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Research Article

Physicochemical Characteristics and Macroinvertebrate Communities of the Crenon and Potamon of the Lobo River in the Rainforest Zone of Cameroon

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Abstract

A study of the physicochemical water quality and the diversity of Benthic Macroinvertebrates (BMIs) in the Lobo River was conducted to characterize its upper and lower reaches. Sampling was carried out between May 2020 to May 2021 across four stations (two in the crenon and two in the potamon), using standard methods for physicochemical analyses. BMIs were collected with a 30-cm square, 400-µm mesh dip net over a 100-meter stretch at each station, following the multi-habitat method. Physicochemical parameters were generally low and homogeneous between the crenon and potamon ($p > 0.05$), with recorded values for dissolved oxygen (61.23 ±4.37%), turbidity (17.43 ±2.15 FTU), and suspended solids (16.81 ±2.29 mg/L); nitrogen forms (0.54 ±0.08 mg/L NH_4^+; 0.36 ±0.18 mg/L NO_3^-) and orthophosphates (0.85 ±0.37 mg/L PO_4^{3-}) being higher in the crenon (L2), whereas nitrites were lower at that zone (0.012 ±0.004 mg/L NO_2^-). A total of 86 BMIs species belonging to 3 phyla, 5 classes, 10 orders, and 38 families were recorded. Key bioindicators recorded were: *Caridina nilotica* and *Phyllomacromia bifasciata* in the crenon; *Micronecta* sp., *Tramea transmarina*, and *Canas macateei* in the potamon. The Shannon-Weaver diversity index indicated sites with low diversity encompassing both pollution-sensitive (Atyidae and Polymictarcyidae) and pollution-tolerant (Libellulidae and Belostomatidae) organisms, as revealed by Principal Component Analysis (PCA).

Keywords

Bioindicator, Ecology, Ecologic Zone, Lotic Ecosystem, Water Uses

1. Introduction

The overexploitation of ecosystem services (food, water, textiles, and other raw materials) degrades the environment and weakens its ability to regulate climate and water [1]. Freshwater has intrinsic value for human life, health, food security, and biodiversity; yet billions of people worldwide face problems of water scarcity and poor water quality [2]. These are interconnected global issues, exacerbated by climate change, population growth, and pollution, leading to health risks (waterborne diseases), economic risks (losses in GDP), and social risks (conflicts) [2]. The most significant challenge for water management is how to increase the quantity and quality of water resources, while simultaneously improving

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ecosystem services for society, biodiversity, and resilience to impacts [3].

The impact of human activities on aquatic ecosystems is often assessed using biological indicator species [4-7]. The species most commonly used worldwide to assess the overall ecological status of aquatic environments are fish communities, benthic diatoms, and benthic macroinvertebrates [8, 9]. Benthic macroinvertebrates are aquatic organisms visible to the naked eye that inhabit the bottoms of lakes and watercourses; these include insects (larvae, nymphs, adults), mollusks, crustaceans, and worms [10, 11]. They are diverse and belong to various phyla. Their species-specific responses to toxins provide information on the degree of stress on aquatic systems and allow for the interpretation of the effects of human activities on the community [8]. These are sedentary organisms with varied life cycles that provide a snapshot of water quality over time [8, 10].

In Cameroon, water quality in aquatic ecosystems is commonly assessed by analyzing physicochemical parameters and benthic fauna [5, 6, 12-18]. In the ecological zone of the rainforests, studies have been conducted by Lactio et al., Nwaha et al., Nwaha, and Dzavi [7, 9, 19, 20]. However, there are still several water systems in the zone whose quality has been little or not at all explored, notably the Lobo River. Understanding water quality is essential for optimizing water resources, designing hydrosystem management plans, helping to resolve conflicts related to water quality, and thereby contributing to the achievement of Sustainable Development Goal 6. With this in mind, a study was conducted on the physicochemical and biological water quality to characterize the crenon and potamon of the Lobo River. The objectives were to assess the ecological status of the freshwater shrimp and river crayfish based on the physicochemical and biological parameters of the water, determine potential water uses, and evaluate the ecological quality of the sites using benthic macroinvertebrates.

2. Materials and Methods

2.1. Study Area

The study was conducted on the Lobo River, located in the humid forest with bimodal rainfall zone [21]; it flows into the Dja River, which empties into the Congo Basin [22] (Figure 1). The climate is of the Guinean equatorial type, with four seasons occurring throughout the year: a long dry season (November to March, LDS), a short rainy season (March to June, SRS), a short dry season (July to August, SDS), and a long rainy season (September to November, LRS) [22]. The following criteria guided the selection of sampling stations: i) accessibility, ii) absence of tributaries, industrial and mining activities near the stations, and iii) the presence of diverse microhabitats. Four (04) stations were selected, with two in the crenon of the river at Sangmelima (02°55’49.7’’N, 011°58’10’’E; 655 m and 02°56’39.1’’N, 011°58’12.9’’E; 662 m) and two at the potamon site in Mekin village (03°16’19.32’’N, 012°24’19.03’’E; 620 m and 03°16’25.9’’N, 012°24’53.6’’E; 620 m) (Figure 1).

