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First data on the diversity and structure of aquatic communities in the peri-urban river « Blondai » at Anyama (South; Ivory Coast)

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Abstract

The aim of this study was to characterise the diversity and structure of aquatic communities in the « Blondai » River (Anyama) with a view to assessing its ecological status. Three representative points (upstream, middle and downstream) were set up for sampling. The physico-chemical parameters of the water were measured *in situ* and in the laboratory. Macroinvertebrates were collected using a Van Veen bucket and a dip net, while plankton was collected by filtering 30 litres of water using a plankton net. Macrophytes were inventoried by direct observation on the banks, and fish by experimental fishing and ethno-zoological surveys. Biological diversity was analysed using the Shannon-Weaver index, Piélou equitability index and canonical correspondence analysis. The water in the « Blondai » river is acidic, poorly mineralised and moderately oxygenated. The taxonomic inventory identified twenty-three species of phytoplankton (18 families, 14 orders), eight species of zooplankton (2 families, 2 orders), twenty-one species of macrophytes (14 families, 14 orders), twelve species of macroinvertebrates (11 families, 9 orders) and four species of fish (3 families, 3 orders). The order Cichliformes has proved to be the most diverse among fish. Chlorococcales, Euglenophytes and Euglenides dominate phytoplankton, Poales macrophytes, while Diptera (Chironomidae), Coleoptera and Basommatophores dominate macroinvertebrates. The Shannon index showed low to moderate diversity, reflecting an unbalanced community structure. The CCA revealed significant relationships between organisms and several physico-chemical variables: pH, total nitrogen and dissolved matter influence zooplankton; BOD_5, COD and temperature condition the distribution of macroinvertebrates; turbidity and dissolved oxygen determine that of macrophytes; and total phosphorus and conductivity structure phytoplankton communities. No significant correlation was observed for fish.

Keywords: Macoinvertebrates; River « Blondai »; Phytoplankton; Zooplankton; Fish; Macrophytes

1. Introduction

Freshwater, one of the rarest and least equitably distributed natural resources, is essential to life, not only for human populations, but also for the vast majority of living species [1]. The « Blondai » river, located on the outskirts of the town of Anyama, is a typical West African peri-urban aquatic ecosystem, highly exposed to anthropogenic pressures. Its catchment area is subject to increasing urbanisation, marked by the construction of road infrastructure, the extension of residential areas and the development of agricultural activities. These dynamics lead to a gradual deterioration in the quality of aquatic habitats and an alteration in the river's ecological functions ([2]; [3]). In this context, peri-urban aquatic ecosystems, despite playing a crucial role in maintaining local biodiversity, regulating hydrology and providing ecosystem services, are among the most vulnerable and least studied. Yet aquatic biodiversity is a sensitive and integrating indicator of the ecological status of environments, because living organisms respond directly to variations in physico-chemical parameters and environmental disturbances ([4] ; [5]). Assessing the structure and diversity of the biological communities in the River « Blondai » is therefore essential if an objective and scientifically robust ecological

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diagnosis is to be made. Not only does it enable us to assess the extent of the impact of human activities (organic and chemical pollution, destruction of habitats, changes in hydrological flows), it also provides a reference base for the implementation of biomonitoring tools ([6]; ([7]). The aim of this study is therefore twofold: (i) to contribute to an understanding of ecological dynamics in a peri-urban environment subject to multiple pressures, and (ii) to provide the scientific information needed to guide local strategies for managing and preserving water resources and associated biodiversity.

2. Materials and Methods

2.1. Sampling site

Table 1 Summary table of sampling station characteristics

Code	**ES1**	**ES2**	**ES3**
Types of ecosystems	River	River	River
Situation	Upstream	Median price	Downstream
Latitude	382804.00 m O	382055.00 m O	381925.00 m O
Longitude	609863.00 m N	609933.00 m N	609847.00 m N
Appearance of the water	Slightly cloudy	Claire	Claire
Substrate	Sandy	Sandy	Sandy
Flow speed	0.10 m/s	0.15 m/s	0.20 m/s
Depth (cm)	56 cm	55,5 cm	55 cm
Canopy	15%	0%	5%
Right bank	Chinese bamboo (*Bambusa vulgaris*) and macrophytes	Chinese bamboo (*Bambusa vulgaris*) and macrophytes	Chinese bamboo (*Bambusa vulgaris*) and macrophytes)
Left Bank	Chinese bamboo (*Bambusa vulgaris*) and macrophytes	Chinese bamboo (*Bambusa vulgaris*) and macrophytes	Chinese bamboo (*Bambusa vulgaris*) and macrophytes

