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Ichthyofauna Structure and Multimetric Fish Index to Assess the Biotic Integrity of Hana River in Tai National Park (Côte d'Ivoire)

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Abstract

The Hana River, a tributary of the Cavally River, is the main stream that crosses Tai National Park from northeast to southwest. This park, located in the southwest of the Ivory Coast, is the largest primary tropical rainforest in West Africa and known to be a biodiversity hotspot. However, anthropogenic activities around the park could disturb the Hana River. The purpose of this study is to assess the water quality of this river from the analysis of the structure of the fish population. Three stations were sampled in the dry season using a battery of 10 gillnets (8 - 40 mm mesh) placed between 5 p.m. and 7 a.m. and 7 a.m. and 12 p.m. The Hana River Biotic Integrity Index is based on the ten metrics used for the analysis of community structure. Scoring criteria were established from these metrics. The biotic index for each station was calculated as the average of the scores of all metrics. 29 species of fish were collected in the Hana River including 12 species of fish at station T1, 19 species at T2 and 24 species at T3. The biotic integrity index obtained in each station indicates that the highest value (3.7) was obtained at station T3 outside the park, the average value (3.3) at T2 in the park and the lowest (2.5) at station T1 in the northeast of the park. The biotic integrity index allowed to show a pollution gradient along the Hana River from southwest to northeast, the most polluted.

Keywords

Biotic Integrity, Human Activities, Fish, Hana River, Taï National Park, Ivory Coast

1. Introduction

Aquatic environments provide many services: to humans on the one hand, by providing a water supply to meet our needs and to the environment on the other hand, by being prodigious reservoirs of biodiversity and abundant living environments. These services are inherent in the quality of ecosystems. However, the latter are sensitive environments which are not immune to the pressures of human activity. In order to better protect these environments, it is necessary to know the state of their quality and to take the appropriate measures. The need to take into account the biological criteria in the evaluation of the state of the system has been underlined by several authors, and in particular by [1] who defines stress as designating any physical or chemical factor affecting recruitment, growth or the survival of organisms, thus affecting the structure or even the composition of populations. The abundance and composition of fish species as well as the differences with the characteristic communities of the environment are used to analyze the quality of the environment. Thus, analyzing the current structure of fish populations will allow: a direct measurement of environmental conditions; highlighting problems that go undetected or are underestimated by other methods; and identifying levels of system recovery.

In Ivory Coast, the water courses in Taï National Park, located in the southwest, are subject to continuous degradation processes that threaten their functionality and the maintenance of associated biodiversity [2]. This park is the largest primary tropical rainforest in West Africa and known to be a biodiversity hotspot. However, the environmental characteristics described in the Taï area indicate that the rivers inside the park are influenced by many human activities [2]. Indeed, anthropogenic activities around the park such as, coffee, cocoa, rubber and oil palm crops, which are preceded by forest clearing, and to the east, the practice of illegal gold panning could disturb these water courses, in this case, the Hana River, through pesticides and heavy metals drained by runoff.

This river is a tributary of the Cavally river. It takes its source outside the park in an agricultural area (cocoa cultivation) and entirely crosses the Taï National Park from northeast to southwest (**Figure 1**).

The purpose of this study is to assess the water quality of this river from the analysis of the structure indicators of the fish population.

2. Material and Methods

Three stations (T1: 5˚55'332"N-6˚52'536"W, entry point to the park in the northeast, T2: 5˚24'318"N-7˚14'707"W, inside the park and T3: 5˚24'052"N-7˚14'662"W outside the park in the southwest) were sampled during the dry season, in January and March 2016.

Stations T1 and T3 are characterized by banana, cassava, coffee and cocoa fields along part of their banks. However, station T1 also featured rubber tree and rice fields, a bridge over the station and traces of artisanal gold mining along the Hana River, towards the Soubré plantation zone. On the other hand, at the T2 station in the park, these fields do not exist.

