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Influence of Physico-Chemical Parameters on the Diversity of Freshwater Fish in Bamingui-Bangoran (Central African Republic)

Jean-Pierre Moalbaye[1*], Lucie Aba-Toumnou[1,2], Emmanuel Kamba Mebourou[1], Narcisse Ouya[1], Michael Ngaraboumé[1], Guy Roland Mbah[1], Guy Magloire Kambade[1], Serge Florent Bolevane Ouantinam[1], Jocelin Ngando[1], Solange-Patricia Wango[1]

[1]Laboratory of Applied Animal Biology and Biodiversity, Faculty of Sciences, University of Bangui, Bangui, Central African Republic
[2]Laboratory of Biological and Agronomic Sciences for Development, University of Bangui, Bangui, Central African Republic
Email: *jeanpierremoalbaye66@gmail.com

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Abstract

Tropical freshwater ecosystems exhibit high biodiversity that is strongly influenced by physicochemical conditions. This study, conducted in the Bamingui-Bangoran watershed (Central African Republic), aimed to assess the influence of these parameters on the structure and diversity of fish communities. Eight sampling stations were investigated, where in situ measurements of temperature, pH, conductivity, dissolved oxygen, and water transparency were performed, while fish were collected using gillnets and cast nets and identified to the species level. The results revealed spatial variability in physicochemical parameters, characterized by generally neutral to slightly alkaline waters, moderate mineralization, and variable oxygen levels, as well as high turbidity in some stations. A total of 213 individuals were recorded, dominated by Mormyridae (37.56%), followed by Cichlidae and Cyprinidae. The distribution of abundances showed a strong dominance at Bamingui 3 station (52.11% of total catches), whereas Shannon diversity indices indicated higher diversity in some Bangoran stations (H' up to 1.57). The average evenness ($E \approx 0.5$) suggested a relatively balanced distribution of individuals despite taxonomic dominance in certain stations, and the low similarity between stations (<10%) reflected high heterogeneity of fish assemblages. These findings demonstrate that physicochemical parameters significantly influence the structuring of fish communities and highlight the importance of water quality and habitat diversity in maintaining aquatic biodiversity, thereby providing essential scientific insights for sustainable fisheries management and freshwater ecosystem conservation in the Central African Republic.

Keywords

Physicochemical Parameters, Fish, Diversity, Freshwater

1. Introduction

Tropical freshwater zones constitute biodiverse ecosystems where interactions between the physicochemical characteristics of the water and biological communities determine trophic structure and the functioning of food webs [1] [2]. Among these interactions, aquatic macroinvertebrates play a central role: they participate in biogeochemical cycles, ensure the decomposition of organic matter, and represent an essential food source for many freshwater fish species. Their availability, abundance, and taxonomic composition directly influence the growth, survival, and reproductive success of consuming fish [3] [4].

The physico-chemical parameters of water strongly modulate the distribution, abundance and diversity of benthic macroinvertebrates [5] [6]. Variations in these parameters, whether of natural origin (hydrological seasonality, flood regime) or induced by anthropogenic activities (agriculture, sedimentation, domestic discharges), lead to measurable community responses in macroinvertebrates, with cascading effects on higher trophic levels, particularly fish [7] [8].

In the Bamingui-Bangoran region, where freshwater fish are a vital source of protein and income for local communities, analyzing the influence of physicochemical parameters on fish diversity is a fundamental tool for assessing the ecological status of aquatic ecosystems, guiding the sustainable management of fisheries resources, and developing biological indicators adapted to local conditions. This study aims to characterize the spatiotemporal variations of physicochemical parameters in aquatic habitats, analyze their effects on fish diversity and abundance, and ultimately provide a relevant scientific framework for the conservation and sustainable management of freshwater ecosystems in the Central African Republic.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Bamingui-Bangoran watershed (**Figure 1**), located in the north of the Central African Republic, a region characterized by a tropical Sudano-Sahelian climate with a marked dry season (November-March) and a rainy season (April-October). The hydrographic network consists of permanent and temporary rivers and streams, exhibiting a diversity of habitats (fast-flowing areas, riffles, slow-moving areas, and varied substrates). The eight sampling stations were selected along the watercourses based on hydromorphological criteria (width, depth, current velocity), accessibility, and potential environmental gradients (upstream-downstream, anthropogenic influence) [9].

