbone that can be observed with the naked eye, for this assessment. These invertebrates constitute a highly diverse taxonomic group comprising several phyla. Their diversity of forms enables them to respond to disturbances in various ways, making them ideal for bioassessment [8]. They are chosen for bioassessment because they can be found on all types of substrates in all seasons. Some species inhabit only a few types of microhabitats and have limited active movement, staying within a few dozen meters. Thanks to their strong adaptability and high tolerance of pollution, they populate most freshwater bodies [9-13]. Macroinvertebrates have also been used as biological indicators of water quality [14-16]. Due to their sensitivity to disturbances such as fine sediment accumulation, pollution, variations in physicochemical parameters, and hydrological changes, they are well suited to this role [17-20]. There is very little data on the ecology of benthic macroinvertebrates in the Ntem watershed. This study aims to evaluate the impact of environmental factors on the ecology of macroinvertebrates in four southern streams.

2. Materials and Methods

2.1. Study Area

The South Region is located between 2°51' and 2°54' north latitude and 11°6' and 11°9' east longitude. It is divided into four divisions: Mvila, Dja and Lobo, Ocean, and Ntem Valley [21]. The region borders the Littoral Region to the Northwest, the Centre Region to the North, and the East Region to the east. The southern part of the region borders three countries: Equatorial Guinea, Gabon, and the Republic of Congo. The western border is the Gulf of Guinea, and the southern part of the region is dominated by the Southern Cameroonian Plateau, which has altitudes ranging from 0 to 1,000 meters. Yellow ferrallitic soils on gneiss cover most of the territory, while red ferrallitic soils and a sedimentary plain are found along the coast [21, 22]. The vegetation is characterized by dense rainforest, of which there are two main types: dense rainforest with two variants (Congolese or Dja evergreen forest and low-altitude coastal rainforest) and dense rainforest with one semi-deciduous, medium-altitude variant (swamp forest) [22, 23]. This study was carried out at twelve sampling stations on four rivers in two localities at the Mvila Division (Figure 1). The first locality was Mvam Essakoe, with two streams: the Bengo stream and the Metyi stream. The second locality was Azem, with two streams, the Sounou and the Lo'o (Table 1).

