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Water quality and ecological stress of fish in the Bandama River Estuary (Cote d'Ivoire, West Africa)

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The Bandama River contributes essentially to the well-being of the Ivorian population. Unfortunately its biodiversity is strongly threatened by human activities. In order to assess the water quality of the Bandama River and its impact on fish fauna, a scientific study was carried out from March 2019 to February 2020 in its estuarine zone. Thus, the physico-chemical variables of the water, the contents of Pb, Mn, Fe, Cd and Hg in the water and sediment matrices were measured in the three stations defined for the study. Twenty fish species were selected to assess the level of ecological stress observed on the fish fauna. The analysis of the water variables revealed a fairly oxygenated watercourse with temperature above 25°C, acidic pH, high conductivity and salinity above 10‰. The analysis of heavy metal contents revealed a high enrichment of the Bandama estuary in Mn and Hg due to human activities in the whole catchment area. Ecological stress data indicated high fish stress with negative allometric growth for most economically important fish collected in the Grand-Lahou area. Awareness raising among local communities and management measures should be implemented for the conservation of aquatic species in this freshwater Key Biodiversity Area.

Key words: Heavy metals, anthropic activity, conservation, Azagny National Park, coastal wetland.

INTRODUCTION

Water is an essential element for human and animal survival. Its availability in sufficient quantity and quality contributes to the maintenance of human health (Makoutode et al., 1999). Unevenly distributed over the earth, this natural resource constitutes a major environmental issue (Dovonon et al., 2011). Yet, a combination of factors including agricultural exploitation, poor management of water resources, and population growth significantly reduces its availability and accessibility (Ouattara et al., 2018). In addition to these anthropogenic factors, climatic factors related to global changes considerably disrupt the availability of water resources. Moreover, rapid urbanization, industrialization and the non-rational use of fertilizers and pesticides

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generate various pollutants which cause numerous disturbances to aquatic environments (McKinney, 2002). This can affect the physico-chemical and biological quality of the receiving aquatic environments (Mulliss et al., 1997). Water quality is therefore becoming one of the permanent concerns of mankind, which has devoted an entire legislation and ratified many international protocols and conventions to ensure its protection and preservation (Kahoul et al., 2014).

The Bandama River is the only river which has its watershed located entirely in Côte d'Ivoire (Iltis and Lévêque, 1982; Kouamé et al., 2011). Due to its north-south orientation, this river covers different climatic and biogeographic zones. Its lower course plays a major role in the conservation of aquatic biodiversity and is therefore classified as the only freshwater Key Biodiversity Area (KBA) of Côte d'Ivoire (Starnes and Darwall, 2021). Its mouth at Grand-Lahou is part of a wetland classified as a Ramsar site and contributes to the maintenance of an impressive wealth of fauna. Unfortunately, the main course of the Bandama River is under the influence of two large hydroelectric dams (Kossou, Taabo) and several hydro-agricultural and agro-pastoral dams (Traoré, 1996). The main riverbed is constantly subject to illegal gold panning. In its watershed, there are intense industrial and agricultural activities with massive use of chemical fertilizers (Lévêque et al., 1983). In the Grand-Lahou region, there are agro-industrial blocks of oil palm and rubber trees as well as a manganese mining industry. All these anthropic activities constitute real threats that could jeopardize the conservation of aquatic biodiversity. Thus, in order to assess the impact of this anthropic pressure on the ichthyological fauna, the present study was initiated in the estuarine zone of the Bandama River. It focuses on the analysis of the physico-chemical environment of the river, its level of contamination in metallic trace elements and the level of ecological stress of fish species. The results of this investigation could contribute to the establishment of a management plan for aquatic resources in the peripheral area of the Azagny National Park, but more importantly, these results could be used as references or management models for future work.

MATERIALS AND METHODS

Study area

The estuarine area of the Bandama River is located in Grand-Lahou, between 5°17 - 5°90 North latitudes and 4°47 - 4°57 West longitudes. At the outlet, the Bandama River joins to the east with the Ebrié lagoon, through the Azagny canal. It is connected in the west to the Grand Lahou Lagoon. The Grand-Lahou pass is the only sea outlet for the lagoon system, the Bandama and the Boubo Rivers. This estuarine zone of the Bandama River constitutes the natural limit with the Azagny National Park and the urban zone of Grand-Lahou. Surveys occurred at 3 sampling sites (Ba1, Ba2 and Ba3) following a longitudinal pattern (Figure 1).