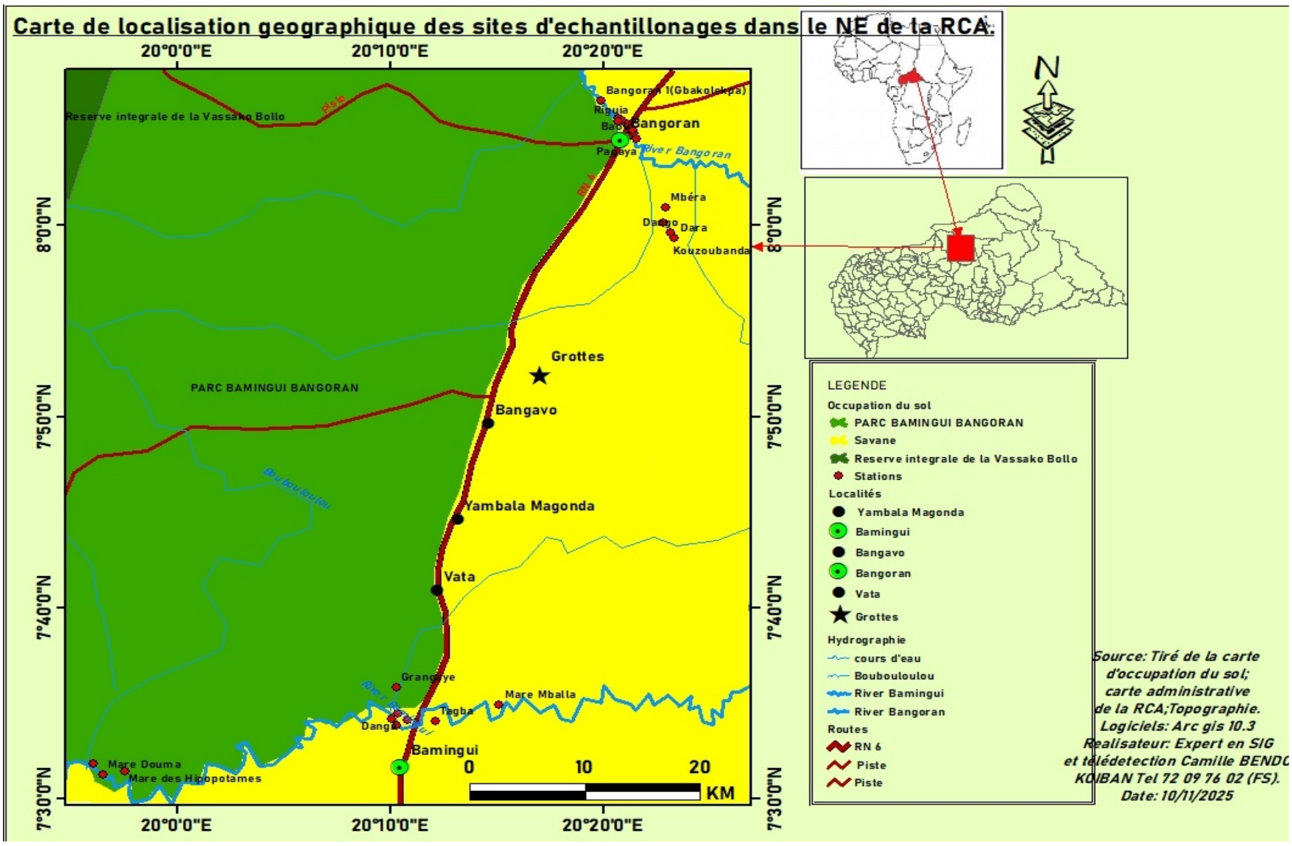

Figure 1. Sample collection stations (Moalbaye, 2025).

2.2. Sample Collection Method

A range of materials and equipment was deployed for the collection and recording of fisheries data at the various sampling stations. Fish were caught using gillnets of varying mesh sizes and hooks, which were deployed and retrieved using a dugout canoe. Furthermore, the biological and environmental data associated with the specimens were recorded on inventory sheets and then digitally entered using the KoboCollect application.