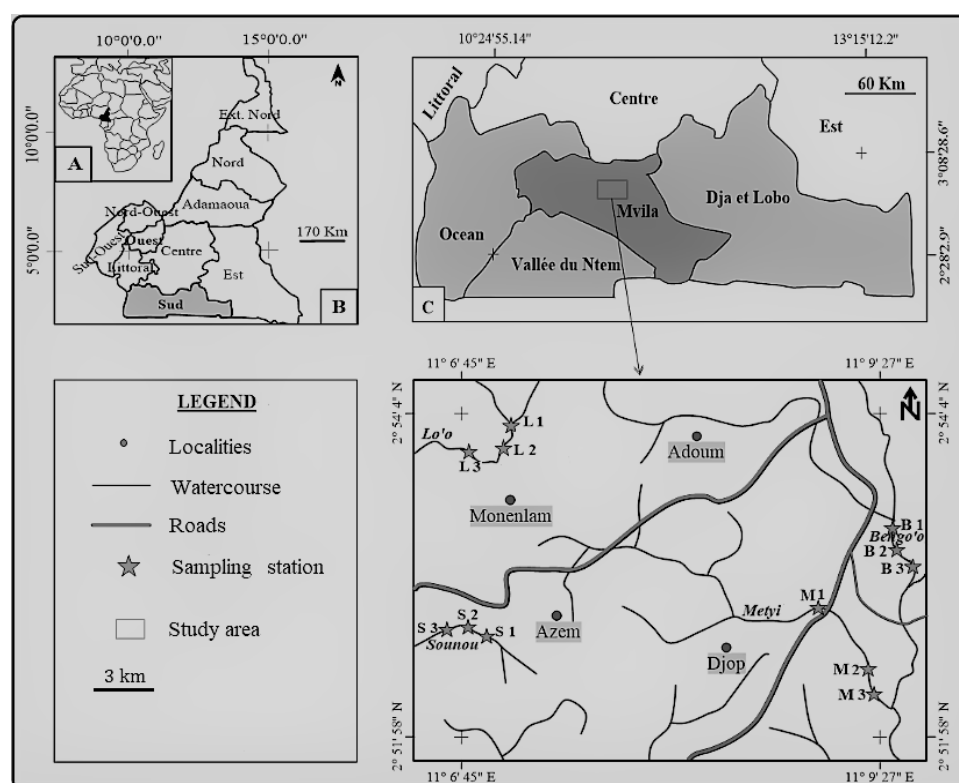


Figure 1. Sampling station in different streams in Ntem watershed [24].

Table 1. Geographic coordinates of sampling stations.

Streams	Station code	Altitude	Geographic coordinates
Metyi	M1	564 m	02°52'22.7'' N and 011°09'19.8'' E
	M2	560 m	02°52'50.6'' N and 011°09'03.3'' E
	M3	559 m	02°52'28.2'' N and 011°09'22.0'' E
Bengo	B1	578 m	02°53'18.2'' N and 011°09'28.2'' E
	B2	577.5 m	02°53'08.3'' N and 011°09'24.9'' E
	B3	574 m	02°53'03.9'' N and 011°09'28.8'' E
Sounou	S1	581 m	02°52'36.7'' N and 011°06'53.8'' E
	S2	576 m	02°52'41.8'' N and 011°06'45.4'' E
	S3	570 m	02°52'43.3'' N and 011°06'41.4'' E
Lo'o	L1	594 m	02°53'48.7'' N and 011°06'47.5'' E
	L2	585 m	02°53'53.7'' N and 011°06'53.4'' E
	L3	579 m	02°59'48.6'' N and 011°06'58.7'' E

2.2. Sampling of Water and Physicochemical Analysis

The physicochemical parameters directly related to macroinvertebrates' ecology were measured monthly from December 2018 to December 2019 following the recommendations of Rodier et al. [25]. Temperature (°C), conductivity (microSiemens per centimeter - $\mu\text{S}/\text{cm}$), total dissolved solids (TDS) (mg/L), and pH were measured in situ using a HANNA HI 991301 portable waterproof meter. Dissolved oxygen was measured in situ using a portable oximeter (HANNA HI 9147). In the laboratory, turbidity (Formazin Turbidity Units: FTU) and suspended solids (mg/L) were measured using Hydrotest HT1000 spectrophotometry.

2.3. Sampling of Benthic Macroinvertebrates

Benthic macroinvertebrates were sampled monthly from December 2018 to December 2019 using the multi-habitat approach [26]. A 30 cm² dip net with a 400 μm conical mesh was used at a depth of 50 cm. For each study station and sampling campaign, approximately twenty dip net strokes were made over an area of about 3 m². Organisms caught in the net were collected with fine forceps and fixed in 10% formalin. In the laboratory, the captured organisms were washed with running water and preserved in 70% ethanol. For each station, the organisms were placed in Petri dishes (90-mm of diameter). They were grouped according to their general characteristics, size, and morphology; identified to genus; and counted under a WILD M3B binocular magnifier. Identification was performed using the keys and books by Tachet et al., Heidemann

and Seidenbusch, De Moor et al., Stals and De Moor [27-30].

2.4. Data Analysis

The data collected during this study were processed and analyzed using standard statistical software. The Shapiro test was used to evaluate the normality of the distribution, while the Kruskal-Wallis and Mann-Whitney tests were performed to check the difference between means ($p < 0.05$).

The frequency of occurrence, or constancy, is noted as "C" and is the ratio, expressed as a percentage, of the number (p) of samples (or samplings) in which species "i" appears, divided by the total number (P) of samples. This index is based on the presence/absence matrix and is calculated according to the formula:

$$C (\%) = \text{Pi}/P \times 100.$$

Pi is the number of samples in which species i is represented, and P is the total number of samples.

Depending on the value of C, five groups of species can be distinguished [31]. C = 100%, ubiquitous species; C = 100%; constant species; C =] 75%; 50%: constant species; C =] 50%; 25%: accessory species; and C =] 25%; 0%), rare or accidental species.