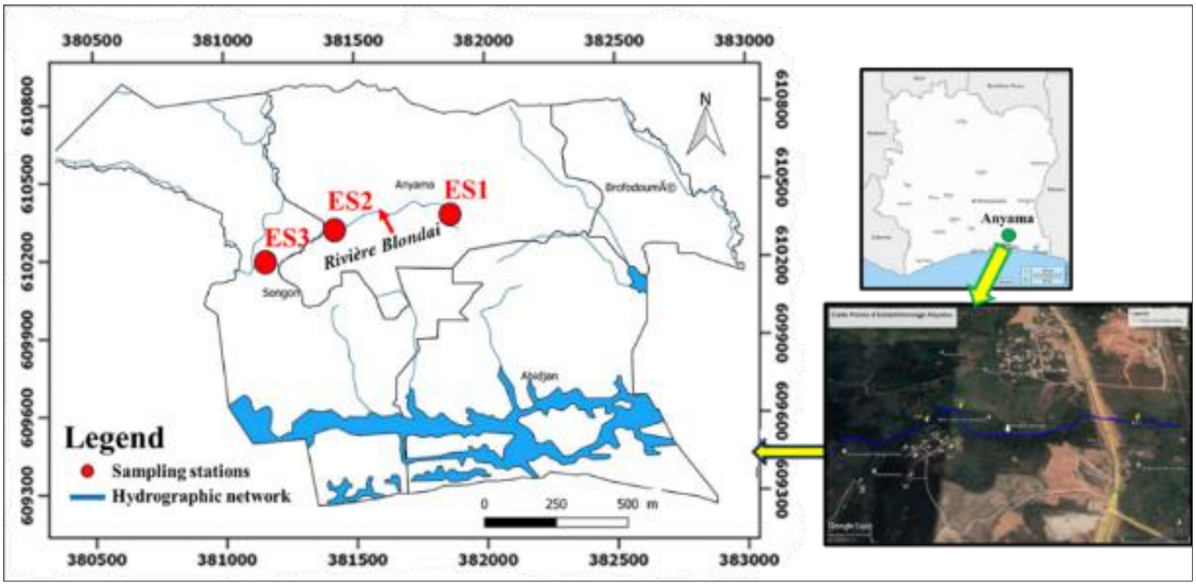

Figure 1 Presentation of the sampling stations

This spot study was carried out in the « Blondai » river located in the town of Anyama in the south of Côte d'Ivoire. The study area lies between latitudes 380,500 m N and 383,000 m N and longitudes 609,300 m W and 610,000 m W (UTM, zone 30N, WGS84) (Figure 1). This study was carried out from 20 to 25 March 2023 at three (03) sampling stations coded ES1, ES2 and ES3 located respectively upstream, midstream and downstream of the river « Blondai ». These points were selected on the basis of the durability of the water, their accessibility and the human activities to which they were subject. Table 1 below shows the characteristics of the various sampling stations

2.2. Methods

2.2.1. Analysis of physico-chemical parameters

Physicochemical parameters were measured in the field and in the laboratory. Temperature, dissolved oxygen content, pH, electrical conductivity and turbidity were measured in situ using an AZOTA multimeter. Water transparency and depth were assessed by fully immersing a Secchi disc attached to a rope until it reached a level below the river bottom. Water samples were also taken at various stations along the river in 500 ml polyethylene bottles. They were transported to the ENVAL laboratory in coolers containing ice packs, where they were kept refrigerated at 5°C before being analysed. These water samples were used to measure total nitrogen (N), total phosphorus, BOD5, COD and dissolved solids according to the standard protocols of the Association Française de Normalisation [8].

2.2.2. Plankton sampling

Sampling of planktonic organisms at each of the stations selected on the « Blondai » river consisted of taking 30 litres of water using three (3) buckets of 10 litres each. This quantity of water was taken and filtered using a plankton net with a mesh size of 20 µm. The filtrate was then collected in 125-millilitre pillboxes containing 70% ethanol. In the laboratory, the plankton were observed directly with an optical microscope between slide and coverslip, after sedimentation of the samples. Phytoplankton organisms were identified using the identification guides in [9], [10] and [11]. Zooplankton organisms were identified using the works in [12]. Counting was carried out using an inverted microscope. Samples were homogenised by hand and poured into 10-millilitre sedimentation tanks in a single operation. In the case of media with a high concentration of particles (epiphytic solution), dilutions of epiphytic samples were made. A pipette with removable one-millilitre tips was used for this purpose. One millilitre of the sample was introduced into a 10-millilitre sedimentation chamber, which was then topped up with 10 millilitres of distilled water using a wash bottle. The solution in the tank was left to settle for 8 hours. Observations were then made at 40x magnification. The count was carried out by transect (diameters). Several fields were visited, enabling at least 400 planktonic objects to be counted [13]. Plankton density (D) is given by the following formula

$$\mathbf{N} = \times \frac{\boldsymbol{n.\,ind} \times \boldsymbol{R}}{\boldsymbol{V}} \times \boldsymbol{F} \quad \boldsymbol{ou}\ \boldsymbol{R} = \frac{\boldsymbol{\pi \times 132}}{\mathbf{(0,112 \times 13 \times 2) \times nb\ dida}}$$

Where: N = number of organisms per mL; n. ind = number of individuals counted; V = sedimented volume (mL); R = count ratio; 0.112 mm = strip width; 13 = chamber radius; nb dia = number of diameters counted; F = dilution factors. When samples are diluted, the dilution factor is 10, when samples are not diluted, the dilution factor is 1.

2.2.3. Sampling macrophytes

The inventory of macrophytes on each of the banks of the selected sections (Upstream, Midstream and Downstream) of the « Blondai » river in the Anyama area consisted of all-round sampling. The specimens encountered were photographed and counted. Identification was carried out using the identification books and keys in [14], [15] and [16].