2.3. Measurement of Physicochemical Parameters

The physicochemical parameters of the water were measured in situ at each sampling station, concurrently with the fish capture campaigns, to reduce biases related to the temporal variability of environmental conditions. The variables measured included water temperature (˚C), potential of hydrogen (pH), total dissolved solids (TDS, $mg \cdot L^{-1}$), and electrical conductivity ($\mu S \cdot cm^{-1}$), using a multiparameter pH/conductivity instrument (WTW Xylem Analytics, Germany). Dissolved oxygen concentration (DO, $mg \cdot L^{-1}$) and percentage oxygen saturation (%) were determined using a multiparameter oximeter (Mettler Toledo, Deutscher SAS), equipped with a dissolved oxygen-specific electrochemical probe and a combined pH and temperature probe.

Temperature and pH measurements were performed by immersing the electrode probe at the water surface (≈1 cm depth), with direct reading of the stabilized values on the instrument's screen. Electrical conductivity, used as an indirect indicator of mineralization and total ionic charge of the water, was measured directly using a conductivity meter, reflecting the total concentration of dissolved ions and the salinity of the medium [10]. Dissolved oxygen was measured by an electrochemical sensor calibrated before each sampling campaign, providing concentrations in $mg \cdot L^{-1}$ as well as relative oxygen saturation values (%).

Water turbidity was estimated from the transparency depth measured using a Secchi disk, a two-colored (black/white) circular disk attached to a graduated string. The disk was submerged vertically until it disappeared completely from view, and the corresponding depth (Secchi depth) was recorded. This measurement provides an optical indicator of water transparency and has an inverse relationship with turbidity [11].

2.4. Fish Sampling

Fish were collected using a combination of passive and active fishing techniques. Initially, gillnets were deployed upstream and downstream of the site to define a capture zone a few meters wide. These nets were deployed vertically and horizontally at a depth adapted to the characteristics of the watercourse. Subsequently, an active fishing session of approximately one hour was conducted using cast nets. In cases of low catches, a disturbance operation was performed by beating the water surface (1 to 2 minutes using wooden sticks) to dislodge fish from their hiding places and optimize capture. The captured specimens were immediately kept in a cooler placed at the water's edge to preserve their biological integrity. They were then sorted and identified to the species level using appropriate taxonomic keys.

2.5. Sorting and Identifying Fish

As part of a fish biodiversity study conducted in the Bamingui-Bangoran region, fish sorting was an essential preliminary step to biological analyses. It was carried out immediately after capture to prevent any alteration of the specimens. Individuals were grouped according to their morphological characteristics, including body shape, fins, scales, coloration, and the presence of barbels, using reference identification guides. A count by species allowed for the estimation of abundance, relative frequency, and species dominance. Taxonomic identification relied on the use of dichotomous keys adapted to the ichthyofauna of Central Africa. This took into account various morphological criteria such as fin arrangement, scale type, ray formula, and mouth morphology. The specimens were then classified by morphotype and coded according to their site of origin. They were weighed precisely and then preserved in 95% alcohol. This rigorous protocol ensured the reliability of the collected data. It thus allowed for an accurate assessment of the species richness and structure of the fish communities.

2.6. Statistical Analyses

Taxonomic composition and richness were assessed based on the total number of taxa recorded, as well as the frequency and percentage of taxonomic units across all studied sites. The collected data allowed for the calculation of several biological indices commonly used in the study of aquatic biodiversity. The species diversity of the communities was estimated using the Shannon-Weaver index, which takes into account both the richness and the relative abundance of taxa. This index is expressed according to the following formula:

$$H' = -\sum Ni/N \cdot Ln\ (Ni/N)$$

With H': Shannon-Weaver index, Ni: number of individuals of a given species, and N: total number of individuals. The Pielou Evenness Index [12], which reflects the degree of diversity achieved, was calculated to identify the balance of the stands according to the following formula:

$$E = H'/H_{max} = H'/Log2S$$

With S: number of species observed.

These indices were determined using the vegan package of the R software (version).