The Shannon and Weaver diversity index was used to estimate the taxonomic diversity of the benthic macroinvertebrate population using the following formula:

$$H' = -\sum_{i=1}^S (p_i \log_2 p_i)$$

H' = Shannon & Weaver index, P = the proportion of the ith taxon in the total number of organisms, and S = the number of

taxa.

The Shannon & Weaver diversity index ranges from 0 (a settlement dominated by a single taxon) to $\log_2 S$ (all taxa are equally represented), where S is the total number of taxa in the sample.

The Pielou equitability index (J) measures the equitable distribution of species in a sample relative to an equal distribution of all species. Equitability values range from 0 (one taxon dominates) to 1 (equitable distribution of taxa).

$$J = H' / \log_2 S$$

J = Pielou equitability index; H' = Shannon & Weaver index; S = total number of taxa in the sample.

Simpson's index (D) provides information on the dominance of one or more species. It is calculated according to the following formula:

$$D = \sum [n_i(n_i-1)]/[N(N-1)]$$

n_i = number of individuals in species i ; N = total number of individuals in the sample.

It expresses the imbalance in abundance between species. When D approaches 0, maximum diversity is maximal, i.e., no

dominance. When D approaches 1, diversity is minimal, indicating strong dominance of one or two taxa.

3. Results

3.1. Physicochemical Parameters

Temperature ranged from 21.80 °C to 25.80 °C, with an amplitude of 4.00 °C. Averaged value is 23.90 ± 0.87 °C. pH ranged from 2.29 to 8.31, with an amplitude of 6.02 around an average of 5.78 ± 0.91 . Dissolved oxygen content ranged from 8% to 90%, representing an 82% variation. The mean value was $58.79\% \pm 19.10\%$. Turbidity ranged from 0.0 FTU to 239 FTU with an amplitude of 239 FTU. The mean value was 28.01 ± 58.01 FTU. Electrical conductivity ranged from 10 $\mu\text{S}/\text{cm}$ to 170 $\mu\text{S}/\text{cm}$, with an amplitude of 160 $\mu\text{S}/\text{cm}$. The mean value was 50.71 ± 45.15 $\mu\text{S}/\text{cm}$. Total dissolved solids ranged from 10 mg/L to 90 mg/L, with an amplitude of 80 mg/L. The mean value was 24.97 ± 23.99 mg/L. Suspended Solids ranged from 0.1 mg/L to 393 mg/L, with an amplitude of 392.9 mg/L. The mean value was 38.90 ± 98.19 mg/L. The Kruskal-Wallis test reveals significant differences between the values of the same parameter ($p < 0.05$) (Table 2).

Table 2. Average values of physicochemical parameters measured during the study period.

	Metvi	Bengo	Sounou	Lo'o	Global
Temperature (°C)	24.11 ± 0.77	24.52 ± 0.58	23.52 ± 0.89	23.48 ± 0.76	23.90 ± 0.87
pH	5.87 ± 0.76	6.34 ± 0.68	5.30 ± 0.99	5.63 ± 0.89	5.78 ± 0.91
Oxygen (%)	53.14 ± 22.53	63.79 ± 14.20	55.82 ± 22.65	61.09 ± 16.77	58.79 ± 19.10
TDS (mg/L)	12.18 ± 5.71	63.85 ± 14.44	11.28 ± 4.09	12.56 ± 4.42	24.97 ± 23.99
Conductivity ($\mu\text{S}/\text{cm}$)	25.38 ± 9.06	124.36 ± 26.24	25.38 ± 6.82	27.69 ± 8.42	50.71 ± 45.15
Suspended Solid (mg/L)	39.38 ± 97.52	38.97 ± 98.90	39.08 ± 100.13	38.15 ± 100.02	38.90 ± 98.19
Turbidity (FTU)	28.96 ± 59.33	26.82 ± 56.85	31.00 ± 58.62	25.28 ± 59.32	28.01 ± 58.01

3.2. Biological Parameters

3.2.1. Benthic Macroinvertebrate Abundance in Study Streams

A total of 7,828 benthic macroinvertebrates belonging to 174 taxa were collected and identified throughout the study period. The Sounou stream had the highest relative abundance (40.69%), followed by the Lo'o stream (21.37%), Bengo stream (21.17%), and Metvi stream (16.77%) (Table 3).