Physico-chemical variables were measured before each fish sample. pH, dissolved oxygen (mg/l), conductivity (µS/cm), dissolved solids (mg/l) and water temperature

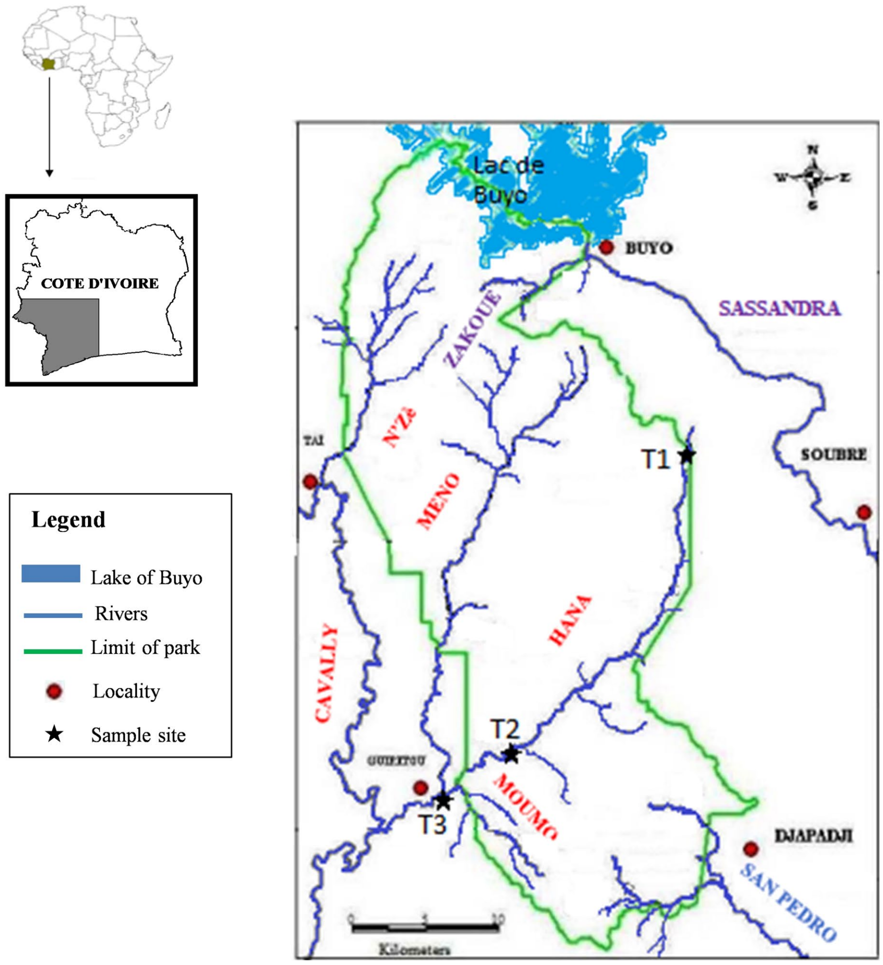

Figure 1. Location of the Hana River and sampling sites ([3] modified).

(˚C) were measured using a Hanna HI 9828 multi-parameter. Canopy closure was estimated in percent (%). Depth (m) was determined using a weighted graduated rope, and transparency (cm) using the Secchi disk. The Kruskal-Wallis test was used to analyze differences between physico-chemical parameters. A battery of 10 gillnets (8 - 40 mm mesh) placed between 5 p.m. and 7 a.m. and 7 a.m. and 12 p.m. was using. The fish collected were identified using the keys of [4]-[6] and scientific names updated using the Fishbase tool [7], then measured and weighed respectively to the nearest millimeter and gram.

To be able to express in a synthetic way the richness of the data obtained, and to favor the interpretation of the observed differences or evolutions, various metrics in relation to the structure of the population were used. These metrics, grouped into three categories of indices [8], are: specific richness, density, biomass (statistical descriptors); Shannon index, Simpson's diversity index, Pielou equitability, Hill index (diversity indices); k-dominance, Clarke index, and Shannon Eveness Proportion index (graphical and distributional methods). Redundancy analysis (RDA) has been used to examine the interrelationships between collected species density, physico-chemical parameters and anthropogenic activities [9].