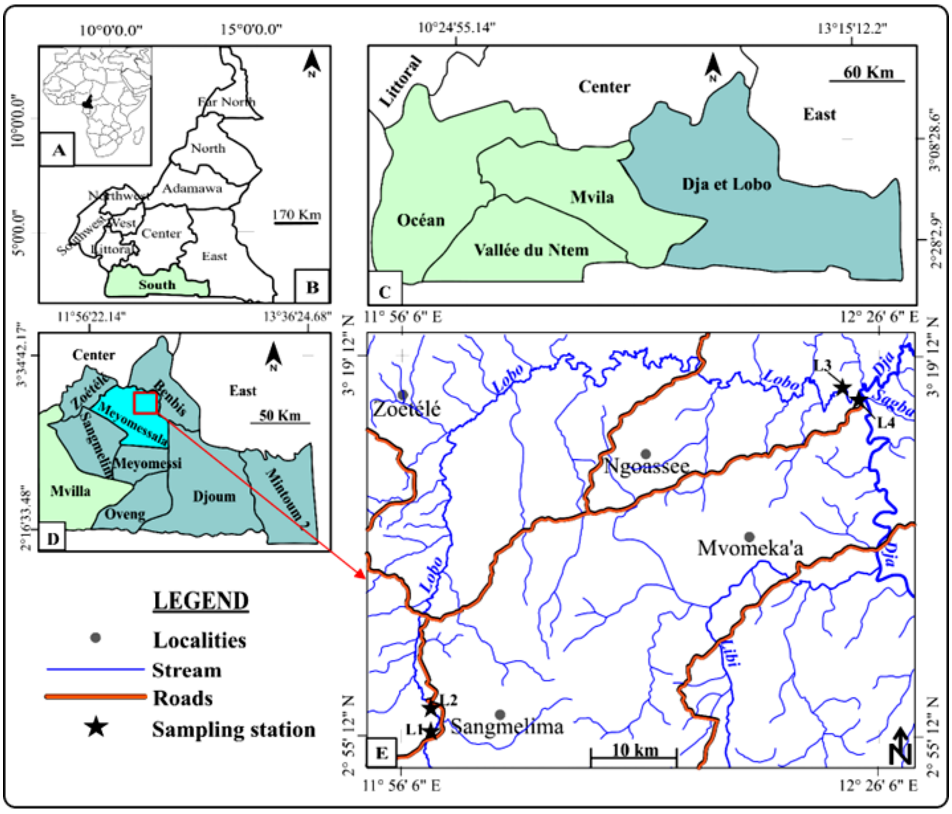

Figure 1. Geographic location of the Lobo River. L1, L2, L3, and L4 = sampling stations.

2.2. Water Sampling and Measurement of Physicochemical Parameters

Physicochemical parameters of water were measured monthly from May 2020 to May 2021 in the field and in the laboratory according to the recommendations of APHA [23] and Rodier et al. [24]. In the field, Dissolved Oxygen (%) and pH were measured using a Hach HQ 30d oximeter and a LAQUA HORIBA multiparameter meter, respectively. Using water samples brought back to the laboratory, Suspended Solids (SS) (mg/L), turbidity (FTU), ammonia nitrogen (mg/L NH_4^+), nitrites (mg/L NO_2^-), nitrates (mg/L NO_3^-), and orthophosphates (mg/L PO_4^{3-}) were measured using a DR 3900 spectrophotometer and specific reagents.

2.3. Sampling of Benthic Macroinvertebrates

BMIs sampling was conducted at the same frequency. The mobile boot-and-net technique recommended by Touzin, Usseglio-Poltera et al. and CCME [4, 25, 26] was used. The sampling equipment consisted of a dip net, comprising a 30 cm × 30 cm metal frame mounted on a 150 cm long steel handle and fitted with a 50 cm deep conical net of 400 µm mesh size. Fauna were collected by moving along transects through the target habitats, striking the substrates with the core sampler to dislodge the benthos and capture it while sweeping the water with the net. Transect sampling began downstream of the section and was conducted for 3 minutes over a 10-meter length, covering a total distance of 100 meters per station. The specimens in the net were placed on a white cloth, then collected using a pair of fine-tipped forceps and transferred to pill bottles containing 96% ethanol. The specimens were identified at the Laboratory of Hydrobiology and Environment at the University of Yaounde 1. Depending on the taxonomic group, identifications were resolved to the family, genus, and/or species level using a WILD M3B binocular magnifying glass with episcopic illumination using identification keys of Durand and Levêque, De Moor and Day, De Moor et al., Martin and Aït Boughrous and Tachet et al. [27-32].

2.4. Data Analysis

The Water Quality Assessment System was applied with the aim of correlating the physicochemical quality of the water with various types of uses. Thus, the average values of the physicochemical parameters measured at the study stations were compared with the classes and indices of water suitability for biological and various other uses in the SEQ-Eau grid (Appendix 1).

The structure of the benthic macroinvertebrate community was determined based on species richness, relative abundance, the Shannon and Weaver diversity indices (H'), and Pielou's evenness index J. Expected species richness was calculated for each of the eight nonparametric estimators (ACE, ICE, Chao 1, Chao 2, Jackknife 1, Jackknife 2, Bootstrap, and MMMean) using the EstimateS 9.1.0 software [33]. All sampling efforts (SE) were expressed using the formula:

$$SE = S \times 100 / T \quad (1)$$

Where S = the number of species actually observed, T = the number of species predicted by fitting the data to one of the theoretical models (nonparametric estimators). The species richness accumulation curve (MAU-TAU curve) was generated using Excel 2016.

The status of a species as a bioindicator was determined based on the calculation of indicator values (IndVal) as described by [34]. It is expressed as follows:

$$IndValkj = 100 \times Akj \times Bkj \quad (2)$$

where Akj = the average abundance of species j at a site / the average abundance of that species across all sites in set k. Bkj = frequency of occurrence of species j across the set k of sites. A species is considered a bioindicator of a habitat only when the "IndVal" value is greater than or equal to 25% or if the permutation test is significant [34]. This analysis was performed using the "indic species" package [35] in R software version 3.0.3 [36].

The Kolmogorov-Smirnov normality test, ANOVA, and Tukey's test were used to set the probability threshold at 5%. Principal Component Analysis (PCA) was performed using environmental variables, BMIs abundance, and sampling sites to assess the relationships among the different variables. All these analyses were conducted using SPSS 20.0 [37] and Past 3.0 [38].