In the Metvi stream, Coleoptera were the most dominant, accounting for 47.06% of the total individuals collected. The

Heteroptera, Odonata, Trichoptera, Ephemeroptera, and Decapoda followed respectively.

In the Bengo stream, Coleoptera was the predominant group with 543 individuals. The Heteroptera followed with 404 individuals, Decapoda with 244 individuals, Caenogastropoda with 176 individuals, Plecoptera with 103 individuals, and Ephemeroptera with 54 individuals.

In the Sounou stream, Decapoda clearly dominated with 1,811 individuals. Next were Heteroptera with 407 individuals, Coleoptera with 328 individuals, Ephemeroptera with 299 individuals, Odonata with 219 individuals, and Trichoptera with 70 individuals.

In the Lo'o stream, decapods were the most dominant group,

with 512 individuals. The Heteroptera and Coleoptera, with 374 and 361 individuals, respectively. Then Ephemeroptera

followed with 179 individuals, Odonata with 160 individuals, and Trichoptera with 44 individuals (Table 3).

Table 3. Abundance (N) of benthic macroinvertebrates.

Orders	Metyi		Bengo		Sounou		Lo'o	
	N	N (%)	N	N (%)	N	N (%)	N	N (%)
Coleoptera	618	47.1	543	32.8	328	10.3	361	21.6
Decapoda	36	2.7	244	14.7	1811	56.9	512	30.6
Diptera	16	1.2	6	0.4	30	0.9	21	1.3
Ephemeroptera	41	3.1	54	3.3	299	9.4	179	10.7
Eulamellibranchia	7	0.5	21	1.3	18	0.6	16	1.0
Heteroptera	395	30.1	404	24.4	407	12.8	374	22.4
Caenogastropoda	1	0.1	176	10.6	0	0.0	0	0.0
Odonata	123	9.4	100	6.0	219	6.9	160	9.6
Plecoptera	0.00	0.0	103	6.2	0	0.0	3	0.2
Trichoptera	76	5.8	4	0.2	70	2.2	44	2.6
Oligochaeta	0.00	0.0	0	0.0	3	0.1	3	0.2

3.2.2. Frequency of Occurrence of Benthic Macroinvertebrate Taxa

Table 4 shows how often benthic macroinvertebrate taxa occurred in the various rivers examined in this study. In the Metyi stream, rare taxa constituted the majority, followed by accessory taxa, constant taxa, regular taxa, and ubiquitous

taxa. In the Bengo stream, rare taxa predominate, followed by accessory taxa, constant taxa, regular taxa, and ubiquitous taxa. In the Sounou stream, rare taxa predominate, followed by accessory taxa, constant taxa, regular taxa and ubiquitous taxa. In the Lo'o stream, rare taxa predominate, followed by accessory taxa, constant taxa, regular taxa, and ubiquitous taxa.

Table 4. Frequency of occurrence (N) of benthic macroinvertebrate taxa in different rivers.

Occurrence	Metyi		Bengo		Sounou		Lo'o	
	N	N (%)	N	N (%)	N	N (%)	N	N (%)
Rare taxa	44	59.5	68	73.1	65	67.0	67	63.2
Accessory taxa	16	21.6	12	12.9	17	17.5	23	21.7
Constant taxa	8	10.8	6	6.5	5	5.2	6	5.7
Regular taxa	5	6.8	5	5.4	5	5.2	6	5.7
Ubiquitous taxa	1	1.4	2	2.2	5	5.2	4	3.8

3.2.3. The Influence of Environmental Parameters on Benthic Macroinvertebrates

Figure 2 shows the impact of physicochemical parameters on biological organisms via Canonical Correspondence Analysis (CCA) along the two primary axes (49.92% of the information on axis 1; and 20.15% of the information on axis 2). Correlation circle showed that physicochemical parameters

significantly influenced the distribution of nearly 85% of organisms. Therefore, suspended solids and colour positively influenced organisms in relation to axis 1 and negatively influenced them in relation to axis 2, while turbidity positively influenced both axes. Dissolved oxygen exerts a negative influence on axis 1 and a positive influence on axis 2. Conversely, temperature, pH, conductivity, and total dissolved solids have a deleterious effect on organisms across both axes.