Scoring criteria (Table 1) were established for these metrics based on their different scales of variation. Scores for each variable range from 1 (poor) to 5 (excellent) [10]. But, for the k-dominance metric, the scores 1 (poor), 3 (average) and 5 (excellent) will be assigned to the three stations according to the position of their curve on the graphic representation. The biotic index for each site was calculated as the average of the scores of all metrics. The integrity classes modified by [10] were used to interpret the calculated indices.

Table 1. Scoring criteria associated to the metrics of Hana River integrity biotic index.

	Scores				
	5	4	3	2	1
Métrics	**(Excellent)**	**(Good)**	**(Fair)**	**(Poor)**	**(Very poor)**
Statistic descriptors					
Specific richness	>24	19 - 24	13 - 18	7 - 12	0 - 6
Biomass	>25	19 - 25	14 - 20	9 - 15	<10
Density	>0.52	0.38 - 0.52	0.25 - 0.39	0.12 - 0.26	<0.13
Diversity indices					
Shannon	>5	3.9 - 5	2.9 - 4	1.4 - 3	<1.5
Simpson	>0.8	0.7 - 0.8	0.5 - 0.6	0.3 - 0.4	<0.2
Equitability	>0.8	0.7 - 0.8	0.5 - 0.6	0.3 - 0.4	<0.2
Hill	<0.2	0.3 - 0.2	0.5 - 0.4	0.6 - 0.7	>0.8
Distributionnal and graphic methods					
Shannon EP	<0.5	0.9 - 0.5	1.4 - 1	1.9 - 1.5	>2
K-dominance	-	-	-	-	-
Clarke	>0.6	0.3 - 0.6	−0.1 - 0.2	−0.5 - (−0.2)	<−0.6

3. Results

3.1. Spatial Organisation of Catches

29 species of fish, belonging to 7 orders, 11 families and 21 genera, were collected in the Hana River including 12 species of fish at station T1, 19 species at station T2 and 24 species at station T3 (Table 2). This fish assemblage contains 27 freshwater species and two species with estuarine affinity (*Pellonula leonensis*, *Sarotherodon galilaeus*).

1812 fish specimens were sampled. *Schilbe mandibularis* (53.03%) and *Brycinus macrolepidotus* (10.54%) represented the most abundant species in the population of the River. The dominant species at T1 are: *Papyrocranus afer* (34.67%), *Bryconalestes derhami* (20.96%), *Coptodon zillii* (16.93%). At stations T2 and T3, the important species are: *Schilbe mandibularis* (63.28% and 51.76% respectively), *Brycinus macrolepidotus* (10.91% and 11.63% respectively). Three species accounted for 66.79% of the total biomass (64112 g) of the Hana River. These species were *Schilbe mandibularis* (31.58%), *Brycinus macrolepidotus* (27.64%), *Papyrocranus afer* (7.57%). Species with high biomass at the station T1 were: *Polypterus palmas* (13.31%) *Papyrocranus afer* (48.15%) and *Coptodon zillii* (16.09%). At the stations T2 and T3, the important biomasses were those of species *Schilbe mandibularis* (41.96% and 31.86% respectively), *Brycinus macrolepidotus* (32.34% and 31.46% respectively).

Table 2. List of species sampled in the Hana River in January and March 2016.