2.2.4. Sampling, sorting, observation and analysis of macroinvertebrates

Macroinvertebrates were sampled using a stainless steel Van Veen bucket for sediment organisms and a dip net for submerged macroinvertebrates. For the benthos, a sediment sample corresponding to a total surface area of 0.15 m2 was taken at each station.

For submerged organisms, a haze net (250 µm mesh) was used using the SASS (South African Scoring System) method [17]. Samples were collected for 3 minutes by submerging the net and dragging it through the water column over an area of 1 m^2 (2 m * 0.5 m). The collected organisms were fixed with 70% ethanol in labelled jars and transported to the laboratory. In the laboratory, each sample, previously preserved in alcohol, was rinsed with tap water. The samples were then sieved and the individuals collected sorted using a binocular magnifying glass to separate the fauna from the debris and sedimentary particles. The organisms collected were counted, photographed and identified to the lowest possible taxonomic level using the appropriate determination keys ([18] ; [19]) and preserved in 70% ethanol.

2.2.5. Ichthyofauna sampling

The inventory of fish in the « Blondai » river in the Anyama area was carried out using two techniques, experimental fishing and ethno-zoological surveys of resource persons in the sacred parts of this river. Experimental fishing was carried out using two (2) landings nets. The ethno-zoological surveys consisted of the identification of fish images by the guardians of the sacred parts of the river. The specimens collected were identified at the specific level using the keys proposed by [20].

2.2.6. Data analysis method

Method of Diversity Analysis

Taxonomic richness, taxonomic group abundances, Shannon diversity indices and Piélou equitability indices were determined to analyse the biological diversity of communities.

- *Taxonomic richness*, highlighted the total number of species encountered at the various sampling stations [21].
- *Abundance of taxonomic groups* was used to determine the structure and distribution of macroinvertebrate communities in the river Blondai. It represents the ratio of the number of individuals of taxon (i) present to the total number of individuals [21]. It varies in space and time. Relative abundance is expressed as follows:

$$Pi = ni/N$$

where Pi is the relative abundance of species (i), ni is the number of individuals of species (i) and N is the total number of individuals.

- *The Shannon-Weaver diversity index* was used to measure specific diversity within macroinvertebrate communities. It is based on the number of species and the regularity of their distribution. $H' = -\Sigma\, p\, i \log 2\, pi$ where pi represents the relative abundance of species i in the sample ($p\, i = n\, i\, /N$). H' fluctuates between 0 and log S. A high Shannon index corresponds to favourable environmental conditions allowing many species to establish themselves. Generally, the value of H' is between 0.5 (very low diversity) and 4.5 or 5 (most diverse communities).
- *Piélou equitability*, has been used to evaluate the degree of homogeneity in the distribution of macroinvertebrate taxa, independently of their species richness. [22].

$$J = H\, log2\, (S)$$

Where H is the Shannon diversity index for a sample and S is its species richness. Equitability varies from 0 to 1.

2.3. Statistical method

The Shapiro-Wilk normality test was used to test the normality of the various data. The Kruskal-Wallis test was used to compare the various parameters measured at different sampling stations.

Canonical Correspondence Analysis (CCA) was performed using Past 3.4 software [23] to match the biotic and abiotic data obtained during sampling. All statistical analyses were carried out using Past 3.14 software.

3. Result

3.1. Spatial variations in the river's physico-chemical parameters

Temperature values ranged from 27.13±1°C (station ES1) to 32.7±0.81°C (station ES3). For pH, the minimum and maximum values observed in the river are 5.06±0.20 (ES3) and 5.83±0.72 (ES1) respectively. Conductivity values in the river ranged from 53.73±0.64 µS/cm (ES1) to 75.16±1.04 µS/cm (ES2). Spatial variation in dissolved oxygen in the river ranged from 3.66±0.5 mg/L (ES2) to 7.53±0.47 mg/L (ES1). The total nitrogen value varies between 0.53±0.04 mg/L (station ES3) and 1.08±0.07 mg/L (station ES1). Spatial variation in turbidity at the river stations ranged from 18.93±0.92 NTU (ES2) to 41.06±0.92NTU (ES1). The minimum and maximum BOD5 values observed at the river stations are 14±1mg/L (ES2) and 22±1 mg/L (ES3) respectively. COD concentrations measured at the river stations ranged from 51.86±0.50 mg/L (ES1) to 80.59±0.53mg/L (ES3). Total phosphorus values varied between 0.03±0.00 mg/L (stations ES1) and 0.12±0.01mg/L (station ES2). Dissolved solids concentrations at the river stations varied between 14±0.5 mg/L (ES2) and 14.5±0.5 mg/L (ES1). Variations in all the parameters measured in the river were not significant at the stations studied (Kruskal-Wallis test, p-value > 0.05).