Data collection

The physic-chemical parameters (water temperature, pH, salinity, dissolved oxygen, conductivity, total dissolved solids) were determined monthly from March 2019 to February 2020 by using a multiparameter $AQUA_{Red}$ Aquameter. The sediment samples were collected using the Van-Veen grab sampler. Once collected, the sediment was immediately placed in stomacher-type polyethylene bags, carefully sealed, labelled and placed in an electric cooler before being transported to the laboratory for cold drying and analysis. The dried samples were ground until all particles passed through a 63 µm nylon sieve after removal of coarse debris. The dried sediment samples were digested in a closed Teflon container with aqua regal (concentrated hydrochloric acid 4/1 v/v to concentrated nitric acid) according to McGrath and Cunlife (1985). All total heavy metal concentrations in the sediment samples were determined by a flame atomic absorption spectrophotometer (type VARIAN SpectrAA 110 or AAS). All measurements of the aforementioned parameters were performed in triplicate and the average of the three independent measurements was reported. The detection limits of AAS were 0.035, 0.013, 0.046 and 0.051 $mg.kg^{-1}$, for Mn, Fe, Pb and Hg, respectively in the sediment samples. Fish samples were captured monthly from March 2019 to February 2020 at gill nets (10, 25, 30, 35, 40, and 50 mm mesh size). Captured fish were identified from Paugy et al. (2003[a,b]) and names were updated in Fishbase (Froese and Pauly, 2019). Identified fish were weighed to the nearest gram, measured in cm and then preserved in 10% formaldehyde.

Data analysis

Descriptive analysis was applied to data in order to highlight the central tendency (mean) and variation (standard deviation) of physicochemical variables. Kolmogorov–Smirnov test for normality at α = 0.05 showed that water variables data were normally distributed, and these were subjected to one-way ANOVA.

The geo-accumulation index (Igeo) initially described by Müller (1969) to assess the degree of contamination of sediments was calculated. It is calculated according to the relationship:

$$Igéo = \log_2 (Cs / 1,5\ Cref)$$

where Cs is the concentration of metal n in the sediment and Cref is the background value of the metal. The constant 1.5 is the correction factor for the background due to lithogenic effects. Due to the lack of background values for trace metals in the study area, the geochemical background concentrations determined by Wedepohl (1995) in the upper continental crust were used. The levels of contamination according to Igeo values are shown in Table 1 (Müller, 1969).

The enrichment factor (EF) defines the number of times an element is enriched relative to its abundance in a reference material abundance in a reference material (earth crust). It makes it possible to discriminate between natural sources (Kinimo et al., 2018; Hakanson, 1980). According to Ghrefat (2006), metal concentration in sediments was normalized to metal concentrations of average shale. Fe and Al are widely used as normalizer. In this study, Fe is used as normalizer element. The EF index for a metal is defined as follows equation (Hakanson, 1980):