Orders	Families	Species	Codes	T1	T2	T3
Polypteriformes	Polypteridae	*Polypterus palmas*	Ppal	+	+	+
Clupeiformes	Clupeidae	*Pellonula leonensis*	Pleo		+	+
Osteoglossiformes	Notopteridae	*Papyrocranus afer*	Pafe	+	+	+
	Mormyridae	*Mormyrus rume*	Mrum		+	+
		Marcusenius senegalensis	Msen	+	+	+
		Marcusenius ussheri	Muss		+	
		Mormyrops anguilloides	*Mang*			+
		Petrocephalus bovei	Pbov	+	+	+
Characiformes	Hepsetidae	*Hepsetus occidentalis*	Hocc	+	+	
	Alestidae	*Bryconalestes longipinnis*	Blon		+	+
		Bryconalestes derhami	Bder	+	+	+
		Brachyalestes nurse	Bnur			+
		Brachyalestes imberi	Bimb	+	+	+
		Brycinus macrolepidotus	Bmac		+	+
		Micralestes eburneensis	Mebu		+	+
Cypriniformes	Cyprinidae	*Raiamas senegalensis*	Rsen		+	+
		Labeo coubie	Lcou		+	+
		Labeobarbus parawaldroni	Lpar			+
		Enteromius trispilos	Etri			+
		Enteromius ablabes	Eabl		+	+
Siluriformes	Claroteidae	*Chrysichthys nigrodigitatus*	Cnig	+	+	+
		Auchenoglanis occidentalis	Aocc			+
	Schilbeidae	*Schilbe mandibularis*	Sman		+	+
	Clariidae	*Heterobranchus isopterus*	Hiso	+	+	
		Clarias buettikoferi	Cbue	+		
Perciformes	Cichlidae	*Hemichromis fasciatus*	Hfas			+
		Hemichromis bimaculatus	Hbim	+		
		Coptodon zillii	Czil	+		
		Sarotherodon galilaeus	Sgal			+
7	**11**	**29**		**12**	**19**	**24**

Diversity indices were generaly higher at T1 station (H' = 2.65; 1-D = 0.8; J = 0.74; Hill = 0.75) than at stations T2 and T3 (Table 3).

The comparative graphical analysis of the biomass and abundance curves showed that at the three stations, the difference in distribution are much more marked with the abundance curve above that of the biomass. ABC curves reflect models of fish assemblage structure affected by human activities at T1 (W = −0.16), T2 (W = −0.227) and T3 (W = −0.184) (Figure 2). However, k-dominance curve show that the station T3 are relatively less affected by the effects of anthropogenic activities (Figure 3) than the other two stations.