Table 2 Spatial variation in the river's physical-chemical parameters

Stations	ES1	ES2	ES3
Temperature (°C)	27.13±1	30.83±0,15	32.7±0.81
pH	5.83±0.72	5.2±0,2	5.06±0.20
Conductivity (µS/cm)	53.73± 0.64	75.16±1,04	70.33±0.58
DBO5 (mg/L)	14.5±0,5	14±1	22±1
Total nitrogen (mg/L)	1.08±0.07	0.81±0,05	0.53±0.04
COD (mg/L)	51.86±0.50	52.51±0.5	80.59±0.53
Dissolved oxygen (mg/L)	7.53±0.47	3.66±0.5	7.16±0.37
Total phosphorus (mg/L)	0.03±0.00	0.12±0.01	0.04±0.00
Turbidity (NTU)	41.06±0.92	18.93±0.92	25.8±0.72
Dissolved Substances (mg/L)	14.5±0.5	14±0.5	14±1

3.2. Taxonomic composition of aquatic organisms in the river

3.2.1. Plankton

The specific compositions of phytoplankton and zooplankton in the river Blondai are shown in the table below. Sampling revealed the presence of 23 species of phytoplankton in 18 families and 14 orders. The most diverse orders were Chlorococcales, followed by Euglenophytes and Euglenides with 05 species, 04 species and 03 species respectively. The other orders are less rich, with 01 species each. Navicula sp. and Eugleuna polymorpha are the species most commonly found in the area.

As regards zooplankton, 08 species belonging to 5 families and 04 orders were encountered. *Mesocyclops leuckarti* is the most common species.

Table 3 Taxonomic composition of plankton in the « Blondai » river

Orders	Families	Species	Upstream	Median	Downstream
Phytoplankton					
Chlorollales	Oocystistaceae	*Oocystis solitaria* (Wittrock. 1879)	-	-	+
Desmidiales	Closteriaceae	*Closterium dianae* (Ehrenberg ex Raifs. 1848)	+	-	-
Euglenides	Phacaceae	*Lepocinclis ovum* (Ehrenberg) Lemmerm. 1901	-	-	+
		Lepocinclis oxyuris (B.Marin & Melkonian 2003)	-	-	+
	Phacidae	*Phacus* sp. (Dujardin. 1841)	-	+	+
Euglenophytes	Eugleunaceae	*Eugleuna polymorpha* (Dangeard. 1901)	+	+	+
		Eugleuna spirogyra (Ehrimberg. 1878)	-	+	-
		Strombomonas sp. (Guiry. 2025)	+	-	+

		Trachelomonas sp. (Ehrenberg. 1833)	-	+	+
Naviculineae	Naviculaceae	*Navicula* sp. (Bory de Saint-Vincent. 1822)	+	+	+
Pseudanabaenales	Pseudanabaenaceae	*Pseudanabaena catenata* (Lauterborn 1915)	+	-	-
Pseudanabaenales	Pseudanabaenaceae	*Pseudanabaena mucicola* (Schwabe. 1964)	+	-	-
Ulotrichales	Ulotrichaceae	*Ulothrix* sp. (Thuret. 1863)	-	-	+
Peridiniales	Peridiniaceae	*Peridinium* sp. (Ehrenberg.1828).	-	-	+
Chlorococcales	Hydrodictyaceae	*Pediastrum duplex (*Meyen. 1829)	-	-	+
	Microcystaceae	*Microcystis elachista* (West. 1894)	-	-	+
	Scenedesmaceae	*Actinastrum hantzschii* (Lagerh.1882)	+	-	-
		Scenedesmus sp*.* (Meyen. 1829)	-	+	-
	Aphanothecaceae	*Aphanothece* sp*.* (Nägeli. 1849)	-	-	+
Synechococcales	Merismopediaceae	*Aphanocapsa* sp. (West. 1894)	+	+	-
Aulacoseirales	Aulacoseiraceae	*Aulacoseira ambigua* (Simonsen. 1979)	-	-	+
Licmophorales	Ulnariaceae	*Ulnaria ulna* (Compère. 2001)	-	-	+
Gymnodiniales	Brachidiniaceae	*Karenia* sp.	-	-	+
Zooplankton					
Cyclopoides	Cyclopidae	*Mesocyclops leuckarti* (Claus. 1857)	+	+	+
Ploimidaes	Brachionidae	*Brachionus urceolaris* (Müller.1773)	-	-	+
		Brachionus sp. (Daday. 1883)	-	+	-
		*Brachionus plicatilis (*Müller. 1786)	+	-	-
Diplostraca	Daphniidae	*Ceriodaphnia affinis*	-	-	+
		*Ceriodaphnia dubia (*Richard. 1894)	-	-	+
	Chydoridae	*Camptocercus* sp. (Baird. 1843)	+	-	-
Hexarthridae	Floscularиaceae	*Hexarthra intermedia* (Wiszniewski. 1929)	-	+	-

+ = present; - = absent

3.2.2. Macrophytes

The specific compositions of macrophytes in the river 'Blondai' are shown in Table 4. The macrophyte inventory yielded 21 species belonging to 14 families and 14 orders. The most diverse order was the Poales (05 species, i.e. 24% of species). However, the Arales, Asparagales, Fabales, Filicales, Gleicheniales, Juncales, Malpighiales, Polypodiales, Solanales and Theales are the least diverse orders, with 01 species, or 05% of the total number of species. The upstream part of the river is the richest in species (10 species). However, the middle section is the least diverse (06 species).

Ludwigia octovalvis and *Synedrella nodiflora* are the most common species found in all three parts of the river (upstream, midstream and downstream). All other species are less common in the area.