$$EF= (Cs/[Fe]s)/(Cref/[Fe]ref)$$

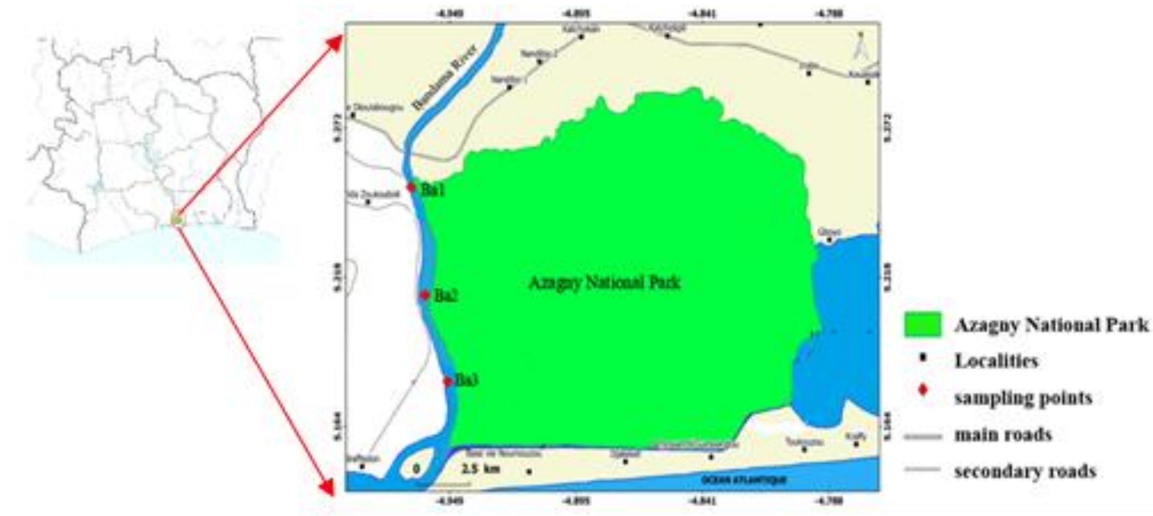

Figure 1. Map showing the different fish sampling points in the Bandama River estuary.
Source: Koné et al., 2021

Table 1. Classification of geoaccumulation index (*Igeo*).

Class	Igeo values	Sediment contamination levels
0	Igeo ≤ 0	Uncontaminated
1	0 < Igeo < 1	Uncontaminated to moderately contaminated
2	1< Igeo < 2	Moderately contaminated
3	2 < Igeo < 3	Moderately to strongly contaminated
4	3 < Igeo < 4	Strongly contaminated
5	4 < Igeo < 5	Strong to extremely contaminated
6	Igeo ≥ 5	Extremely contaminated

Source: Müller, 1969

Table 2. Enrichment factor classes.

Enrichment factor	Categories of contamination
EF < 1	No enrichment
1 < EF < 3	Minor enrichment
3 < EF < 5	Moderate enrichment
5 < EF < 10	Moderately to severe enrichment
10 < EF < 25	Severe enrichment
25 < EF < 50	Very severe enrichment
EF > 50	Extremely enrichment

Source: Sakan et al., 2009

and Fe in the sampled sediment, respectively and Cref and [Fe]ref are background concentration in the UCC. Different classes of sediment enrichment in trace metals are shown in Table 2.

The Kruskall-Wallis K-test was applied to the dataset to assess the spatial variation of metal pollution levels in the Bandama River estuary.

The application of the ecological stress index such as the ABC curve allows the use of fish fauna to determine the environmental conditions existing in the aquatic environments (Hay et al., 1996). The ABC curve is defined as the average of the difference between

Table 3. Mean values (±Standard Deviation) of physico-chemical variables in Bandama River estuary

Site	Descriptives	Temp (°C)	pH	DO (mg/L)	Cond (µS/cm)*	Salinity (‰)
Ba1	Mean	27.86	6.31	6.62	70.94	11.86
	SD	1.61	1.23	0.74	3.99	6.82
Ba2	Mean	28.85	6.20	5.70	134.26	15.29
	SD	1.22	0.99	1.12	18.15	2.42
Ba3	Mean	29.39	6.41	6.41	400. 60	16.76
	SD	1.75	0.81	0.66	6.90	1.62

SD = Standard deviation; Temp: Temperature; DO: dissolved oxygen; Cond: Conductivity; *: significant variation.
Source. Kamelan et al., 2022

the cumulative proportions in terms of biomass and abundance:

$$ABC = \frac{B_i - A_i}{N}$$

where ABC = Abundance-Biomass Comparison Index; Bi = proportion in biomass of species i (ranked in descending order of proportion); Ai = proportion in abundance (number of individuals) of species i (ranked in descending order of proportion); N = total number of species observed.

The graphs obtained are curves that make it possible to distinguish schematically three phases in the evolution of a stand (Warwick et al., 1987): a non-stress phase, when the biomass curve is above that of abundance; a light stress phase, when the two curves almost overlap; and a high stress phase, when the abundance curve is above that of biomass.

The log-transformed linear model expressed by the following equation (Lévêque, 2006) was used to determine the length-weight relationship:

$$\text{Log } W = \log a + b \log TL$$

where W: the weight of the fish in g and TL: the total length of the fish in cm. The constant "a" represents the intercept of the regression line and b the slope of the relationship. Student's t-tests (ts) were used to test whether the slope "b" was significantly different from the theoretical value of 3 ($p < 0.05$). Thus, the ts value for each species was calculated according to the following expression (Zar, 1984):

$$ts = (b-3)/sb$$

where b the slope and sb the standard error of the slope.

$$S = \sqrt{((SW/STL) - b^2)/(n-2)}$$

where SW: the variance of the body weight, STL: the variance of the total length and n: the sample size.