3. Results

3.1. Physicochimical Parameters

In the crenon, dissolved oxygen saturation levels ranged from 18.50% (L2, May 2020) to 97.70% (L1, July), with an average of 61.23 ±4.37% (Figure 2A). In the potamon, values ranged from 5.40% (L3, October) to 87.80% (L3, September), with an average of 57.51 ±4.50%. No significant differences were observed between stations throughout the study period (ANOVA; p = 0.39).

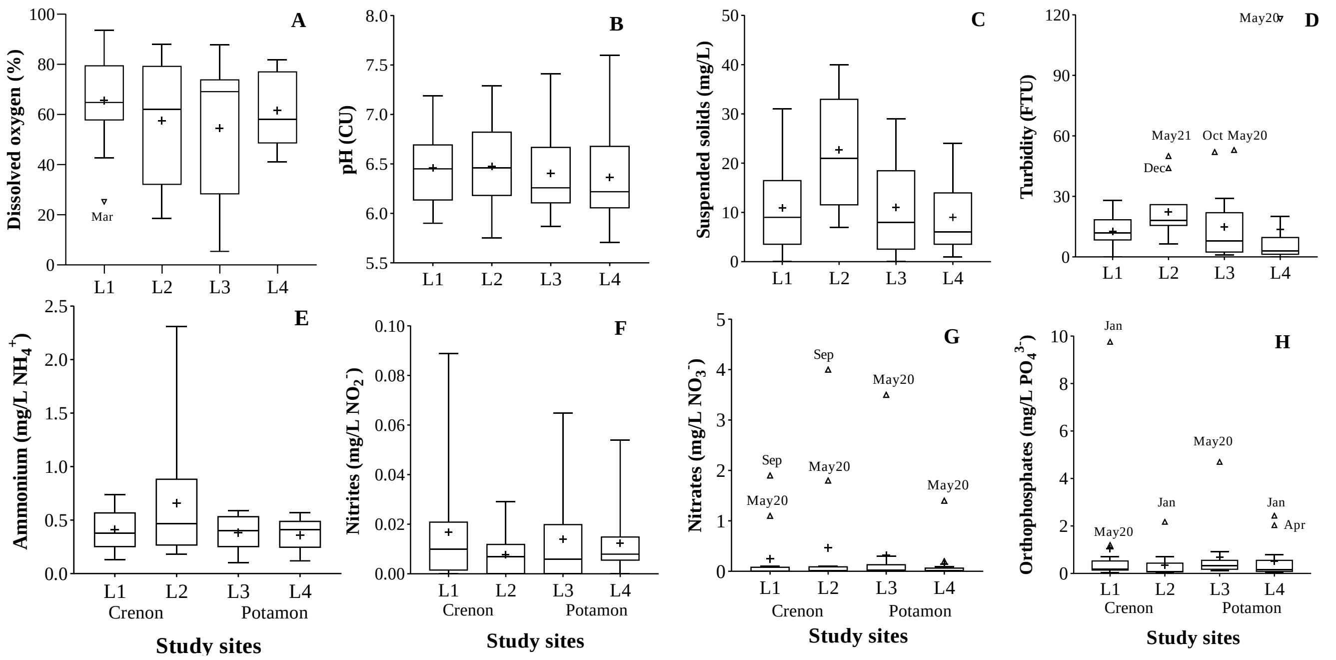

Figure 2. *Spatiotemporal variations in physicochemical parameter values during the study period. A. Dissolved oxygen; B. pH; C. SS; D. Turbidity; E. Ammonia nitrogen; F. Nitrites; G. Nitrates; H. Orthophosphates.*

In the crenon pH values ranged from 5.75 CU to 7.29 CU at L2 in October and August, respectively (Figure 2B), fluctuating around an average of 6.47 ± 0.08 CU. In the potamon, pH values ranged from 5.71 CU and 7.6 CU at L4 in October and July, respectively, with a mean of 6.34 ± 0.14 CU. No significant variation was observed between the stations ($p = 0.99$). Suspended Solids (SS) concentrations were very low across all stations during the study, ranging from 0 mg/L (L1) to 40 mg/L (L2) in December for the crenon and from 0 to 29 mg/L (L3) in December and October, respectively, for the potamon (Figure 2C). Comparison of means SS concentrations using the ANOVA test revealed significant differences between L2 and L3 ($p = 0.01$) and between L2 and L4 ($p = 0.003$). Turbidity values remained low across all stations (Figure 2D). However, notably high turbidity levels (>35 FTU) were recorded in the crenon at L2 (44 FTU in December and 50 FTU in May 2021), with an overall mean of 17.43 ±2.15 FTU. Similarly, in the potamon, values exceeding 35 FTU were obtained at L3 (52 FTU in October and 53 FTU in May 2020) and L4 (118 mg/L in May 2020), varying around an average of 14.34 ± 4.99 FTU. No significant difference was observed between stations ($p = 0.73$).