2.7. Stand Similarity Analysis

The similarity of fish populations between stations was assessed based on the average abundances of taxa. A distance matrix was constructed using the Euclidean method, allowing for the quantification of dissimilarities between stations. Community structure was analyzed using hierarchical clustering (McQuitty method), performed with the ade4 packages and stats using the R software. This approach made it possible to identify groupings of stations with similar populations.

3. Results

3.1. Physico-Chemical Parameters of the Stations

Temperature: Station 2 (Bamingui) had the highest temperature (37.3˚C), due to its full sun exposure and lack of vegetation cover. The other stations, partially shaded by forest or wooded savanna, were cooler. Dissolved oxygen: Overall, higher levels were recorded at the Bamingui stations than at the Bangoran stations. The highest value was recorded at station 2 (6.2 mg/L), while station 6 (Bangoran) had the lowest level (3.8 mg/L), likely related to the density of aquatic vegetation.

Electrical conductivity: Measurement of the presence of ions in water, necessary for the transport of electric current. The conductivity varied between 95 and 110 µS/cm, except at station 2 (Bamingui) where it was low (53 µS/cm), indicating a low ion concentration.

pH: Characterizes the acidity or alkalinity of the water. Stations 2 and 4 were slightly alkaline with pH values of 7.3 and 7.4 respectively.

The variations observed between stations reflect the influence of sunlight, vegetation, and the chemical composition of the water on the physicochemical parameters. Bamingui had more oxygenated and slightly less ionized water, while Bangoran showed generally less oxygenated and turbid water (see Table 1).

Table 1. Physico-chemical parameters determined in situ at the surveyed stations in Bamingui and Bangoran.

Locality	No. Station	Secchi distance (m)	Temp (˚C)	Oxygen dissolved (mg/L)	Conductivity electric (µS/cm)	pH
station_1	1	0.9	29.9	6	96.6	7
station_2	2	0.45	27.3	6.2	53.3	7.3
station_3	3	0.6	26	5.5	110.1	7.05
Station_4	4	0.5	26	5.4	136	7.4
Station_5	5	0.38	26	5.4	102.8	6.7
Station_6	6	0.7	27	3.8	98.6	6.8
Station_7	7	0.6	26	5.4	109.8	6.9
station_8	8	0.65	28	4.9	95.1	6.8

Turbidity: Determined by the distance from Secchi. The shorter the distance, the more turbid the water. The most turbid stations were: station 2 (Bamingui) and stations 4 and 5 (Bangoran).

3.2. Abundance of Individuals in the Surveyed Stations

The hippopotamus pond (Bamingui 3) was the station with the highest number of fish collected, with 112 individuals collected out of 213, representing 52.11% (Figure 1). The second highest number of individuals was Bangoran 2 (station 5) with 37 caught, or 17.37%. The Bamingui 1 and 2 stations had the lowest numbers of individuals, with 5 and 6 individuals respectively (2.82% and 2.35%, respectively; Figure 2).

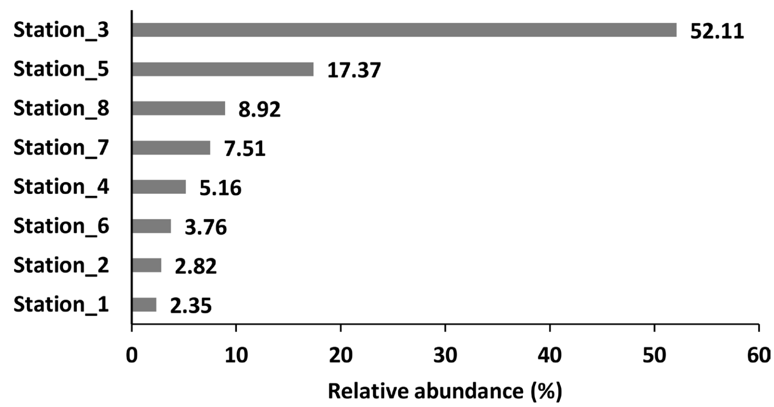

Figure 2. Frequency of fish caught (total = 213 individuals) in the surveyed aquatic environments.