Table 4 Taxonomic composition of macrophytes in the « Blondai » river

			ES1	ES2	ES3
Orders	**Families**	**Species**	**Upstream**	**Median**	**Downstream**
Arales	Araceae	*Cyrtosperma merkusii* (Hassk. Schott, 1857)	+	-	-
Asparagales	Liliaceae	*Dracaena fragrans* (Ker Gawl. 1808)	+	-	-
Asterales	Asteraceae	*Struchium sparganophorum* (Kuntze. 1891)	+	-	-
		Synedrella nodiflora (Gaertner.1791)	+	-	+
Commelinales	Commelinaceae	*Palisota bracteosa*	-	-	+
		Palisota sp.	+	-	-
Fabales	Fabaceae	*Vigna radiata* (Wilczek.1954)	+	-	-
Filicales	Woodsiaceae	*Gymnocarpium dryopteris* (Newman. 1851)	-	-	+
Gleicheniales	Gleicheniaceae	*Gleichenella pectinata* (Ching. 1940)	-	-	+
Juncales	Juncaceae	*Luzula sylvatica* (Gaudin. 1811)	+	-	-
Malpighiales	Euphorbiaceae	*Alchornea cordifolia* (Müll.Arg.. 1865)	-	-	+
Myrtales	Onagraceae	*Ludwigia decurrens* (walter.1788)	-	+	-
		Ludwigia octovalvis (Raven. 1962)	-	+	+
Poales	Poaceae	*Sorghum arundinaceum* (Stapf. 1917)	-	+	-
		Oplismenus compositus (Beauv.1812)	+	-	-
		Paspalum dilatatum (Poir. 1804)	-	-	+
		Pennisetum pedicellatum (Trin. 1832)	-	+	-
		Sorghum halepense (Pers. 1805)	-	+	-
Polypodiales	Thelypteridaceae	*Thelypteris palustris* (Schott. 1834)	+	-	-
Solanales	Convolvulaceae	*Ipomoea aquatica* (Forssk. 1775)	-	+	-
Theales	Cluciaceae	*Hypericum calycinum*	+	-	-
Total = 14	**14**	**21**	**10**	**6**	**7**

+ = present; - = absent

3.2.3. Macroinvertebrates

The taxonomic compositions of aquatic macroinvertebrates in the 'Blondai' river are shown in Table 5. Sampling revealed the presence of 12 species divided into 11 families and 9 orders. The most diverse orders were Basommatophora, Coleoptera and Diptera, with 02 species each, or 17% of the species richness. The other orders are less rich, with 01 species each, or 08% of species.

The downstream part of the river is the richest in species (10 species). However, the middle and upstream sections are the least diverse, with 02 species each. *Grenitis* sp. and *Polypedilum abyssiniae* are the species most frequently encountered in the three sections (upstream, midstream and downstream). All the other species were seen less frequently in the river.

Table 5 Taxonomic composition of macroinvertebrates in the « Blondai » river

			Upstream	**Median**	**Downstream**
Orders	**Families**	**Species**	**ES1**	**ES2**	**ES3**
Rhynchobdellides	Erpobdellidae	*Barbrania* sp.	-	-	+
Archaeogastropods	Neritidae	*Clithon* sp.	-	-	+
Basommatophora	Physidae	*Aplexa marmorata*	-	+	-
	Planorbidae	*Afrogyrus rodrignezensis*	-	-	+
Littorinimorphs	Hydrobiidae	*Tomichia differens*	-	-	+
Sorbeoconchs	Thiaridae	*Melanoides tuberculata*	-	-	+
Coleoptera	Gyrinidae	*Dineutus* sp.	-	-	+
	Hydrophilidae	*Grenitis* sp.	+	-	+
Diptera	Chironomidae	*Polypedilum laterale*	-	+	-
		Polypedilum abyssiniae	+	-	+
Hemiptera	Belostomatidae	*Diplonychus* sp.	-	-	+
Odonata	Libellulidae	*Zygonyx torrida*	-	-	+
9	**11**	**12**	**2**	**2**	**10**

+ = present; - = absent

3.2.4. Fish

Table 6 shows the specific composition of fish in the 'Blondai' river. A total of 04 species of fish were inventoried, divided into 03 families and 03 orders. The most diverse order is the Cichliformes (02 species, i.e. 50% of the species collected). However, the least diverse are the Siluformes and Synbranchiformes with 01 species, or 25% each.

The distribution of species richness shows that the upstream part of the river is the richest in species (04 species), while the middle and downstream parts are the least diverse (03 species each). *Sarotherodon melanotheron* and *Mastacembelus nigromarginatus* are the two species most frequently encountered in the three sections of the river (upstream, midstream and downstream). The least common are *Hemichromis bimaculatus* and *Clarias anguillaris*.

Table 6 Taxonomic composition of fish in the « Blondai » river

			ES1	ES2	ES3
Orders	**Families**	**Species**	**Upstream**	**Median**	**Downstream**
Cichliformes	Cichlidae	*Hemichromis bimaculatus* (Gill. 1862)	+	-	+
		Sarotherodon mélanotheron (Rûppell. 1852)	+	+	+
Siluriformes	Clariidae	*Clarias anguillaris* (Linnaeus. 1758)	+	+	-
Synbranchiformes	Mastacembelidae	*Mastacembelus nigromarginatus* (Boulanger. 1898)	+	+	+
Total = 3	3	4	4	3	3

+ = present; - = absent

3.3. Diversity of aquatic communities in the « Blondai » river

3.3.1. Plankton

Station ES3 recorded the highest taxonomic richness with 20 taxa, while the lowest taxonomic richness was recorded at station ES2 with 10 taxa.