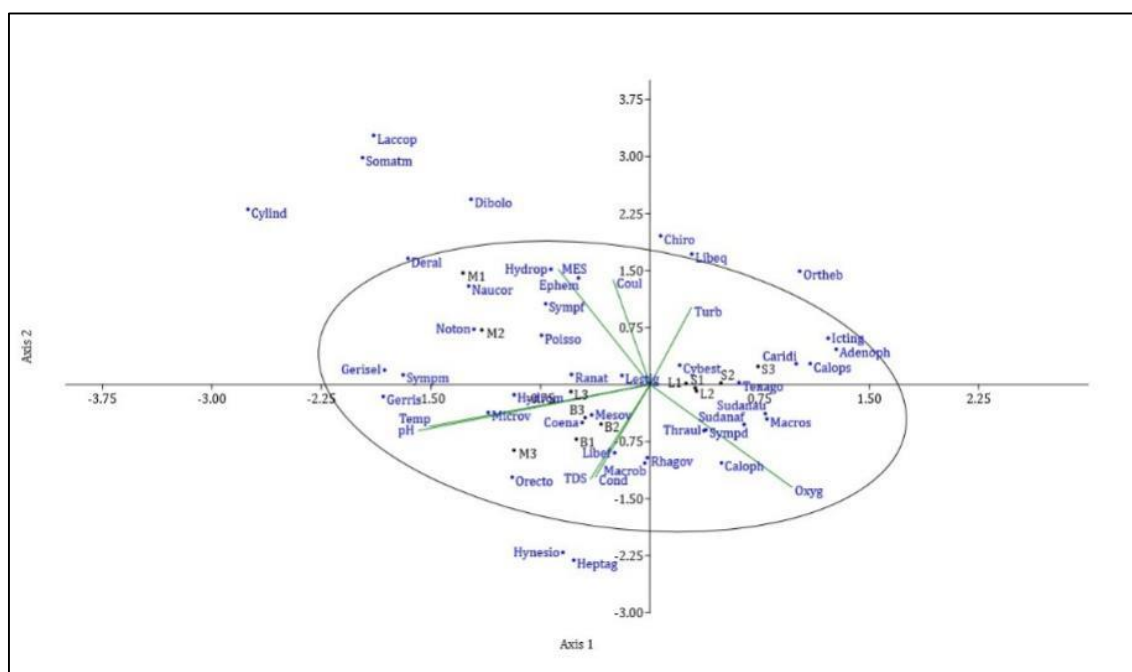


Figure 2. Canonical Correspondence Analysis (CCA) of ubiquitous, regular, and constant macroinvertebrate taxa in relation to abiotic parameters. Macrob = Macrobrachium; Caridi = Caridina; Ranat = Ranatra; Poisso = Poissonia; Hydrom = Hydrometra; Cyllind = Cyllindrostethus; Tenago = Tenagobius; Rhagov = Rhagovelia; Mesov = Mesovelia; Microv = Microvelia; Naucor = Naucoris; Deral = Derallus; Orecto = Orectogyrus; Laccop = Laccophilus; Heptag = Heptagenia; Ephem = Ephemerella; Thraul = Thraulius; Hydrom = Hydrometra; Lestig = Lestinogomphus; Ortheb = Orthetrum; Sympd = Sympetrum; Coena = Coenagrion; Temp = Temperature; pH = Hydrogen potential; Oxyg = Dissolved oxygen; TDS = Total Dissolved Solids; Cond = Electrical conductivity; MES = Suspended solids; Turb = Turbidity.

3.2.4. Trophic Groups

Predators are the most abundant, with 3,562 individuals. Next are grazers/shredders with 2,651 individuals, followed by scrapers with 830 individuals, detritivores with 533 individuals, and finally, filter feeders with 246 individuals.