3.3. Abundance of Individuals per Family

Individuals from the Mormyridae family were the most abundant (80 individuals) and represented 37.56% of the fish caught. The Cichlidae (41 individuals), Cyprinidae (40 individuals), and Clacriidae (27 individuals) families represented approximately 19.25%, 18.78%, and 12.68% of the fish population caught during the survey, respectively. Some identified fish families are presented in Figure 3.

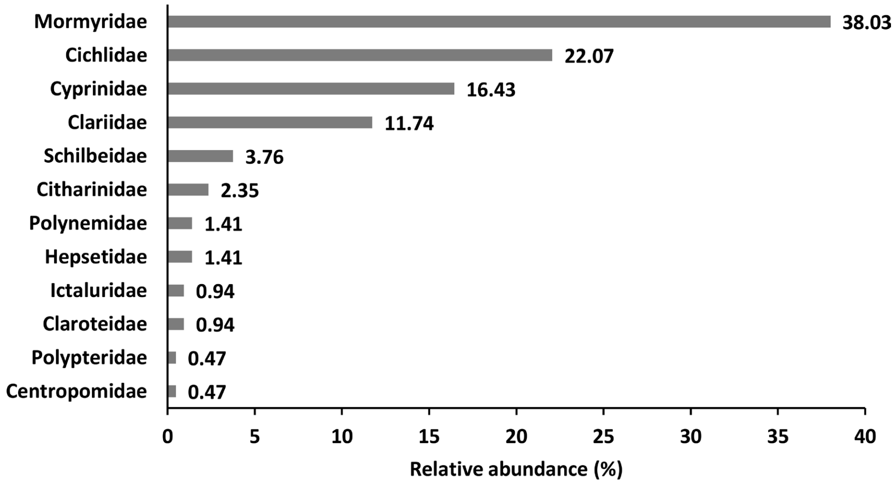

Figure 3. Frequency of fish caught per family (total = 213 individuals).

3.4. Fish Population Diversity Analysis

Table 2. Diversity indices of fish collected in Bamingui and Bangoran.

	S	H'	E	D
station_1	3	1.05	0.67	0.64
station_2	3	0.87	0.55	0.50
station_3	13	1.22	0.33	0.49
Station_4	5	1.50	0.65	0.76
Station_5	7	1.57	0.56	0.73
Station_6	4	1.26	0.63	0.69
Station_7	5	1.41	0.61	0.73
station_8	4	1.24	0.62	0.69

Fish populations were more diverse at Bangoran 2 (station 5, H' = 1.57) and Bangoran 1 (station 4, H' = 1.5), although these stations had lower numbers of individuals caught than Bamingui 3 (station 3, H' = 1.22). The station with the least diverse population was Bamingui 2 (station 1; Table 2).

The abundance of taxonomic groups at each surveyed station is around the average (E = 0.5) on the Pielou scale. This implies that the population is generally distributed across at least two taxa at each station, but the abundance of taxa is not identical at each station. Furthermore, at Bamingui 3, most of the fish collected (81/112) belonged to a single family (Mormyridae, sp.), which explains the lowest Pielou index (E = 0.33).

3.5. Similarity of Fish Population between Surveyed Stations

The fish population at the stations varied considerably from one station to another. The similarity rate between each pair of stations was less than 10%. Station 3 at Bamingui (where more than 50% of the fish were collected) was approximately 22% similar to all the other stations combined (**Figure 4**).

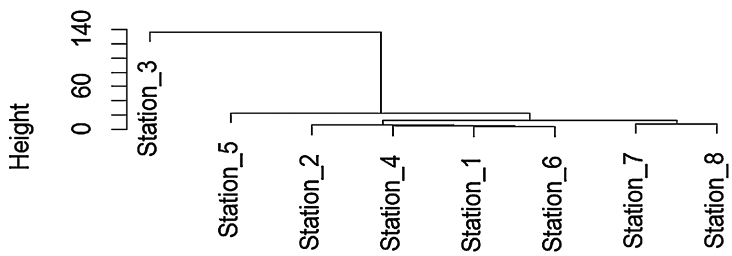

Figure 4. Dendrogram of similarity (hierarchical cluster analysis) between fish families in the surveyed stations.