RESULTS AND DISCUSSION

The results of the measurements of the physico-chemical variables of the water are recorded in Table 3. For all these variables, the ANOVA test showed a significant spatial variation ($p < 0.05$) only for the electrical conductivity and salinity of the water, which are higher in station Ba3 (400.6 µS/cm; 16.76‰) and lower in station Ba1 (70.94 µS/cm; 11.86‰). The absence of significant spatial variation for the other variables indicates that this area has physico-chemical homogeneity. Electrical conductivity and salinity which follow an increasing gradient towards Grand-Lahou channel which connects the Atlantic Ocean and Tagba lagoon. This spatial variation of these parameters would be linked to the rise of marine waters from the Atlantic Ocean in the estuarine zone of the Bandama River. Salinity is a characteristic parameter of the Bandama River estuary. It varies between 11.86 and 16.76‰, whereas it is zero in the upper part of the river. Wognin et al. (2007) indicated that this salinity is linked to the upwelling of marine waters at the mouth of the river which can reach up to 70 km upstream. For these authors, the physico-chemical environment of the Bandama River estuary is influenced by the lagoon systems (Ebrié and Grand Lahou) and the marine seasons. The average range of water temperatures (27.86-29.39°C) measured in the estuarine zone of the Bandama River was found to be relatively close to the average values obtained on the upper part of the river by Aboua (2012) (27.60°C) and Lozo (2016) (28.05) by Kouassi et al. (2005) in the Ebrié Lagoon. In the Bandama River estuarine zone, the waters are acidic (6.20-6.41) while the upper part of this river indicates a more alkaline zone (pH = 7.59; 7.06) (Aboua, 2012; Lozo, 2016). The relatively lower pH values in the estuarine zone compared to the upper Bandama River could be explained by the acidification of the marine waters that seasonally ascend into the Bandama River estuarine zone through the Grand-Lahou pass (Koné et al., 2021). The dissolved oxygen level (5.70-6.62 mg/L) indicates a fairly oxygenated estuarine zone compared to the values obtained (2.06 - 7.5 mg/L) in the upper river by Aboua

Table 4. Trace metals concentrations (mg/kg) in sediments (p > 0.05) from Bandama estuarine (March 2019- February 2020).

Sites	Descriptives	Fe	Cd	Mn	Pb	Hg
Ba1	Mean	18137	0.017	2344	5.63	0.750655
	SD	6.187	0.007	18.625	4.709	1.060
Ba2	Mean	17555	0.1165	3760.5	4.885	0.425485
	SD	10.543	0.120	38.247	3.939	0.600
Ba3	Mean	18505	0.08575	2867	5.455	0.450605
	SD	9.199	0.006	26.078	3.755	0.636
UCC (Wedepohl, 1995)		30890	0.102	527	17	0.05

Source. UCC: Composition of the Continental Crust

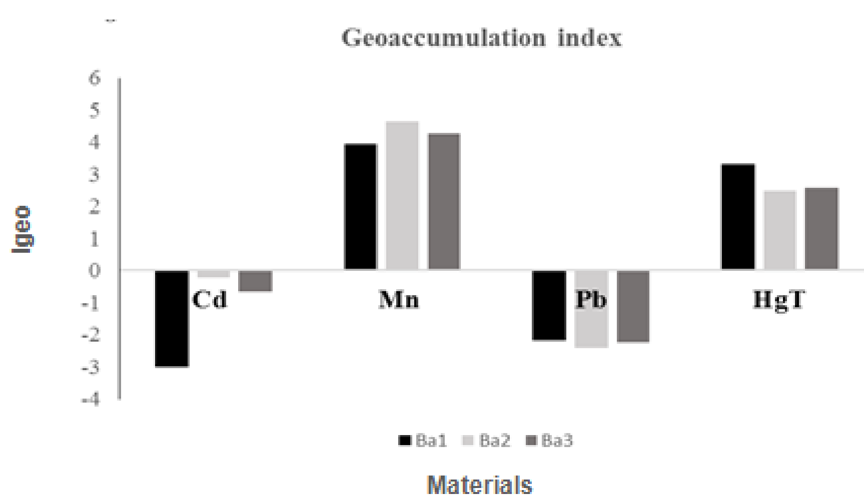

Figure 2. Variation of the geoaccumulation index of trace metals in the Bandama River estuary (March 2019- February 2020).
Source. Kamelan et al., 2022

(2012). This oxygenation of the environment could be associated with the weak water flow in the estuarine zone. This would favour the development of phytoplankton, the main source of oxygen in the aquatic environment. High values of electrical conductivity were measured in the estuarine zone with a significant variation between stations B1 and B3.