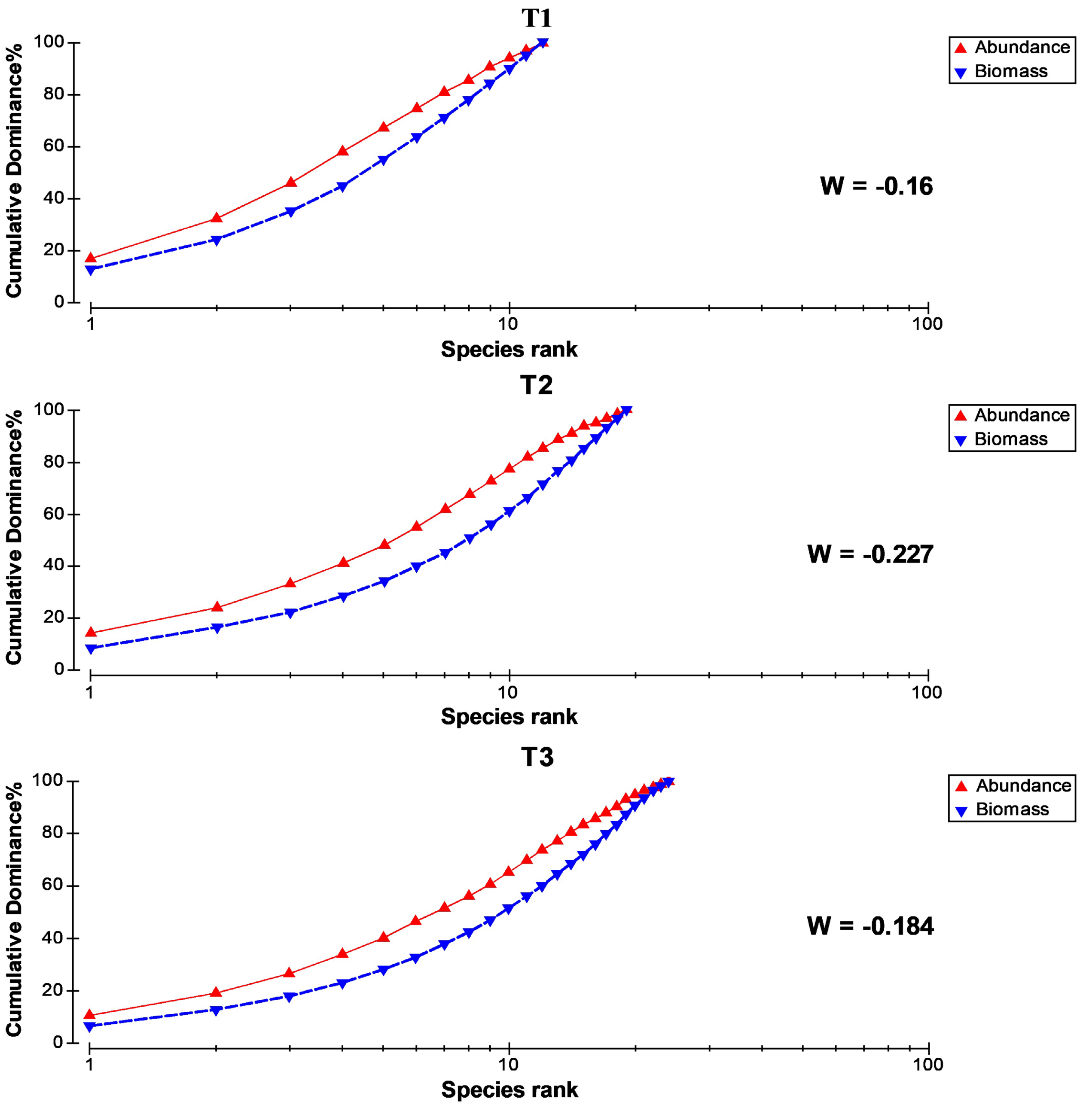

Figure 2. Comparison curves of abundance and biomass of stations T1, T2 and T3.

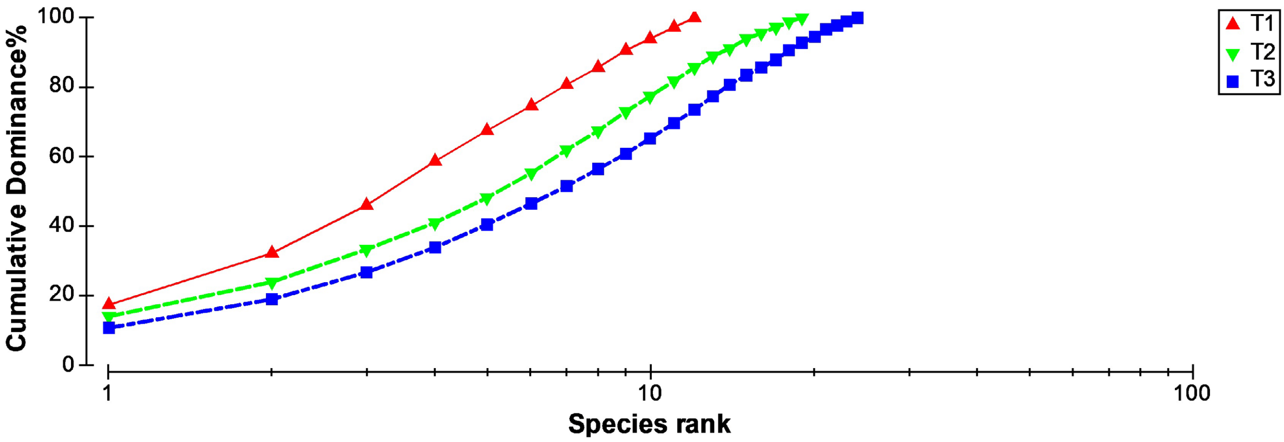

Figure 3. Comparaison of k-dominance curves between stations T1, T2 and T3.