4. Discussion

The spatial variations in physicochemical parameters observed between the Bamingui and Bangoran stations reflect marked environmental heterogeneity, characteristic of tropical aquatic ecosystems [13]. The low water transparency recorded at some stations indicates high turbidity, which may limit light penetration and reduce primary production, thus affecting the availability of trophic resources [14]. This turbidity likely results from sediment resuspension or a high organic matter load, common in tropical lentic environments.

In comparable tropical contexts, several studies have demonstrated the crucial role of physicochemical parameters in structuring fish communities. Temperature, pH, redox potential, and electrical conductivity are key variables influencing species distribution and abundance [15] [16]. These relationships are particularly critical in the Sahelian and Sudanian regions, where seasonal hydrological variations and anthropogenic pressures rapidly alter environmental conditions [17] [18].

The differences observed between stations suggest a direct influence of physicochemical parameters on the organization of aquatic communities. High turbidity at some stations (notably stations 2, 4, and 5) can reduce primary productivity and disrupt food webs. Furthermore, relatively high temperatures, especially in highly exposed areas, accelerate metabolic processes and can alter the species composition of the communities [19].

Dissolved oxygen concentrations, generally higher at Bamingui, are favorable to sensitive species, while the low levels observed at Bangoran, particularly at station 6, could indicate increased decomposition of organic matter or the beginning of eutrophication [20]. Similarly, electrical conductivity, as an indicator of mineralization, influences species distribution, with some species being adapted to weakly ionized environments [21].

The higher taxonomic richness observed at Bangoran reflects greater ecological heterogeneity, a factor known to promote biodiversity [22]. Shannon diversity indices (H') indicate moderate to high diversity in the majority of stations, which corresponds to the characteristics of relatively undisturbed tropical ecosystems.

In contrast, the low diversity observed at some stations in Bamingui, particularly station 2, suggests restrictive environmental conditions that may lead to a simplification of biological communities [23]. The average evenness ($E \approx 0.5$) reveals an overall balanced distribution of individuals, although some stations are dominated by a few taxa, reflecting conditions favorable to competitive species [24].

The marked dominance of the Mormyridae family is a structuring element of the fish population. This group, well adapted to tropical environments, can efficiently exploit various ecological niches, which explains its high abundance in certain sites [25]. This dominance is particularly visible at Bamingui 3, where more than 50% of individuals were counted, leading to a decrease in evenness.

This type of distribution, characterized by high abundance associated with moderate diversity, is typical of systems where certain dominant species preferentially exploit available resources. It illustrates the fact that total abundance does not necessarily reflect biological diversity.

The very low similarity observed between stations highlights a significant spatial structuring of fish communities. This differentiation reflects a high degree of habitat heterogeneity and relative ecological isolation, factors that promote population diversification [26]. Local variations in environmental conditions, combined with the ecological preferences of the species, contribute to this spatial organization.

Overall, the results highlight a relatively high but spatially heterogeneous biodiversity, strongly influenced by physicochemical parameters and habitat characteristics. Sites located in less disturbed areas appear better preserved, while some sites show signs of degradation, particularly related to organic pollution. These observations underscore the importance of sustainable management of aquatic ecosystems, especially in tropical regions subject to increasing anthropogenic pressures. Preserving water quality and habitat heterogeneity appears essential for maintaining biodiversity and the ecological functioning of aquatic systems.

5. Conclusion

This study highlights a high degree of spatial variability in physicochemical conditions and aquatic communities in the Bamingui and Bangoran environments. The differences observed between stations, particularly those related to turbidity, temperature, oxygenation, and habitat structure, significantly influence fish diversity. The Bangoran stations generally exhibit higher diversity, reflecting greater ecological heterogeneity, while some Bamingui stations show more challenging conditions. The biological quality of the water is generally acceptable, although signs of local disturbances, particularly of organic origin, have been observed. The fish population, characterized by high heterogeneity and the dominance of certain groups, confirms this environmental structure. Macroinvertebrates play a central role in trophic functioning and constitute relevant bioindicators of ecological status. These results highlight the importance of physico-chemical factors in the organization of aquatic communities and underscore the need for ecological monitoring and sustainable management to preserve the biodiversity of the Bamingui-Bangoran basin in the face of increasing anthropogenic pressures.

Conflicts of Interest

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

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