Grazer/Shredders are the most diverse in terms of taxonomic richness, represented by 18 families. Next are predators, represented by 16 families. There are grazers/shredders, represented by 12 families, and scrapers, represented by 11 families. Last are filter feeders, represented by four families.

In the Metyi stream, predators dominate with 860 individuals. The scrapers followed by 218 individuals, grazers/shredders by 85 individuals, filter feeders by 81 individuals, and

detritivores by 68 individuals. In the Bengo stream, predators were the most abundant with 1,022 individuals, followed by scrapers with 333 individuals, detritivores with 247 individuals, grazers/shredders with 28 individuals, and filter feeders with 24 individuals. In the Sounou stream, detritivores were the most abundant, with 1,988 individuals. Next were predators, with 944 individuals; then, scrapers, with 130 individuals; filter feeders, with 82 individuals; and finally, grazers/shredders, with 38 individuals. In the Lo'o stream, predators were most abundant with 732 individuals, followed by detritivores with 651 individuals, scrapers with 161 individuals, grazers/shredders with 69 individuals, and filter feeders with 59 individuals (Table 5).

Table 5. Diets of the various taxa collected in the different watercourses.

Trophic groups	Metyi		Bengo		Sounou		Lo'o		Global	
	Absolute abundance	Number of families	Absolute abundance	Number of families	Absolute abundance	Number of families	Absolute abundance	Number of families	Absolute abundance	Number of families
Grazers / Shredders	85	6	28	5	38	6	69	7	2651	12
Scrapers	218	7	333	10	130	8	161	8	830	11
Detritivores	68	8	247	10	1988	10	651	12	533	18
Filters	81	2	24	2	82	3	59	3	246	4
Predators	860	9	1022	13	944	14	732	14	3562	16

In terms of taxonomic richness, the Metyi stream has the following trophic groups listed in descending order of richness: predators (9), detritivores (8), scrapers (7), grazers/shredders (6) and filter feeders (2). In the Bengo stream, there are 13 predator families, 10 detritivore families, 10 scraper families, 5 grazer/shredder families, and 2 filter feeder families. In the Sounou stream, there are 14 predator families, 10 detritivore families, eight scraper families, 6 grazer/shredder families, and three filter families. In the Lo'o stream, the respective figures are 14, 12, 8, 7, and 3 families respectively for predators, detritivores, scrapers, grazers/shredder and filters.

3.3. Diversity Indexes

The overall Shannon and Weaver diversity index ranged from 3.29 to 4.48 bits/ind, averaging 4.12 ± 0.56 bits per ind. Pielou's equitability ranged from 0.50 to 0.68, averaging 0.63 ± 0.09 . Simpson's index ranged from 0.73 to 0.90, averaging 0.85 ± 0.08 . In the Metyi stream, the Shannon-Weaver index had an overall value of 4.24 bits per individual, Pielou's equitability had a value of 0.68, and the Simpson index had a value of 0.88. In the Bengo stream, the Shannon and Weaver index showed an overall value of 4.47 bits/ind, Pielou's equitability indicated a value of 0.68, and the Simpson index had a value of 0.90. In the Sounou stream, the Shannon and Weaver index showed an overall value of 3.29 bits per individual, Pielou's evenness showed a value of 0.50, and the Simpson index showed a value of 0.73. In the Lo'o streams, the Shannon and Weaver diversity index gave an overall value of 4.48 bits/ind, Pielou's evenness index showed a value of 0.66, and the Simpson index gave a value of 0.90.

4. Discussion

4.1. Physicochemical Parameters

The mean temperature value obtained during this study (23.90 ± 0.87 °C) can be attributed to the ambient temperature,

which is, in turn, induced by the plant cover present in the various watercourses. Mzungu et al. also made this observation, noting that forest vegetation was responsible for low river temperatures [20]. However, this mean temperature is slightly higher than the values obtained by Mzungu et al. in the Isiukhu River in Kenya ($19.94 - 22.86$ °C) and slightly lower than the value obtained by Foto et al. (24.06 ± 1.51 °C) in the Ndongo River in Southwest Cameroon [6, 10]. However, it is lower than the value obtained by Temgoua Zemo et al. (26.01 ± 1.83 °C) in Yaoundé's urban streams [32]. The high mean value obtained in the Bengo stream (24.52 ± 0.58 °C) and the low value obtained in the Lo'o stream (23.48 ± 0.76 °C) may be due to the time of day when sampling occurred, depending on the level of sunshine.