3.2. Physico-Chemical Parameters, Anthropogenic Activities and Relationship with Fish Populations

Table 3 shows the physico-chemical variables measured in each station. Overall, a low amplitude of variation was noted, which was insignificant for pH, dissolved oxygen, conductivity, dissolved solids and depth. With regard to transparency, it was highest at station T3 and lowest at station T2. However, this difference is not significant. On the other hand, canopy closure varied significantly between stations T1 and T2 ($p = 0.036$) and T1 and T3 ($p = 0.033$), reflecting the change in vegetation cover from the park entrance to the interior.

Table 3. Values of physico-chemical parameters measured in the Hana River station and anthropogenic activities.

Anthropogenic activities		pH	DO (mg/l)	Cnd (µS/cm)	TDS (mg/l)	Transp (cm)	Temp (˚C)	Depth (m)	Cc (%)
T1	**T1**								
Fields of Banana,	Min	4.36	3.8	51.1	24	19	24.9	1.93	0
Cassava, Coffee,	Max	6.43	4.4	57.8	37.7	42.8	26.5	3.06	0
Cocoa, Rubber tree	Mean	5.73	4.1	53.73	28.73	30.9	25.56	2.495	0
and gold mining	Sd	1.19	0.42	3.57	7.77	16.83	0.83	0.799	0
T2	**T2**								
	Min	6.3	6.3	53.6	30.6	21	25.9	2	20
Nothing	Max	6.92	6.9	65.2	34.6	21	27.9	2.01	50
	Mean	6.61	6.6	59.4	32.6	21	26.9	2.005	35
	Sd	0.44	0.42	8.2	2.83	0	1.41	0.007	21.21
T3	**T3**								
Fields of Banana,	Min	6.6	4.89	47.3	22.3	19.5	24.3	2.28	20
Cassava, Coffee,	Max	6.77	8.12	55	35.7	78.5	27.3	5.1	60
Cocoa,	Mean	6.69	6.58	51.22	28.75	58.83	25.87	3.69	40
	Sd	0.072	1.62	3.62	7.08	34.06	1.26	1.994	28.28

pH: Hydrogen potentiel; DO: Dissolved oxygen ; Cnd: Conductivity; TDS: Total dissolved solids; Transp: Transparency; Temp: Temperature; Cc: Canopy closure.

The redundancy analysis carried out (**Figure 4**) allowed us to understand the complex interactions between fish, their environment and human activities. DRA axis I expresses 86.0% of the variance and axis II, 14.0%. The analyses showed, in the positive part of axis 1, station T1 (at the park entrance) characterized by a strong presence of anthropogenic activities (artisanal gold mining, rice, rubber, cocoa, coffee, banana and manioc fields) correlated with a decrease in dissolved oxygen, pH and canopy. Only the fish species *Hepsetus occidentalis*, *Heterobrancus isopterus*, *Polypterus palmas*, *Papyrocranus afer*, *Hemichromis bimaculatus*, *Coptodon zillii* and *Claris buettikoferi* are abundantly represented in this station. The negative part of Axis 1, where most of the species collected are found, can be subdivided into two groups.