The trace metal concentrations in the sediments of the different stations are summarised in Table 4. This result indicated an order of importance in the following sense: Fe > Mn > Pb > Hg > Cd for all the stations visited. The Kruskall-Wallis test applied to the data set did not indicate significant spatial variation. However, the results revealed very high concentrations of total mercury and manganese in the Bandama River estuarine zone. Analysis of the geo-accumulation values (Figure 2) for these heavy metals shows that the Bandama River sediments could be considered uncontaminated for Cd and Pb (Igeo < 0). The Igeo values for Hg (about 3) suggest that all sediments are moderately to highly contaminated with Hg and those of Mn (Igeo ≥ 4) reveal that all sediments are highly to extremely contaminated with Mn. According to Mir et al. (2021), heavy metals may come from natural and anthropogenic processes and end up in various environmental compartments (soil, water, air and their interface). The natural emissions of heavy metals occur under numerous and certain environmental conditions. Volcanic eruptions, sea-salt sprays, forest fires, rock weathering, biogenic sources and particles of wind-borne soil are included in these pollutants. The

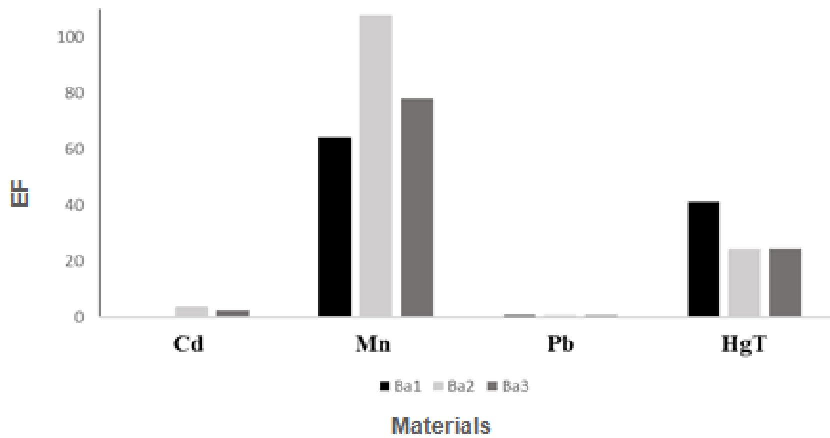

Figure 3. Variation of the enrichment factor of trace metals in the sediments of the Bandama River estuary (March 2019- February 2020).
Source. Kamelan et al., 2022

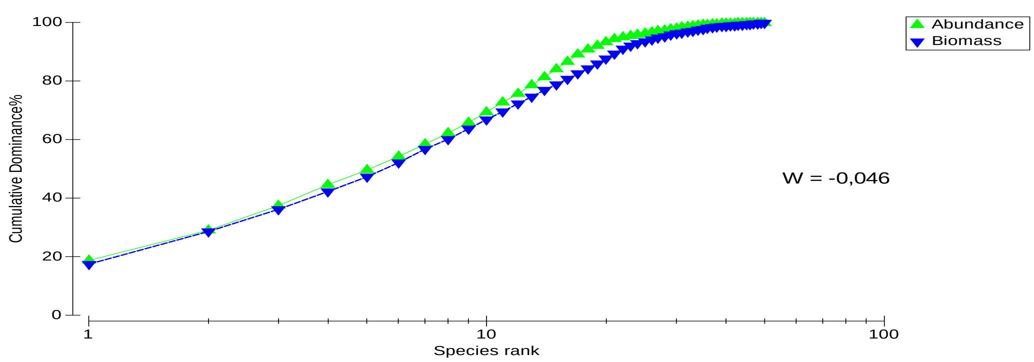

Figure 4. Variation of ecological stress indices in the Bandama River Estuary.
Source. Kamelan et al., 2022

release of metals from their endemic spheres to different environmental compartments will lead to natural weathering processes. However, Cheikh et al. (2018) indicate that the high metal levels in the sediments could be due to human activities. The enrichment factor (EF) values show that the sediments are low in Pb enrichment, with EF values less than 1 while it is moderately enriched with cadmium with EF ranging between 1 and 4 (Figure 3). In contrast, sediments of Bandama River estuary are severely to extremely enriched in Hg and Mn with EF values more than 25. This trend of Hg and Mn enrichment in the Bandama River estuarine zone suggests an anthropogenic source while the presence of Pb and Cd in the sediments could be of natural origin. According to Mir et al. (2021), industries, irrigation, drainage, mining and metallurgical processes, as well as runoff contribute to the release of pollutants into various compartments of the ecosystem.

