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Full Length Research Paper

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):

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

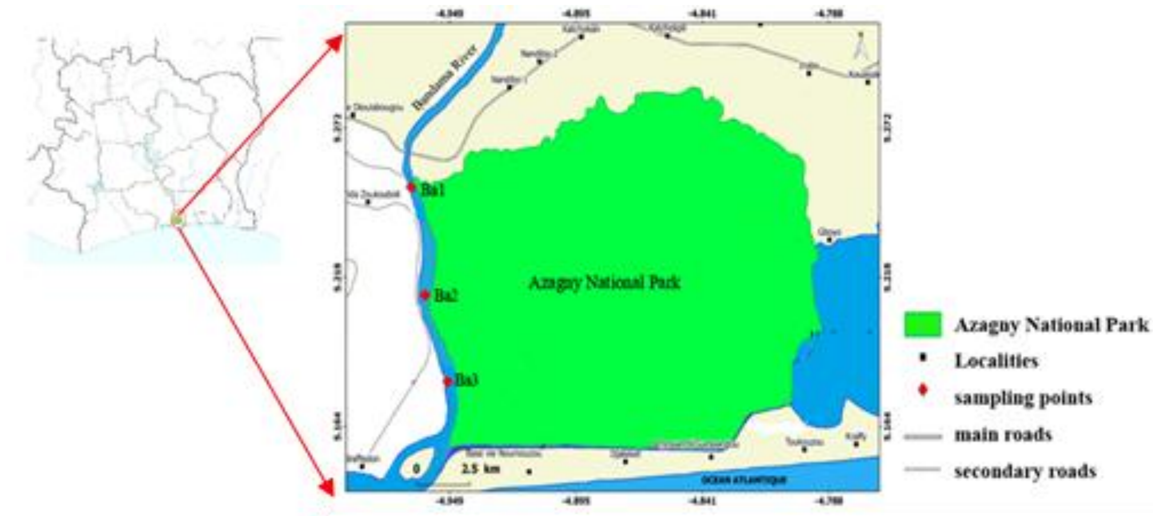

Figure 1. Map showing the different fish sampling points in the Bandama River estuary.
Source: Koné et al., 2021

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:

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

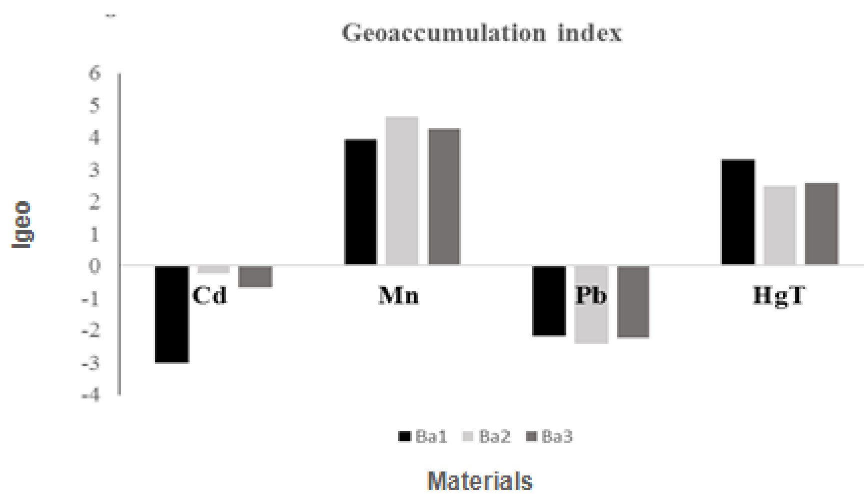

Figure 2. Variation of the geoaccumulation index of trace metals in the Bandama River estuary (March 2019- February 2020).
Source. Kamelan et al., 2022