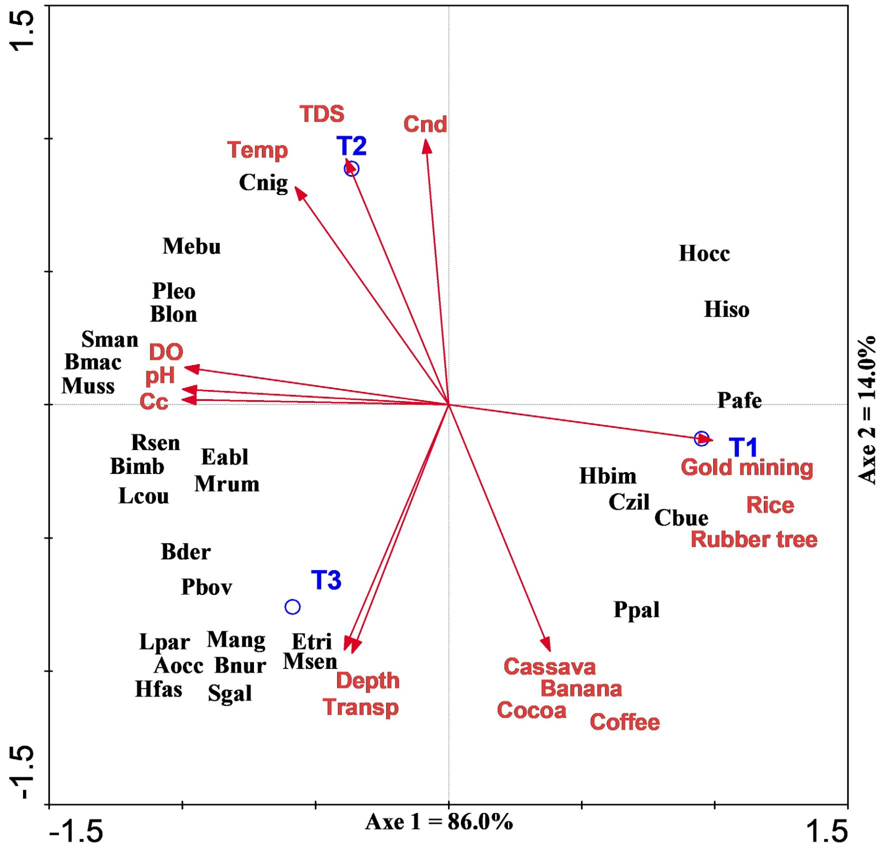

Figure 4. Relationship between physico-chemical parameters, anthropogenic activities and fish populations.

The first sub-group, located in the positive part of axis 2, is represented by station T2 and defined by high values of temperature, conductivity and dissolved solids. These parameters are negatively correlated with transparency and depth, in the negative part of axis 2, corresponding to station T3 (at the park exit) where the highest number of species was recorded with some anthropogenic activity.

3.3. Index of Biotic Integrity-Fish of Hana River

The biotic integrity index obtained in each station (**Table 4**) indicates that the highest value (3.7) was obtained at station T3 outside the park, the average value (3.3) at T2 in the park and the lowest (2.5) at station T1 in the northeast of the park. These values indicate good, reasonable and critical-bad water quality respectively. The biotic integrity index allowed to show a pollution gradient along the Hana River from southwest to northeast, the most polluted.

4. Discussion

The fisheries carried out at the three sites, during dry season, provided a total of 29 species of fish in the Hana River against 36 species recorded by [11]. Fish sampling during the dry season has several advantages, which can be justified by ecological, practical, and scientific reasons [12] [13].

Table 4. Multimetric fish index and water quality of the sites of the Hana River.

	T1		T2		T3	
Métrics	**Value**	**Score**	**Value**	**Score**	**Value**	**Score**
Statistic descriptors						
Specific richness	14	3	19	4	24	4
Biomass	9.42	1	27.76	5	34.05	5
Density	0.13	1	0.83	5	1.04	5
Diversity indices						
Shannon	2.65	2	2.1	2	2.63	2
Simpson	0.8	4	0.58	3	0.7	4
Equitability	0.74	4	0.49	3	0.57	3
Hill	0.75	2	0.49	3	0.57	3
Distributionnal and graphic methods						
Shannon EP	0.87	4	1.18	3	1.14	3
K-dominance		1		3		5
Clarke	−0.16	3	−0.22	2	−0.18	3
Sum		25		33		37
Average (IBI value)		2.5		3.3		3,7
Water quality	**Critical-bad**		**Reasonable**		**Good**	

Indeed, in the dry season, fish are concentrated in restricted areas, making their capture and study more efficient. In addition, the dry season can be a period of stress for aquatic ecosystems due to lower water levels and pollutant concentration. According to [14] and [15], Sampling during this period enables us to assess the resilience of species and the impact of harsh conditions and pollutants on fish.

However, the observed decrease in species richness would be due here to the capture gear used. Because, according to [16], the vulnerability of species is different depending on the fishing gear used. Indeed, only gillnets were used during two sampling campaigns in this study against that of [11] who, in addition to gillnets, used hoop nets and landing nets during four sampling campaigns.