From the north of Côte d'Ivoire, the Bandama River drains its basin with important mining industries, vast agricultural exploitation and urban areas for which the estuarine zone becomes a real outlet. This important agricultural, mining and urban focus could explain the severe enrichment of Hg and Mn. These heavy metals may reach the body of the fish directly from water or sediments through the gills/skin of the fish or from the food/prey of the fish through its food canal.

The level of ecological stress of fish in the Bandama estuary was assessed using ABC curves (Figure 4). This result shows that the species abundance curve is above the biomass curve with a Clark index value lower than 0 (W= - 0.046). This result highlights the existence of high stress at the fish species level. In agreement with Whitfield and Elliot (2002), environmental degradation

Table 5. Length-weight relationship and condition factor of 20 fish species sampled in the Bandama River estuarine zone of Azagny National Park between March 2019 and February 2020.

Species	Number	Total length (TL)Min-Max (Cm)	Mean	Weight (g) Min-Max	Mean	a	b	SD (b)	r^2	Growth
Elops lacerta	47	9.9 - 33.7	17.36	6 - 421	67.19	0.0790	2.29	0.026	0.761	A-
Pellonula vorax	24	6 - 9.1	7.01	1.0 - 12	3.58	0.0004	3.97	0.035	0.538	A+
Mormyrus rume	42	7.0 - 40	28.87	28 - 325	195.9	0.0016	1.93	0.018	0.636	A-
Mormyrops anguiloides	15	12.5 - 50.5	32.3	21 - 1185	320.3	0.0016	2.88	0.024	0.961	A-
Hepsetus odoe	16	13 - 33.2	22.74	51 - 434	28.20	0.0016	3.41	0.022	0.866	A+
Distichodus rostratus	168	9.0 - 35	24.442	9.0 - 450	111.4	0.0221	2.77	0.016	0.807	A-
Labeo coubie	56	8.2 - 40.5	19.66	17.5 - 400	26.29	0.0016	1.95	0.018	0.944	A-
Chrysichthys maurus	32	9.0 - 28	16.25	6.5 - 767	122.4	1.2342	1.53	0.049	0.826	A-
Chrysichthys nigrodigitatus	72	5.2 - 28.3	13.70	10 - 288	48.42	0.1140	2.23	0.023	0.651	A-
Schilbe mandibularis	103	9.2 - 25.2	14.55	24 - 174	27.30	0.0117	2.68	0.011	0.552	A-
Hemichromis fasciatus	16	6.2 - 29.1	14.26	10 - 438	106.8	0.1123	2.49	0.025	0.921	A-
Coptodon hybride	20	12 - 18.2	14.75	6.0 - 273	128.7	0.1130	2.55	0.040	0.717	A-
Sarotherodon melanotheron	46	4.4 - 18.5	15.26	6 - 261	151.6	0.0279	2.93	0.087	0.905	Is
Tylochromis jentinki	23	7.3 - 19	11.38	6 - 165	50.96	0.2019	2.05	0.041	0.641	A-
Pelmatolapia mariae	19	8.6 - 21.3	14.65	19 - 364	128.3	0.0016	1.95	0.029	0.769	A-
Pomadasys jubelini	32	7.3 - 22.8	14.76	06 - 259	19.20	0.0181	2.91	0.024	0.802	A-
Monodactylus sebae	26	4.2 - 33.3	9.28	06 - 278	47.92	0.1292	2.59	0.307	0.812	A-
Polydactylus quadrifilis	30	12.2 - 27.7	17.34	16 - 223	83.13	0.0053	3.08	0.088	0.871	Is
Liza falcipinnis	17	4.0 - 31	23.32	02 - 407	29.19	0.0335	2.56	0.001	0.985	A-
Awaous lateristriga	16	10 - 16.3	13.73	18 - 89	32.71	0.0155	3.08	0.021	0.788	Is

a: Intercept of the regression line, b: coefficient of weight growth, r2: coefficient of determination, Standard Deviation, K: condition factor, Is: isometric, A+: positive allometric, A-: negative allometric, LWR: Length-weight relationship, Nbre: number, Min: minimum, Max: maximum, Cm: centimeter, g: gram.
Source. Kamelan et al., 2022

and fishing pressure, heavily practiced in the Bandama estuary, may be the cause of the ecological stress observed on the fish fauna.