The highest value of the Shannon diversity index (1.51bits) was observed at station ES3, while the lowest value of this index (1.01bits) was recorded at station ES2. The maximum equitability value (0.96) was observed at station ES1, while the lowest index value (0.9206) was recorded at station ES2, located in the middle of the river.

3.3.2. Macrophytes

Maximum abundance (37 individuals) was recorded at station ES1 located upstream in the river, while minimum abundance was observed at station ES2 (18 individuals) in the middle of the river. Station ES1 recorded the highest taxon richness with 10 taxa, while the lowest taxon richness was recorded at station ES2 with 6 taxa. Relative abundance varied between 34.52% (ES1) and 44.04% (ES1).

The highest Shannon diversity index value (2.05bits) was observed at station ES1, while the lowest value (1.49bits) was recorded at station ES3. The maximum equitability value (0.89) was observed at station ES1, while the lowest index value (0.77) was recorded at station ES3, located downstream.

3.3.3. Macroinvertebrates

Maximum abundance (46 individuals) was recorded at station ES3 downstream from the river, while minimum abundance was observed at station ES1 (2 individuals) upstream from the river. Station ES3 recorded the highest taxon richness with 10 taxa, while the lowest taxon richness was recorded at stations ES1 and ES2 with 2 taxa. Relative abundance varied between 3.85% (ES1) and 92% (ES3).

The highest Shannon diversity index value (1.65bits) was observed at station ES3, while the lowest value (0.69bits) was recorded at stations ES1 and ES2. The Piélou equitability index shows a different pattern to the Shannon index. The maximum value of equitability (1) is observed at stations ES1 and ES2, while the lowest value of the index (0.72) is recorded at station ES3, located downstream of the river.

3.3.4. Fish

Abundance (4 individuals) was similar at all sampling points. Station ES1 recorded the highest taxon richness with 4 taxa, while the lowest taxon richness was recorded at stations ES1 and ES2 with 3 taxa. Relative abundance was similar at all sampling points.

The highest Shannon diversity index value (1.38bits) was observed at station ES1, while the lowest value (1.04bits) was recorded at stations ES1 and ES2. The Piélou equitability index shows a different pattern to the Shannon index. The maximum equitability value (1) was observed at station ES1, while the lowest index value (0.94) was recorded at stations ES2 and ES3, located respectively in the middle and downstream reaches of the river.

Analysis of the indices using the Kruskal-Wallis test revealed no significant difference between the stations ($p > 0.05$).

Table 7 Diversity of aquatic organisms in the « Blondai » river

		Upstream	**Median**	**Downstream**
Organisms	**Diversity Index**	**ES1**	**ES2**	**ES3**
Plankton	Taxonomic richness	11	10	20
	Shannon index (H)	1.33	1.01	1.51
	Equitability E	0.96	0.9206	0.9591
Macrophytes	Taxonomic richness	10	6	7
	Number of individuals	37	18	29

	Relative abundance	44.04%	40.90%	34.52%
	Shannon index (H)	2.05	1.52	1.49
	Equitability E	0.89	0.85	0.77
Macroinvertebrates	Taxonomic richness	2	2	10
	Number of individuals	2	4	46
	Relative abundance	3.85%	7.69%	92%
	Shannon index (H)	0.69	0.69	1.65
	Equitability E	1	1	0.72
Fish	Taxonomic richness	4	3	3
	Number of individuals	4	4	4
	Relative abundance	33.33%	33.33%	33.33%
	Shannon index (H)	1.386	1.04	1.04
	Equitability E	1	0.94	0.94

3.4. Relation of physico-chemical parameters and aquatic organisms in the river

The following graph shows the result of the CCA between the physico-chemical parameters and the abundances and densities of aquatic organisms in the river « Blondai » (Figure 2). The information contained in the variables is 99% controlled by the axes 1 and 2 system. The first axis is negatively and strongly correlated with pH, total nitrogen and the concentration of dissolved matter. This same axis is positively and strongly correlated with Biochemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD) and temperature. The second axis is negatively and strongly correlated with total phosphorus and conductivity. It is also strongly and positively correlated with turbidity and dissolved oxygen. Dissolved oxygen, conductivity, temperature, turbidity, pH, COD, BOD5, total phosphorus, total nitrogen and dissolved matter therefore influence the distribution of aquatic organisms in the River « Blondai ». The projection of aquatic organisms onto the vector axes of environmental parameters (Figure 2) shows that on axis 1, there is a strong negative correlation between zooplankton species and pH, total nitrogen and dissolved matter concentration. On the same axis, there is a strong positive correlation between macroinvertebrate species and Biochemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD) and temperature at station ES3 downstream. In addition, on axis 2, there was a positive association between macrophytes and turbidity and dissolved oxygen. On the same axis, there was a negative association between phytoplankton organisms and total phosphorus and conductivity.