(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

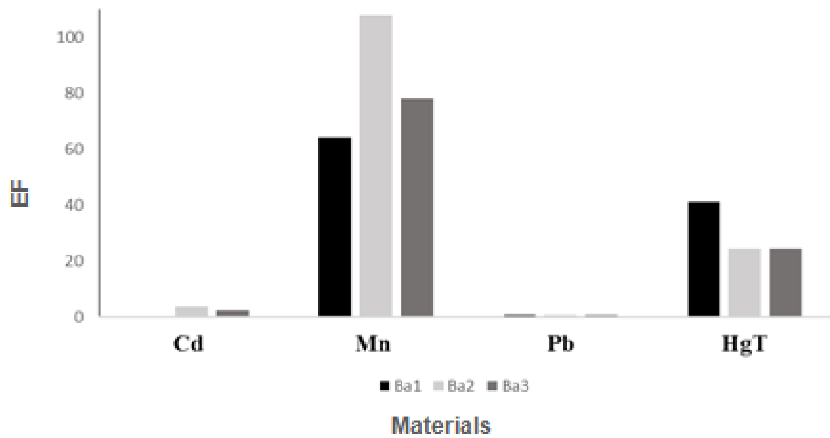

Figure 3. Variation of the enrichment factor of trace metals in the sediments of the Bandama River estuary (March 2019- February 2020).
Source. Kamelan et al., 2022

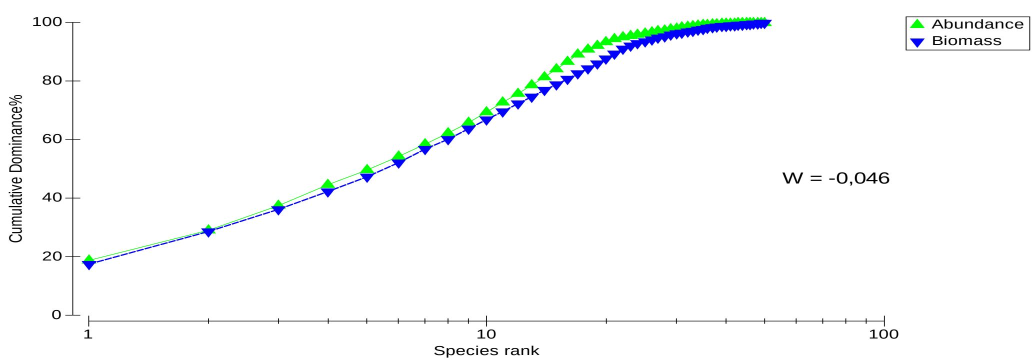

Figure 4. Variation of ecological stress indices in the Bandama River Estuary.
Source. Kamelan et al., 2022

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.

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Floristic diversity and regeneration of wild edible fruit species in the Reserve of Moutourwa and its surroundings (Far-North Cameroon)

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In order to assess the diversity, regeneration and structure of wild edible fruit trees, a study was carried out in the Laf-Madjam forest reserve and its surroundings. A semi-structured interview with local residents and a floristic inventory of woody plants (8 transects of 1000 m × 20 m each) were carried out. 24 species were cited as being used by the local residents. A total of 2134 individuals subdivided into 69 species, 43 genera and 27 families were counted, including 448 edible fruit individuals divided into 25 species, 19 genera and 14 families. The latter with important IVIs are: *Balanites aegyptiaca*, *Sclerocarya birrea*, *Ziziphus mauritiana* and *Hexalobus monopetalus*. Diversity is medium in edible fruit trees (HSI=3.10 bits, E= 0.67). Fruit trees with individuals of diameter ≥ 21 cm are in the majority. Inverted "L" and bell-shaped gaits are observed. The regeneration rate of fruit trees is higher in *Annona senegalensis*, *H. monopetalus*, and *B. aegyptiaca*. The involvement of local people in the management of the reserve's fruit trees is important for sustainable management.

Key words: Edible fruits, Moutourwa, sustainable management, structure, phytodiversity.

INTRODUCTION

The Central Africa forests are sources of income for the countries of the sub-region in both the formal and informal sectors (Eba'a et al., 2011). In most countries of the Congo Basin, the exploitation of forest resources remains the main provider of private wage employment, particularly in remote rural areas. Most scientific work recognises many benefits of forests, which are classified under the theme of ecosystem services (M.E.A, 2005; Arrif et al., 2011). These services include reducing air pollutants (Nowak et al., 2006), reducing heat islands (Akbari et al., 2001), enhancing precipitation and CO_2 absorption, regulating local climate and mitigating global

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climate change (Laporte and Cordeau, 2007). They also improve the environmental quality of localities on which people's health depends (Jim and Chen, 2008).