The average pH value (5.78 ± 0.91) indicates that the water in the study area is slightly acidic. This value could be attributed to the nature of the soils or to the basin's humic acid content resulting from the activity of acidifying bacteria. These observations align with those in the Mabounié watershed by Mboye [33]. The mean value obtained here is similar to values obtained by Gwos et al. in some East Cameroon streams (5.18 ± 0.30), but lower than values obtained by Temgoua Zemo et al. in Yaoundé urban streams (7.23 ± 0.24) and by Mzungu et al. in Kenya's Isiukhu River ($6.72 - 9.7$) [6, 32, 34]. The low mean value obtained in the Sounou stream (5.30 ± 0.99) is thought to be due to the stream's low water velocity caused by barriers built by riparian populations for fishing activities. The low water flow leads to the high accumulation of organic matter and, consequently, the high activity of acidifying bacteria.

The average value of the dissolved oxygen content ($58.79 \pm 19.10\%$) can be attributed to the slow velocity of the water flowing in all of the studied streams. This value could also be explained by the mineralizing activity of decomposer bacteria, which consume oxygen during the decomposition of organic matter on the stream bottoms. This mean value is significantly lower than that obtained in the Ndongo stream ($82.21 \pm 6.59\%$)

by Foto et al., but statistically higher than that obtained in some Yaoundé urban streams ($9.72 \pm 11.74\%$) by Temgoua et al. [10, 32].

The average turbidity of the water (28.01 ± 58.01 mL/L) in the different streams is primarily due to the low contribution of allochthonous suspended matter and the low degree of anthropization of the watershed. This average value is similar to those obtained by Ndourwe et al. and Dzavi et al. in three forest streams in Cameroon's Littoral Region and several tropical forest streams, respectively [12, 35]. However, the high mean turbidity values obtained in all the streams were due to heavy rainfall the day before sampling. This resulted in significant soil leaching and consequent input of suspended matter into the streams.

4.2. Biological Parameters

A qualitative analysis of the biological data from the studied streams revealed a high taxonomic richness of 174 taxa. This should be explained by the nature of the substrate and the low velocity of the water flow. Water flow velocity affects the composition of macrobenthic fauna. Too high a velocity causes unadapted macroinvertebrates to drift. Conversely, too low a velocity directly impacts the circulation of organic matter and, above all, the oxygen renewal of the water. These conditions are highly unfavorable for the establishment of certain pollution-sensitive groups. Similar observations were made by Eyre et al., who noted that factors such as flow rate and water velocity were related to the structure of the benthic macrofauna population [36]. Furthermore, Karabore et al. suggests that this taxonomic richness is linked to the diversity of ecological niches and microhabitats in these streams [37]. Nevertheless, the taxonomic richness obtained in this study is low compared to that in the Mabounié watershed in Gabon (202 taxa) [33] and in Côte d'Ivoire (199 taxa) [38]. However, this figure is higher than those obtained by Temgoua Zemo et al. in a few urban streams in Yaoundé (42 taxa) and by Ndourwe et al. in three forest streams in the Littoral of Cameroon (117 taxa) [32, 35].