The length-weight relationship of the 20 species caught in the Bandama estuary was studied in the present study (Table 5). These results showed that the coefficient of determination (r^2) ranged from 0.552 (*Schilbe mandibularis*) to 0.985 (*Liza falcipinnis*). Besides, 55% of the LWRs had r2 values higher than 0.80, 20% had r2 values between 0.80 and 0.70, while 25% had r2 values lower than 0.70. The estimates of b ranged from 1.530 for *Chrysichthys maurus* to 3.970 for *Pellonula vorax* with a mean value of 2.590 (SD = 0.576). The kind of growth, determined by Student's t-test, revealed that three species, *Polydactylus quadrifilis, Awaous lateristriga* and *Sarotherodon melanotheron* showed isometric growth (b=3). For the other species, b was significantly (Student t-test: $p < 0.05$) different from 3. Two species (*P. vorax* and *Heseptus odoe*) showed positive allometric growth (b>3) and the 15 last ones a negative allometric growth (b<3) (Table 2). It is true that several reasons can explain the negative allometric growth observed in these 15 fish species. However, it is noted that most of these fish are fish of economic interest to the local communities. Therefore, it is likely that the negative allometric growth observed in most of the fish in the Bandama estuarine zone is the cumulative effect of environmental degradation and artisanal fishing, which is the main source of income for local communities living along the Bandama River mouth of the Grand-Lahou lagoons.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Aboua BRD (2012). Développement d'un indice d'intégrité biotique piscicole pour la préservation de la biodiversité du fleuve Bandama. Thèse de Doctorat. Université Félix Houphouët Boigny, Côte d'Ivoire, 227 p.

Cheikh TD, Ibrahima D, Momar N, Cheikhna D, Birame N, Abdoulaye D (2018). Contamination d'une espèce de poisson (Brama Brama) de la Côte Dakaroise. European Scientific Journal 14(12):1857-7881.

Dovonon LFC, Soclo HH, Gbaguidi MAN, Youssao A (2011). Utilisation des os calcinés dans la défluoruration des eaux contaminées: Détermination expérimentale de la température de calcination et de la granulométrie optimales des os. International Journal of Biological and Chemical Sciences 5(4):1712-1726.

Froese R, Pauly D (2019). FishBase. World Wide Web Electronic Publication. Available at: https://fishbase.in/search.php

Ghrefat H, Yusuf N (2006). Assessing Fe, Cu, Zn, and Cd pollution in bottom sediments of Wadi Al-Arab Dam, Jordan. Chemosphere, 65:2114-2121. https://doi.org/10.1016/j.chemosphere.2006.06.043

Hay CJ, Van ZYL BJ, Steyn GJ (1996). A quantitative assessment of the biotic integrity of the Okavango river, Namibia based on fish. Water SA 22:263-284.

Hakanson L (1980). An ecological risk index for aquatic pollution control. A sedimentological approach. Water Research 14(8):975-1001.

Iltis A, Lévêque C (1982). Caractéristiques physico-chimiques des rivières de Côte d'Ivoire. Revue d' Hydrobiologie Tropicale 15(2):115-130.

Kahoul M, Derbal N, Aliaua A, Ayad W (2014). Evaluation de la qualité physico-chimique des eaux de puits dans la région de Berrahal (Algerie). Larhyss Journal 18:1112-3680.

Koné TS, Kamelan TM, Konan YA, Etilé RN, Lozo RN, Yao KM and Kouamelan EP (2021). Fish distribution pattern and environmental influence in the Bandama River estuary (West Africa). International Journal of Fisheries and Aquatic Studies 9(1):6-13.

Kouamé KA, Kouame KF, Kouassi AM, Oulare S, Adon GCR, Bernier M (2011). Mise en place d'une base de données pour une modélisation hydrologique distribuée du bassin versant du Bandama (Côte d'Ivoire): apport d'un modèle numérique d'altitude, de la télédétection et du SIG Physitel. Afrique Science 7(2):94-114.