Ammonia nitrogen concentrations in the crenon ranged from 0.13 mg/L NH_4^+ (L1, October) to 2.31 mg/L NH_4^+ (L2, March), with a mean of 0.54 ± 0.08 mg/L NH_4^+ (Figure 2E). In the potamon, values ranged from 0.10 mg/L NH_4^+ (L3, July) to 0.59 mg/L NH_4^+ (L3, November), with a mean of 0.37 ± 0.03 mg/L NH_4^+. These concentrations did not vary significantly among stations ($p = 0.09$). During the study, the highest nitrite concentration in the crenon was recorded at L1 (0.089 mg/L NO_2^-, December) (Figure 2F); whereas in the potamon it was highest at L3 (0.065 mg/L NO_2^-, February). The lowest concentrations were 0 mg/L NO_2^-, recorded at all stations during several months. Significant differences were found between L2 and L3 ($p = 0.02$) and between L2 and L4 ($p = 0.02$). Nitrate concentrations remained generally low (below 0.50 mg/L NO_3^-) across all months and stations, except at L1 (1.10 mg/L NO_3^- in May 2020, and 1.90 mg/L NO_3^- in September) and L2 (1.80 mg/L NO_3^- in May 2020, and 4 mg/L NO_3^- in September) in the crenon (Figure 2G). In the potamon, the highest levels were occured in May (L3, 3.50 mg/L NO_3^- and L4, 1.40 mg/L NO_3^-). Means concentration were 0.25 ± 0.16 mg/L NO_3^- (L1); 0.47 ± 0.32 mg/L NO_3^- (L2); 0.32 ± 0.27 mg/L NO_3^- (L3) and 0.14 ± 0.11 mg/L NO_3^- (L4). Nitrate concentrations did not vary significant among stations (ANOVA, $p = 0.78$). In the crenon, orthophosphate concentrations ranged from 0.03 mg/L PO_4^{3-} at L1 and L2 (October and November, respectively) to 9.76 mg/L PO_4^{3-} at L1 in January (Figure 2H). Concentrations fluctuated a mean of 0.85 ± 0.37 mg/L PO_4^{3-}. In the potamon, the lowest concentration (0.05 mg/L PO_4^{3-}) was recorded at L4 in February and the highest (4.7 mg/L PO_4^{3-}) at L3 in May 2020. Concentrations fluctuated around a mean of 0.60 ± 0.20 mg/L PO_4^{3-}. The ANOVA test revealed no significant difference ($p = 0.75$) among stations.

3.2. Application of Water Quality Assessment Systems (SEQ-Eau) to the Studied Hydrosystems

The assessment of water suitability for aquatic life in the crenon and potamon streams of the Lobo River indicated that both sites belong to the green quality class (Table 1). This classification reflects conditions that are generally favorable for the development of aquatic communities, although reduced sensitivity of certain demanding taxa may suggest a slight ecological impairment.

The suitability class for drinking water production was also green at all sites (Table 1). This class corresponds to a suitability index of 60 and 80, representing good-quality water that nevertheless requires simple treatment prior to human consumption. The suitability of the water for livestock drinking corresponds to the color blue (Table 1). According to SEQ-Eau, the water in these hydrosystems is of very good quality for animal consumption.

Table 1. *Water quality classes for biology, drinking water production, and animal drinking, based on average values of physicochemical parameters.*

Aptitude level	Aptitude for biology				Drinking water production				Watering animals			
Study sites	**Crenon**		**Potamon**		**Crenon**		**Potamon**		**Crenon**		**Potamon**	
Sampling stations	**L1**	**L2**	**L3**	**L4**	**L1**	**L2**	**L3**	**L4**	**L1**	**L2**	**L3**	**L4**
O_2 (%)	65,63	57,52	54,51	61,63	65,63	57,52	54,51	61,63				
pH (UC)	6,46	6,48	6,4	6,36	//							
SS (mg/L)	10,92	22,69	11	9	10,92	22,69	11	9	//			
Turbidity (FTU)	12,66	22,2	14,98	13,69	12,66	22,2	14,98	13,69				
NH_4^+ (mg/L NH_4^+)	0,41	0,66	0,38	0,36	0,41	0,66	0,38	0,36				
NO_2^- (mg/L NO_2^-)	0,02	0,01	0,01	0,01	0,25	0,47	0,32	0,14	0,02	0,01	0,01	0,01
NO_3^- (mg/L NO_3^-)	0,25	0,47	0,32	0,14	//				0,25	0,47	0,32	0,14
PO_4^{3-} (mg/L PO_4^{3-})	1,04	0,35	0,69	0,51					//			
Quality class	Good				Good				Very good			

3.3. Taxonomic Composition of Benthic Macroinvertebrates

A total of 2,890 benthic macroinvertebrates were recorded in the Lobo River, belonging to three phyla: Arthropoda, Mollusca, and Annelida. These organisms were distributed across 5 classes, 10 orders, 38 families, and 86 genera/species. In the crenon, 673 individuals were collected, composed of 95.51% Arthropods, 3.14% Mollusks, and 1.35% Annelids (Figure 3A). Of the 2,217 individuals collected in the potamon, 98.01% were Arthropods and 1.99% were Mollusks. The class Insecta was the most abundant in the crenon with a relative abundance of 82.31%, followed by Crustacea (14.41%) and Gastropoda (2.38%) (Figure 3B). In the potamon, only Insects (98.24%) and Gastropods (1.76%) were recorded.

Of the 10 orders of BMIs recorded in the stream, Heteroptera were the most abundant at 22.59%; followed by Ephemeroptera (22.29%), Coleoptera (16.49%), Decapoda (14.41%), Odonata (10.99%), and Diptera (9.56%); the other orders accounted for 3.29% of cumulative relative abundance (Figure 3C). In the potamon, Odonata were the most abundant (36.13%), followed by Ephemeroptera (22.28%), Heteroptera (20.66%), Coleoptera (14.30%), and Diptera (4.87%), while other orders accounted for 1.76% of cumulative relative abundance.

Regarding families, Baetidae (22.29%) were most abundant in the crenon, followed by the Atyidae (14.41%), Dytiscidae (10.25%), Belostomatidae (8.17%), Notonectidae (7.43%), Libellulidae (5.94%), and Chironomidae (5.94%) (Figure 3D). In the potamon, the most abundant was Libellulidae at 23.59%, followed by Polymictarcidae (19.80%), Coenagrionidae (12.13%), Hydrophilidae (6.50%), Dytiscidae (6.41%), and Notonectidae (6.18%).