The predominance of insects (63.67%) can be attributed to their high adaptive faculties, resulting from genetic plasticity, and their ability to colonize varied ecological niches due to cosmopolitanism [10, 35, 39]. These results are similar to those obtained by Paredes-Agurto et al. in Peru and Biram et al. in four forest streams in Central Cameroon, but differ from those obtained by Temgoua Zemo et al. in several urban streams in Yaoundé [13, 32, 40]. The high proportion of Decapod crustaceans in the streams (33.29%) is thought to be linked to adequate oxygen levels and an abundance of litter that provides refuge. Favorable environmental conditions (biotic and abiotic variables) also contribute to their proliferation [12, 27]. According to Anderson et al. and Agadjihouede et al., shrimp distribution in watercourses depends on the specific requirements of various taxa and the environmental characteristics of these watercourses [41, 42]. Similarly, Toto Kouame

et al. found that dissolved oxygen levels strongly influence the abundance and distribution of shrimp species [43]. The results of this study are similar to those of studies in four streams in East Cameroon by Gwos et al. and in three forest streams in Cameroon's Littoral Region by Ndourwe et al. [34, 35]. The high abundance of decapods in these streams reflects their good ecological health. Consequently, decapods could serve as indicators of the good quality of lotic environments. Tchakonte et al. and Nyamsi et al. had already addressed this hypothesis [44, 45].

The predominance of organisms in the Sounou is linked to the nature of the bottom substrate and, above all, to the diversity of microhabitats. This could also be due to the shallow water column. Conversely, the low abundance of benthic macroinvertebrates (16.77%) and low diversity (74 taxa) in the Metyi stream could be attributed to the limited number of microhabitats and ecological niches. This is evidenced by the predominance of Coleoptera and Heteroptera, which live on the water's surface and do not require a specific habitat. The high diversity of macroinvertebrates in the Lo'o and Sounou streams (107 and 97 taxa, respectively) reflects environments little disturbed by human activity. Similar observations were made by Aazami et al., who noted that environments with little anthropogenic pressure favor the settlement and development of benthic macrofauna [46].

4.3. Trophic Group

Analysis of the various streams' trophic functional groups revealed that predators (45.54%) and grazers/shredders (33.89%) dominated the population in terms of. This strong dominance is thought to be linked to the abundance of prey for predators and the abundance of organic matter from the canopy that supplies the streams with litter. According to Monoury, grazers and shredders, along with hyphomycetes, are vital to the decomposition of litter [47]. These results are similar to those obtained by Tenkiano and Masese et al. in Guinean and Kenyan streams, where predators dominated the benthic macroinvertebrate population [48, 49]. In this study, scrapers are also important, accounting for 10.61% of the population. Scrapers feed on various resources, including algae attached to rocks and benthic biofilms composed of bacteria, fungi, and algae that cover substrates [49]. Thus, the presence of scrapers indicates that, despite the large canopy, the streams receive enough light to support primary producers. In terms of taxonomic richness, detritivores were the richest (18 families), and predators followed with 16 families. These results differ from those obtained in the Mabounié watershed by Mboye, in which predators were the most diverse, followed by shredders [33].

4.4. Biocenotic Indices

The values of the Shannon-Weaver, Pielou, and Simpson indices indicate a diverse and equitably distributed population of benthic macroinvertebrates. However, the low values of the

Shannon-Weaver (3.29 bits/ind) and Pielou equitability (0.50) indices in the Sounou stream indicate lower diversity of macroinvertebrates compared to other streams. This low diversity is linked to the predominance of one group of organisms: decapod crustaceans. This has led to an imbalance in the benthic macroinvertebrate population. According to Davies et al., low diversity index values reflect poor settlement organization resulting from the proliferation of a few dominant species at the expense of others [50].

5. Conclusion

The aim of this study was to investigate the ecology of benthic macroinvertebrates in relation to water physicochemistry. The results show that benthic macroinvertebrates in this area are predominantly insects. Of the four rivers studied, the Sounou had the highest abundance of benthic macroinvertebrates, followed by the Lo'o, the Bengo, and the Métyi, respectively. Predators were the most abundant throughout the study period in terms of diet, followed by grazers/shredders. Filter feeders were the least abundant. Physicochemical parameters influence the distribution of benthic macroinvertebrates depending on their nature and concentration in the environment. Shannon and Weaver's diversity index and Pielou's evenness index reveal a rich, diverse, and equitably distributed benthic macroinvertebrate population.

Abbreviations

TDS	Total Dissolved Solids
FTU	Formazing Turbidity Units
µS/cm	microSiemens per Centimeter

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Conflicts of Interest

All authors declare no conflicts of interest.

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