Kinimo KC, Yao KM, Marcotte S, Kouassi NLB, Trokourev A (2018). Distribution trends and ecological risks of arsenic and trace metals in wetland sediments around gold mining activities in central-southern and southeastern Côte d'Ivoire. Journal of Geochemical Exploration 190:265-280.

Kouassi AM, Tidou AS, Kamenan A (2005). Hydrochemical and microbiological characteristics of the waters of the Ebrié lagoon (Ivory Coast). Agronomie Africaine 17(2):73-162.

Lévêque C (2006). Croissance et ontogénie. In Lévêque C, Paugy D (Eds), Les poissons des eaux continentales africaines: Diversité, écologie, utilisations par l'homme. Paris: IRD pp. 177-190.

Lévêque C, Dejoux C, Itis A (1983). Limnologie du fleuve Bandama (Côte d'Ivoire). Hydrobiologie 100(1):113-141.

Lozo RN (2016). Composition floristique et distribution des peuplements de micro-algues du fleuve Bandama (Côte d'Ivoire). Thèse de Doctorat. Université Félix Houphouët Boigny, Côte d'Ivoire 161 p.

Makoutode M, Assani AK, Ouendo EM, Agueh VD, Diallo P (1999). Qualité et mode de gestion de l'eau de puits en milieu rural au Bénin: cas de la sous-préfecture de Grand-Popo. Médecine d'Afrique Noire 46(11):528-534.

McGrath SP. Cunliffe CH. (1985). A Simplified Method for the Extraction of the Metals Fe, Zn, Cu, Ni, Cd, Pb, Cr, Co and Mn from Soils and Sewage Sludge. Journal of the Science of Food and Agriculture 36:794-798.

McKinney ML (2002). Urbanisation, biodiversity and conservation. BioSciences 52(10):883-890.

Mir MA, Delower H, Al-Imran MSK, Maksuda B, Mahadi HO (2021). Environmental Pollution with Heavy Metals: A Public Health Concern. In Nazal M, Zhao, H (Eds.), Heavy Metals - Their Environmental Impacts and Mitigation. Available at https://econpapers.repec.org/bookchap/itopchaps/219023.htm

Mulliss RM, Revitt DM, Shutes RBE (1997). The impacts of discharges from two combined sewer overflows on the water quality of an urban watercourse. Water Science Technology 36(8-9):195-199.

Müller G (1969). Index of geoaccumulation in sediments of the Rhine River. Geojournal 2:109-118.

Ouattara AA, Yao KM, Soro MP, Diaco T, Trokourey A (2018). Arsenic and Trace Metals in Three West African rivers: Concentrations, Partitioning, and Distribution in Particle-Size Fractions. Archives of Environmental Contamination and Toxicology 75(3):449-463.

Paugy D, Lévêque C, Teugels GG (2003a). Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Tome 1. Paris: IRD; Paris: MNHN; Tervuren: MRAC 457 p.

Paugy D, Lévêque C, Teugels GG (2003b). Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Tome 2. Paris: IRD; Paris: MNHN; Tervuren: MRAC 815 p.

Sakan SM, Đorđevi´c DS, Manojlovi´c DD, Predrag PS (2009). Assessment of heavy metal pollutants accumulation in the Tisza river sediments. Journal of Environmental Management 90:3382-3390.

Starnes T, Darwall WRT (2021). Identification et validation des Zones clés pour la biodiversité des eaux douces d'Afrique occidentale. Gland, Suisse: UICN. Available at https://doi.org/10.2305/IUCN.CH.2021.RA.1.f

Traoré K (1996). État des connaissances sur les pêcheries continentales ivoiriennes. Rapport de consultation Avril 1996. Projet F.A.O. TCP/ IVC/4553 135 p.

Warwick RM, Pearson T, Ruswahyuni H (1987). Detection of pollution effects on marine macrobenthos: further evaluation of the species abundance/biomass method. Marine Biology 95(2):193-200.

Wedepohl K (1995). The composition of the continental crust. Geochimica Cosmochimica Acta 59(7):1217-1232.

Whitfield AK, Elliott M (2002). Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. Journal of Fish Biology 61:229-250.

Wognin AV, Monde S, Affian K, Coulibaly A, Aka K (2007). Model of water circulation in the Bandama River estuary in Ivory Coast. Sud Sciences and Technologies 15:5-12.

Zar JH (1984). Biostatistical Analysis. 2nd Edition., New Jersey : Prentice-Hall Incorporated 718 p.