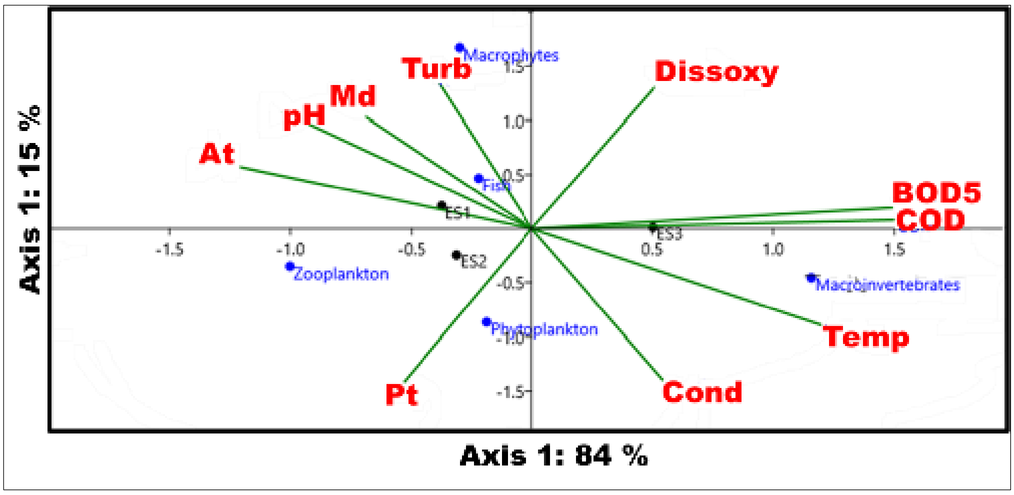

Figure 2 Canonical Correspondence Analysis of Organisms and Physical-Chemical Variables at stations in the « Blondai » river

Temp: Temperature, Cond: Conductivity, Turb: Turbidity, Oygdiss: Dissolved oxygen, pH, COD: Chemical Oxygen Demand, BOD5: Biochemical Oxygen Demand, Md: Dissolved matter, At: Total nitrogen, Pt: Total phosphorus

4. Discussion

The most important of these factors are temperature and dissolved oxygen levels. In our study, the range of temperature values is relatively high (27.13±1°C-32.7±0.81°C). This can be explained by the existence of a low canopy and therefore exposure of the water surface to solar radiation. Such high temperature values could have a negative influence on the concentration of dissolved oxygen [24]. Average dissolved oxygen concentrations in the river « Blondai » fluctuate between 3.66±0.5 mg/L and 7.53±0.47mg/L. The higher dissolved oxygen values can be explained by the renewal of the water due to run-off during this period. In fact, run-off helps to stir up the water and therefore increase oxygenation. Also, the solubility of dissolved oxygen is greater at low temperatures than at high temperatures, and is also lower in stagnant water [25]. Other authors such as [26] have also shown that low water transparency could also lead to a reduction in the dissolved oxygen content of the water. In addition, low dissolved oxygen levels could pose a threat to aquatic organisms on the one hand and a reduction in oxidation processes on the other. In addition, low values were observed for electrical conductivity (53.73± 0.64-75.16±1.04 µS/cm), reflecting low mineralisation at the river sampling stations [27]. In the present study, the low mineralisation is confirmed by the low concentrations of calcium ions. This state could favour better development of molluscs (macroinvertebrates) due to the availability of calcium salts, a constituent element of their shells.

Concentrations of total nitrogen and total phosphorus in the river are low. These low nitrogen and phosphorus concentrations may reflect the low impact of agricultural inputs such as fertilisers on the aquatic ecosystem. This finding implies that a more extensive sampling effort should be carried out throughout the reservoir in order to gain a better understanding of the impact of agricultural activities. The river water is acidic, with pH values of 5.06±0.20 and 5.83±0.72 respectively. The acidity could be linked to the geological bedrock over which the river flows.

In the context of this study, the sampling period was characterised by low levels of turbidity, TSS, COD and BOD5. The low values of these parameters are due to the rapid renewal of the river water, which carries with it particles of varying size, depending on the quantity of water in motion and the gradient [28]. Overall analysis of these physico-chemical variables reveals fairly good water quality.

The taxonomic inventory of the aquatic communities of the river « Blondai » revealed a relatively limited diversity, marked by 23 species of phytoplankton, 08 species of zooplankton, 21 species of macrophytes, 12 species of macroinvertebrates and only 04 species of fish. This low species richness, observed in the majority of groups, suggests an altered ecological state under the effect of the anthropic pressures exerted in the catchment (urbanisation, agriculture and infrastructures).

In phytoplankton, the predominance of Euglenophytes and Cyanobacteria generally reflects an adaptive response to eutrophic and unstable conditions ([29] ; [30]). These groups are known for their tolerance of environmental variations and their ability to reproduce rapidly, which confirms the trend observed in other urban and peri-urban rivers in Côte d'Ivoire.