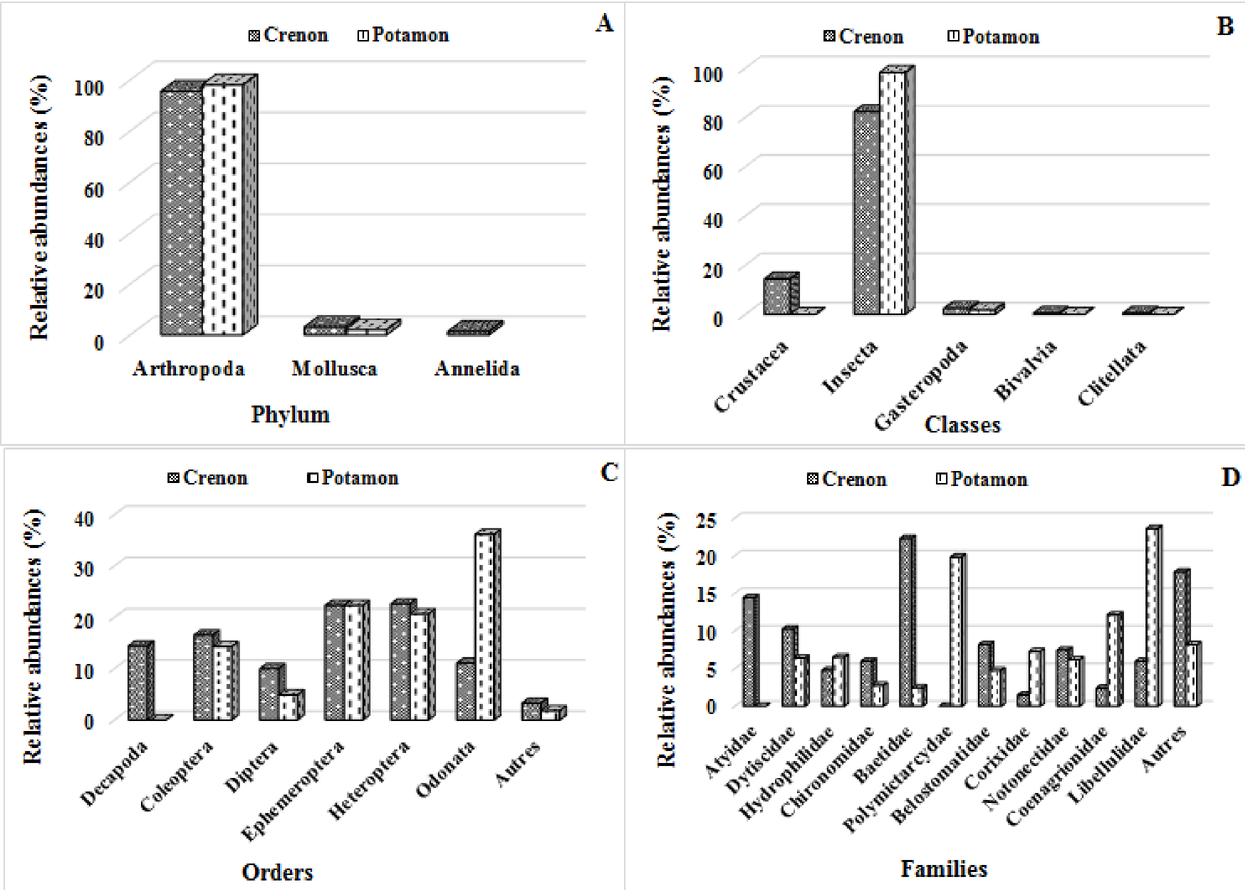

Figure 3. *Distribution of the relative abundance of benthic macroinvertebrates identified in the Lobo River during the study period. A. Phylum; B. Classes; C. Orders; D. Families. Note: Only families representing more than 5% of relative abundance are shown.*

3.4. Sampling Success

The highest (87.9%) and lowest (82.06%) sampling success rates were obtained at L3 and L1, respectively, using the Bootstrap estimator (Table 2). Across seasons, the highest success rate (91.28%) was obtained during the SDS and the lowest (88.37%) during the LDS using the same estimator.

The trend in species richness as a function of BMI abundance indicates that the stream has been sampled almost exhaustively; the plateau suggests that the data are approaching the actual species richness of the habitat (Figure 4A). The L3 curve lies above the other curves, indicating greater species richness at this station. The L1 curve has a slope nearly identical to that of L3, but its species richness is lower, indicating that additional sampling effort is required. Analysis of the seasonal species rarity curves (Figure 4B) shows that the SRS curve tends to reach the saturation plateau. This curve lies above the others, indicating higher species richness compared to other seasons.

Table 2. *Sampling success using non-parametric estimators of species richness at stations and across seasons.*

Nonparametric estimators	Stations				Seasons			
	L1	L2	L3	L4	LDS	LRS	SRS	SDS
S	35	38	51	37	48	33	61	34
ACE	46,6 (75,11)	47,16 (80,58)	61,5 (82,93)	44,81 (82,57)	68,5 (70,07)	88 (37,5)	79,21 (77,01)	52 (65,38)
ICE	58,46 (59,87)	64,64 (58,79)	66,11 (77,14)	48,78 (75,85)	63,6 (75,47)	59,56 (55,41)	99,19 (61,5)	48,55 (70,03)
Chao 1	44,71 (78,28)	46,98 (80,89)	61,99 (82,27)	46,33 (79,86)	61,18 (78,46)	55,45 (59,51)	86,48 (70,54)	42,98 (79,11)
Chao 2	54,73 (63,95)	55,54 (68,42)	66,69 (76,47)	44,62 (82,92)	59,48 (80,7)	37 (89,19)	87,77 (69,5)	35,77 (95,05)