Moreover, this decline in species richness could also be explained by the degradation of the aquatic ecosystems of Taï National Park. Indeed, pollutants from anthropogenic activities around the park and carried by runoff water have modified the physico-chemical structure of the waters inside the park [3]. This change was also the case for water resources in the town of San-Pédro [17].

The ecological stress analysis of the Hana River, using ABC curves, showed that the abundance curve is well above the biomass curve. This observation generally indicates that the fish population of the watercourse is dominated by species of small size [18]. According to the theoretical model of [19], the Hana River ecosystem is close to the high stress phase. In the three stations, the preponderance of the abundance curves revealed that the fish populations tend to be dominated or are dominated by species of small size, high abundance and low biomass. Large-bodied, high-biomass species are becoming scarce in catches from the Hana River.

Discharges from artisanal mining and agriculture, as well as the use of fertilizers and pesticides, can alter river habitat and levels of certain physico-chemical parameters such as depth, canopy closure, temperature, pH, dissolved solids, dissolved oxygen, conductivity and transparency, which in turn can affect water quality, abundance and distribution of fish species. Redundancy analysis was used to determine the extent to which environmental parameters explain the distribution of fish populations.

At station T1, for example, an open canopy favours bank erosion due to the absence of natural protection (the result of clearing for cultivation), as do low pH and dissolved oxygen levels. These changes to the aquatic environment can have repercussions on aquatic ecosystems. Indeed, of all the species present on this station, the predators *Polypterus palmas*, *Papyrocranus afer*, *Clarias buettikoferi*, *Heterobranchus isopterus* and *Hepsetus occidentalis* [20] are the most important, reflecting a dysfunctional aquatic ecosystem [21].

Furthermore, the station T1, located to the northeast, presents low values of specific richness (S = 14), density (A = 0.13), biomass (Biom = 9.42). In addition, the Hill index value is higher at station T1 (Hill = 0.75). The calculated multimetric fish index indicates critical-bad water quality. These parameters show that there is a disturbance of the population structure caused by human activities.

The "reasonable" water quality at Station T2 could be explained by the location of this station inside the park, where it would be less influenced by disturbing human activities. However, at this station, the water is loaded with organic matter and fine particles from the entire upstream system of the Hana River. The highly turbid water prevents the penetration of light at depth and, consequently, the development of benthic plants. These conditions could also explain the abundance at this station of *Chrysichthys nigrodigitatus*, which is characterized by good tolerance to various water parameters [22] [23], such as salinity and temperature, and less oxygen.

At station T3, depth is high, and turbulence and agitation are reduced. This station does not receive enough sediment. These factors will contribute to a drop in dissolved oxygen, which can be compensated for by oxygen production from the strong photosynthetic activities of plants (planktonic or benthic). The balance of aquatic life is assured. In addition, species sensitive to pollution, such as *Mormyrus rume*, *Petrocephalus bovei*, *Mormyrops anguilloides* and *Marcusenius senegalensis* [24] were observed.

The high value of the index from one site to another could reflect a restoration of the aquatic environment due to the addition of new water sources. This could explain the good quality of the water observed at station T3, which would be due to its position at the level of the Hana-Meno confluence. According to [25], an increase in the IBI from one station to another would reflect a recovery of the ecosystem due to an increase in resources.

It should therefore be noted that Physico-chemical parameters, such as pH, temperature, conductivity, total dissolved solids, dissolved oxygen content, transparency and canopy closure and depth are essential indicators of water quality. Human activities, such as agriculture, industry, gold panning, can have a significant impact on these parameters, often degrading them. These parameters, however, have a significant impact on the fish population in an aquatic ecosystem. Species sensitive to pollution can provide information on water quality and habitat integrity. By integrating biological data into assessments of the quality of aquatic environments, the complex interactions between abiotic and biotic factors can be better understood and help identify the pressures exerted on these ecosystems.

With the anthropization around the Taï National Park, these results could serve as references for subsequent investigations in the monitoring of ichthyological fauna.

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Conflicts of Interest

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

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