The low diversity of zooplankton (only two taxa) contrasts with the work of [31], which recorded 30 species in small reservoirs in northern Côte d'Ivoire. This difference may be the result of the deterioration in physico-chemical conditions (high turbidity, organic pollution) and methodological limitations related to sampling equipment. The macrophyte community is dominated by Poales, in particular Poaceae, a group characterised by a short reproductive cycle and a high capacity for vegetative multiplication (tillering). This dominance reflects favourable conditions for pioneer species adapted to disturbed environments, as also reported by [32] on the Kondi river and [33] in the lower Ferlo valley (Senegal). The species richness of macrophytes in the « Blondai» river (21 species) remains well below that of less degraded environments, such as the Seine (69 species, [34] or certain Cameroonian rivers (97 species, [32]), confirming the negative effect of local human disturbance.

Among macroinvertebrates, the high representation of Diptera (Chironomidae), Coleoptera and Basommatophora is consistent with the observations of [35] and [36], which highlight the dominance of aquatic insects in African rivers. This dominance is explained by the great diversity of this group and the aquatic nature of most of their larval stages [37].

Finally, the fish community is reduced to four species divided into three families. This number is much lower than that reported in the Bagoé river (70 species, [38]), reflecting a strong simplification of the ichthyofauna. This situation is probably linked to the fragmentation and degradation of habitats, confirming a moderately disturbed ecological state of the river.

Overall, these results converge with studies carried out on other West African river systems and illustrate the vulnerability of peri-urban aquatic ecosystems in the face of increasing anthropogenic pressures. They highlight the need to strengthen management and biomonitoring measures in order to preserve aquatic biodiversity and the associated ecosystem services. Biodiversity analysis indicates that the Bondai river is poorly diversified. The Shannon index value of less than 2 at almost all the sampling stations indicates a low diversity of aquatic organisms. In contrast, the Pielou Equitability Index indicates average regularity in the distribution of taxa. This low diversity seems to reflect a generally average ecological state of the river. In fact, the richness and composition of aquatic organisms are closely dependent on the ecological quality of the environment, as already emphasised by [39] in their work on West African hydrosystems.

Analysis of the correlations between physico-chemical parameters and aquatic communities in the Bondai river reveals a strong dependence of biological organisms on environmental conditions. Zooplankton density appears to be mainly influenced by pH, total nitrogen and dissolved solids concentration. This result is consistent with the observations of [31] in small reservoirs in the north of Côte d'Ivoire, where rotifers and copepods are highly sensitive to pH variations and nutrient enrichment. Similarly, studies carried out in Burkina Faso [7] confirm that total nitrogen is a major limiting factor in the structuring of plankton communities in eutrophic environments.

In macroinvertebrates, the dependence on BOD_5, COD and temperature illustrates their role as bioindicators sensitive to organic loads and thermal pollution. Indeed, high oxygen demand is often associated with increased decomposition of organic matter, which alters the availability of dissolved oxygen and impacts the survival of sensitive groups. These results are consistent with the work of [36] on the Agnéby River and [4] on the Mé River, which emphasise the importance of oxygenation quality and thermal stability in the structuring of benthic macroinvertebrates.

The distribution of macrophytes is correlated with turbidity and dissolved oxygen. High turbidity limits light penetration and restricts the development of many species, while an oxygen deficit reduces their productivity. This finding is consistent with the work of [32] in Cameroon and [33] in Senegal, which show that macrophytes decline in environments subject to human disturbance and a high sediment load.

Phytoplankton density is influenced by total phosphorus and conductivity; two parameters closely linked to eutrophication. Phosphorus is recognised as a limiting nutrient for primary production [40], and conductivity reflects the accumulation of mineral salts and nutrients. These results are in line with those of [29], which showed that cyanobacteria and euglenophytes dominate in phosphorus-enriched rivers in Côte d'Ivoire.

Finally, the absence of a significant relationship between physico-chemical parameters and fish distribution suggests that the ichthyofauna of the Bondai river is more constrained by structural and ecological factors (habitat fragmentation, obstacles to migration, fishing pressure) than by the chemical characteristics of the water alone. This observation is in line with the conclusions of [38] in the Bagoé river, where fish diversity is strongly conditioned by the availability of habitats and their longitudinal connectivity.

5. Conclusion

The aim of this study, carried out on the « Blondai » river in the peri-urban area of Anyama (southern Côte d'Ivoire), was to characterise both the physico-chemistry of the water and the structure of the aquatic communities, in a context marked by strong anthropogenic pressures (urbanisation, agriculture and infrastructure). The results show that the river's waters are generally acidic, poorly mineralised, moderately oxygenated and low in nutrients (nitrogen, phosphorus) and suspended solids.

The biological inventory identified twenty-three species of phytoplankton, eight species of zooplankton, twenty-one species of macrophytes, twelve species of macroinvertebrates and four species of fish, reflecting limited specific diversity. Analysis of the structure of the benthic fauna confirms a poorly diversified and poorly organised population.

The analyses revealed a strong dependence of biological communities on physico-chemical parameters. Overall, these results highlight the sensitivity of peri-urban aquatic communities to physico-chemical alterations and underline the importance of integrating these indicators into biomonitoring and ecological management programmes for watercourses subject to strong anthropogenic pressures. This study thus constitutes a reference base for future monitoring of the ecological quality of the « Blondai » river and, more broadly, of peri-urban hydrosystems in Côte d'Ivoire.

Compliance with ethical standards

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No conflict of interest to be disclosed.

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