Nonparametric estimators	Stations				Seasons			
	L1	L2	L3	L4	LDS	LRS	SRS	SDS
Jack 1	52,54 (66,62)	55,54 (68,42)	66,69 (76,47)	48,08 (76,96)	61,5 (78,05)	41,5 (79,52)	85 (71,76)	40,5 (83,95)
Jack 2	63,19 (55,39)	65,41 (58,1)	75,65 (67,42)	52,8 (70,08)	67,5 (71,11)	41,5 (79,52)	97,6 (62,5)	40,5 (83,95)
Bootstrap	42,65 (82,06)	45,81 (82,95)	58,02 (87,9)	42,17 (87,74)	54,32 (88,37)	37,25 (88,59)	71,89 (84,85)	37,25 (91,28)
MM Means	67,85 (51,58)	65,59 (57,94)	63,96 (79,74)	45,79 (80,8)	65,78 (72,97)	50,53 (65,31)	95,31 (64)	44,52 (76,37)

Legend: LDS. Long Dry Season; *LRS.* Long Rainy Season; *SRS.* Short Rainy Season; *SDS.* Short Dry Season; *S.* Observed species richness; the capture success rate is given in parentheses. The maximum and minimum sampling success rates are indicated by the numbers in bold.

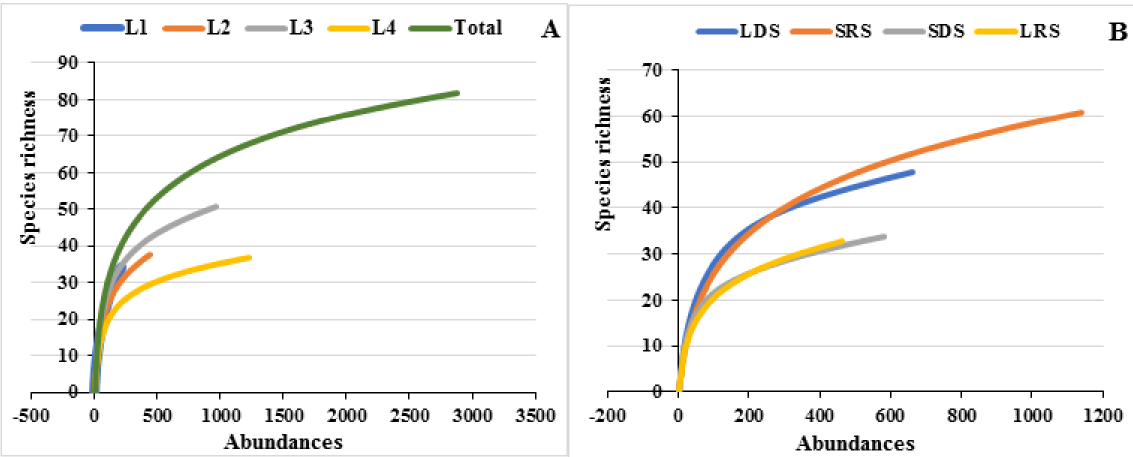

Figure 4. *Specific accumulation curves showing the increase in specific abundance as a function of sampling effort at stations and seasons.*

The Shannon-Weaver index (H') ranged from 0 bits/ind (L1) to 3.21 bits/ind (L2) in the crenon and averaged 1.80 ±0.17 bits/ind (Figure 5). In the potamon, it ranged from 0.24 bits/ind. (L4) to 4.04 bits/ind. (L3) and averaged 2.61 ±0.18 bits/ind. This index differed significantly between L1 and L3 (ANOVA test, p = 0.00). Pielou's J-index of equitability fluctuated between 0.81 and 5.91 (L2) in the crenon, with a mean of 0.39 ±0.06, and from 0.18 to 0.82 (L4), with a mean of 0.59 ±0.04, in the potamon (Figure 5). A significant difference was observed between L1 and L3 (ANOVA test, p = 0.04).

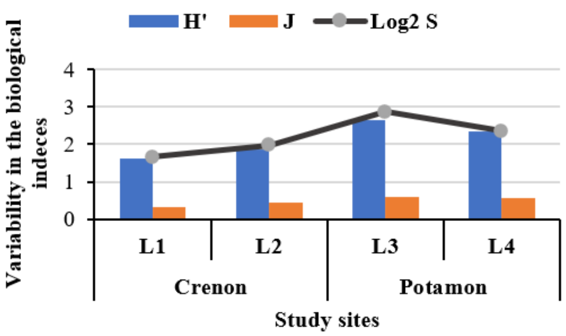

Figure 5. *Variation in the Shannon-Weaver diversity index, Pielou's evenness, and Log2 S at the different study sites; S. species.*

3.5. Biondicator Species

IndVal showed that at the 5% threshold, the following species are potentially indicator: *Caridina africana* and *Phyllomacromia bifasciata* (L1), *Micronecta* sp., *Tramea transmarina* (L3), *Canas macateei* (L4), and *Notonecta* sp. (SRS) (Table 3). No bioindicator species were identified at station L2 or during the LDS, SDS, and LRS.

3.6. Principal Component Analysis (PCA)

The PCA showed that the first two dimensions explain 78.64% of the variation observed in the aquatic macroinvertebrate community (Figure 6). The negative portion of axis 1 (G1) is correlated with dissolved oxygen, NO_2^-, PO_4^{3-}, and organisms of the Atyidae family; waters with these characteristics are found at L1. The negative part of axis 2 (G2) is correlated with Belostomatidae, Polymictarcyidae, Noteridae, and Libellulidae, which are found predominantly at L4. The positive part of axis 1 (G3) is correlated with Dytiscidae, Chironomidae, Corixidae, and Coenagrionidae, which were more abundant at L3. The positive part of axis 2 (G4) is correlated with pH, NH_4^+, SS, turbidity, and L2, where Baetidae were predominantly recorded.

***Table 3**. Indicator values for benthic macroinvertebrate taxa of the crenon and potamon of the Lobo River during the study period.*

Taxa	Sites	Stations/ season	Specificity (%)	Loyalty (%)	Indicative Value (%)	pvalue
Caridina africana	Crenon	L1	100	75.00	86.60	0.036
Phyllomacromia bifasciata		L1	100	75.00	86.60	0.036
Micronecta sp.	Potamon	L3	80.70	100	89.80	0.014
Tramea transmarina		L3	100	75.00	86.60	0.026
Canas macateei		L4	87.50	75.00	81.00	0.044
Notonecta sp.	//	SRS	100	75.00	86.60	0.036

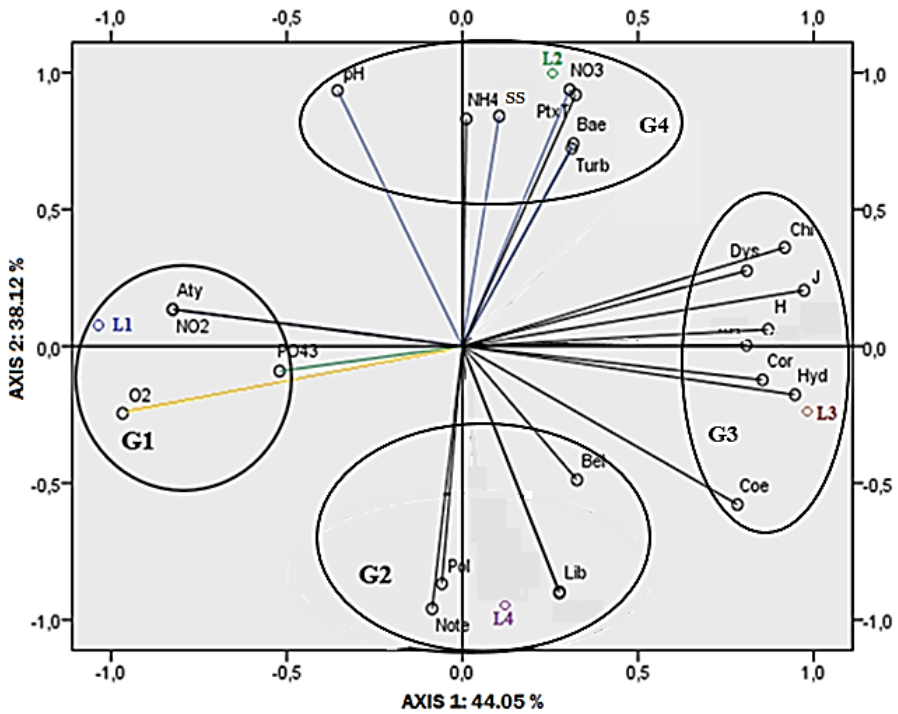

***Figure 6**. Principal Component Analysis performed on the families of benthic macroinvertebrates collected at the stations during the study.*

Acronyms: *G1*. Group 1; *G2*. Group 2; *G3*. Group 3; *G4*. Group 4; *Cor*. Corixidae; *Hydr*. Hydraenidae; *Coe*. Coenagrionidae; *Cana*. Canidae; *Lib*. Libellulidae; *Dys*. Dytiscidae; *Hyd*. Hydrophilidae; *Note*. Noteridae; *Bae*. Baetidae; *Poly*. Polymictarcyidae; *Bel*. Belostomatidae; *H*. Shannon and Weaver; *J*. Pielou's evenness.

4. Discussion

4.1. Physicochimical Parameters

The saturation of dissolved oxygen in the water was lower in the potamon. Indeed, the demand for dissolved oxygen to break down organic matter at this site is likely high due to direct sunlight on the water surface and the decomposition of submerged trees following the construction of the Mekin Dam. According to Sambraus et al. [39], dissolved oxygen levels in water are lower in waters exposed to sunlight, and physical phenomena that contribute to water warming can further reduce these levels. Nwaha et al. [9], Menbohan et al. [14], and Dzavi [20] observed low oxygen levels in a watercourse that had received a large amount of decomposing organic matter in the same ecological zone.

The values for pH, TSS, turbidity, NH_4^+, NO_2^-, and NO_3^- were low throughout the study and did not differ significantly between the crenon and the potamon. The water is therefore considered to be of good physicochemical quality owing to the forested nature of the Lobo River. According to Rodier et al. [18], Betsi [24] and Melle Epounde [40], in a healthy stream, the pH is slightly acidic to basic, ranging between 6 and 9 pH units, SS levels are low, the water is not very turbid, and nutrients are present in low concentrations. Low nutrient concentrations were reported by Gwos Nhiomock and Nwaha et al., in the humid forest ecological zone [5, 9]. These parameters fall into the "good" quality class for biological assessement, drinking water production, and livestock watering [41]. These parameters differ from those obtained by Dzavi [20] in the Nyong watershed. Orthophosphate levels were higher in the crenon at L1, which could be explained by the use of detergents for domestic activities at the station. According to CEAEQ [42], phosphorus in natural waters comes mainly from the use of detergents, however waters can also become enriched with orthophosphates from the soils they flow through and from leached rocks [24, 43].

4.2. Benthic Macroinvertebrates

The aquatic fauna is characterized by the presence of crustaceans of the family Atyidae, specifically *Caridina africana* in the crenon (14.41%), and their absence in the potamon. With an indicator value of 86.60%, this species was 100% specific and 75% faithful to L1. The presence of dense canopy cover, biodegradable plant material, a sandy-silty substrate, and low water mineralization in the crenon may explain this abundance. According to Tachet et al. [32], crustaceans are often found in the leaf litter, which serves as food and shelter from predators. Betsi [18] identified *Caridina africana* as a bioindicator at sites with similar characteristics. The order Odonata was less abundant in the crenon (10.99%) than in the potamon (33.13%). Similarly, the family Libellulidae was less abundant in the crenon (5.94%) than in the potamon (23.59%). These low abundances are likely linked to the near absence of macrophytes in the crenon due to the presence of canopy cover. Dzavi, Schriever et al. and Milot noted that odonates tend to thrive in sites with high macrophyte potential, as these provide favorable egg-laying sites and conditions for the rapid development of their larvae [20, 44, 45]. The odonate *Phyllomacromia bifasciata* was 100% specific and 75% faithful to L1 (IndVal = 86.60%, $p = 0.036$). The L1 site indeed offers favorable environmental conditions, as this species prefers sandy-silty sediments and leaf litter [46].

The species richness obtained at each station was lower than the theoretical species richness estimated using non-parametric estimators. However, the species accumulation curves at each station reveal that sampling efforts were sufficient to discover the majority of species present at those sites. According to Longino and Wandji et al., as sampling effort increases in a given habitat, a saturation threshold is reached, and species richness changes little with the addition of new species [47, 48]. Thus, the species recorded at each station is representative of the crenon and potamon of the Lobo River and generally indicates a satisfactory sampling effort (87.90%, L3, and 91.28%, SDS); however, additional effort would have been needed at all stations to reach 100%.

The Shannon-Weaver index across all stations was low suggesting low overall diversity. According to Simboura and Zenetos, a habitat with a Shannon-Weaver index between 1.5 and 3 bits/ind. is considered poor and moderately polluted [49]. This result differs from that of Nwaha et al. [9], who obtained diversity values greater than 3 bits/ind. in the forested part of the rainforest zone, and is similar to those obtained by Lactio et al. [7] in the urban part of the same ecological zone.

The PCA analysis reveals a predominance of pollution-sensitive taxa from the family Atyidae in the crenon (L1), while pollution-sensitive taxa from the family Polymictarcyidae were more abundant in the potamon (L4). The dominance of Polymictarcyidae could be explained by the abundance of large woody debris at this site, as these organisms are burrowers found in large rivers that dig tunnels in their substrates [50]. Allouko and Kouame Affoue report the presence of Polymictarcyidae in the Ahgien lagoon and the Sassandra River basin in Côte d'Ivoire, respectively, both of which are subject to the same seasonal variations as the Lobo River [51, 52].

5. Conclusion

Based on the studies conducted in the crenon and potamon of the Lobo River, it appears that the waters of the crenon are slightly more oxygenated and turbid, with slightly higher pH, nitrogen forms, and orthophosphate values than those of the potamon. The levels of these variables fall within the "good quality" class, favorable for the development of aquatic organisms, the production of drinking water, and animal watering. In terms of fauna, the crenon is characterized by the presence of the indicator species *Caridina africana* and *Phyllomacromia bifasciata*, which are absent from the potamon. The potamon is characterized by the presence of Polymictarcyidae, which are absent from the crenon. Libellulidae present at both sites, are less abundant in the crenon due canopy cover. *Micronecta* sp., *Tramea transmarina*, and *Canas macateei* are identified as bioindicators of the potamon, and *Notonecta* sp. as a bioindicator of the short rain season. The Shannon-Weaver diversity index indicates low diversity across sites, with communities comprising both pollution-sensitive organisms (Atyidae and Polymictarcyidae) and pollution-tolerant organisms (Libellulidae and Belostomatidae), as revealed by PCA.

Abbreviations

BMI	Benthic Macroinvertebrate
SS	Suspended Solid
PCA	Principal Component Analysis
LDR	Long Dry Season
LRS	Long Rainy Season
SDS	Small Dry Season
SRS	Small Rainy Season

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Author Contributions

Boudem Tsane Cecile Rita: Conceptualization, Data curation, Formal Analysis, Methodology, Resources, Software, Visualization, Writing – original draft, Writing – review & editing

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Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

***Table A1.** SEQ-Eau Grid (MEDD and AE, 2003).*

Aptitude level	**Blue**	**Green**	**Yellow**	**Orange**	**Red**
Aptitude Index	**80**	**60**	**40**	**20**	
Biology					
Dissolved oxygen (%)	90	70	50	30	20
NH_4^+ (mg/L NH_4^+)	0.5	1.5	4	8	10
NO_2^- (mg/L NO_2^-)	0.03	0.3	0.5	1	2
NO_3^- (mg/L NO_3^-)	2				>2
PO_4^{3-} (mg/L PO_4^{3-})	0.1	0.5	1	2	>2
pH (UC)	8	8.5	9	9.5	>9.5
SS (mg/L)	25	50	100	150	>150
Turbidity (FTU)	15	35	70	100	>100
Drinking Water Production					
Dissolved oxygen (%)	70		50	30	20
NH_4^+ (mg/L NH_4^+)	0.5		1.5	4	6
NO_3^- (mg/L NO_3^-)	50				>50
SS (mg/L)	2	50	2000	5000	>5000
Turbidity (FTU)	1	35	1500	3750	>3750
Color (Pt.Co)	15	20	100	200	>200
Transparency (cm)	600	100	10	5	< 5
Watering animals					
NO_2^- (mg/L NO_2^-)	0.1		30	>30	
NO_3^- (mg/L NO_3^-)	50		450	>450	
Assessment	Very good	Good	Critical	Bad	Very bad

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