In addition, more than half of the world's population lives in urban areas and uses forest resources to meet their needs (Véron, 2007). These high anthropogenic activities are very accentuated and the direct consequence is the marked deterioration of these resources on green spaces. The phenomenon is more noticeable in developing countries, where the sensitivity of city dwellers to the presence of vegetation becomes weaker as the city becomes more densely built (Rusterholz, 2003). This environmentally damaging situation is also observed in Cameroon (Wolff, 2005). The creation of protected areas in Cameroon is in line with the government's desire to preserve ecosystems in order to maintain biological diversity. The Government of Cameroon's objective in terms of biodiversity conservation is to eventually convert 30% of the national territory into protected areas. These include national parks, nature reserves, and zoos (Tieguhong and Betti, 2008). In Cameroon, the total area of protected areas covers more than 17% of the national territory. They are located in both forest and savannah ecosystems. The Far North Region in particular, characterised by a low vegetation cover and very aggressive, has a vast network of protected areas made up of 5 forest reserves and 3 national parks which are also subject to strong anthropic pressure for the exploitation of resources (Wafo, 2008; Fotsing, 2009). The boundaries of the protected areas have greatly regressed and are poorly managed, and the lack of involvement of local populations in management is noticeable (Barbault, 2007). The reserves in the Far North Region, such as those in the Moutourwa locality, have been the scene of abusive exploitation of resources for decades. The latter, despite its status, is threatened by human activity, further accentuated by the unsustainable exploitation of plant species in general and edible fruit trees in particular.

The dry zones of sub-Saharan Africa are characterized by a long dry season and a short rainy season each year. In addition, the Far North Region of Cameroon is characterized by a population explosion and aridity of the soil. This situation is partly responsible for the scarcity of foodstuffs. The populations living in the vicinity of the Laf-Madjam reserve enter this reserve to collect non-timber forest products (NTFPs) such as edible fruits. This exploitation is anarchic and does not allow for the sustainability of these fruit trees and it is important to evaluate them. The real problem here is the unsustainable use of fruit species in the Laf-Madjam Forest Reserve. Several studies have been conducted in and around the reserve, such as those by Fotsing et al. (2003) and Todou et al. (2016). These authors focused their studies on the state of the reserve and riparian areas and on the floristic diversity in this area. Little is known about the floristic diversity of harvested edible fruit trees in this reserve. This study contributed to the development of edible fruit trees for their effective conservation and sustainable use in the Moutourwa district. Thus, it was a question of inventorying the edible and non-edible fruit trees of the reserve and its surroundings, but also of determining the diversity of fruit species exploited by the local population in the reserve and its surroundings.

MATERIALS AND METHODS

Study site

The district of Moutourwa is located in the division of Mayo Kani, Far North Region. It is located between 10° 09' 36 '' - 10° 19' 12 '' North latitude; and between 14° 2' 21'' - 14° 17' 7'' East longitude (Figure 1). The climate of the Moutourwa council is the Sudano-Sahelian type and is characterized by 2 seasons: a long dry season, from October to May and a rainy season, from June to September. The average annual rainfall is 867 mm and the average annual temperature is 27°C, with a maximum of 38°C from March to April and a minimum of 18°C from December and January (Suchel, 1987). Four types of soils with different characteristics that are threatened by the effects of rain and especially wind erosion. The woody and herbaceous vegetation has elements of Sudano-Sahelian savannahs, dry savannahs and Sahelian steppes (Letouzey, 1968). The flora is characteristic of the thorny steppes, consisting of tree and shrub savannahs with a very irregular herbaceous cover.

Data collection

Ethnobotanical survey

This phase, carried out in September 2020, consisted of administering a questionnaire using the tools of the Accelerated Participatory Research Method (APRM) and a participatory approach described by Sunderland (1998) and Guedjé (2002). These surveys were complemented by direct field observations. They were conducted with local populations and actors involved in the exploitation of resources. The choice of interviewees was random. This interview targeted all categories of people. In total, 4 villages were selected for this survey (Laf, Moulva, Mayel Guinnadji and Bajava) and 117 people were interviewed. The overall survey approach made it possible to gather the following information the demographic and socio-economic characteristics of the populations of the Laf-Madjam forest reserve, the peasant perception and importance of the forest reserve for the local population, the main human activities practiced in the forest reserve, the most important edible fruit species for the local population, the main NTFPs harvested, the state of the vegetation, the management and development of the vegetation in the area, as well as the priority edible fruit species for the local pharmacopoeia. Data on the use of plant species in all areas were collected.

Floristic inventories

The inventory of plant species was done in 8 transects of size 1000 m × 20 m and consisted of counting all woody individuals present in the different types of plant formations. Following along a line of layons, members of the inventory team scanned the transect to identify, count, measure, and observe individuals of woody species encountered using an inventory form. Each species was identified

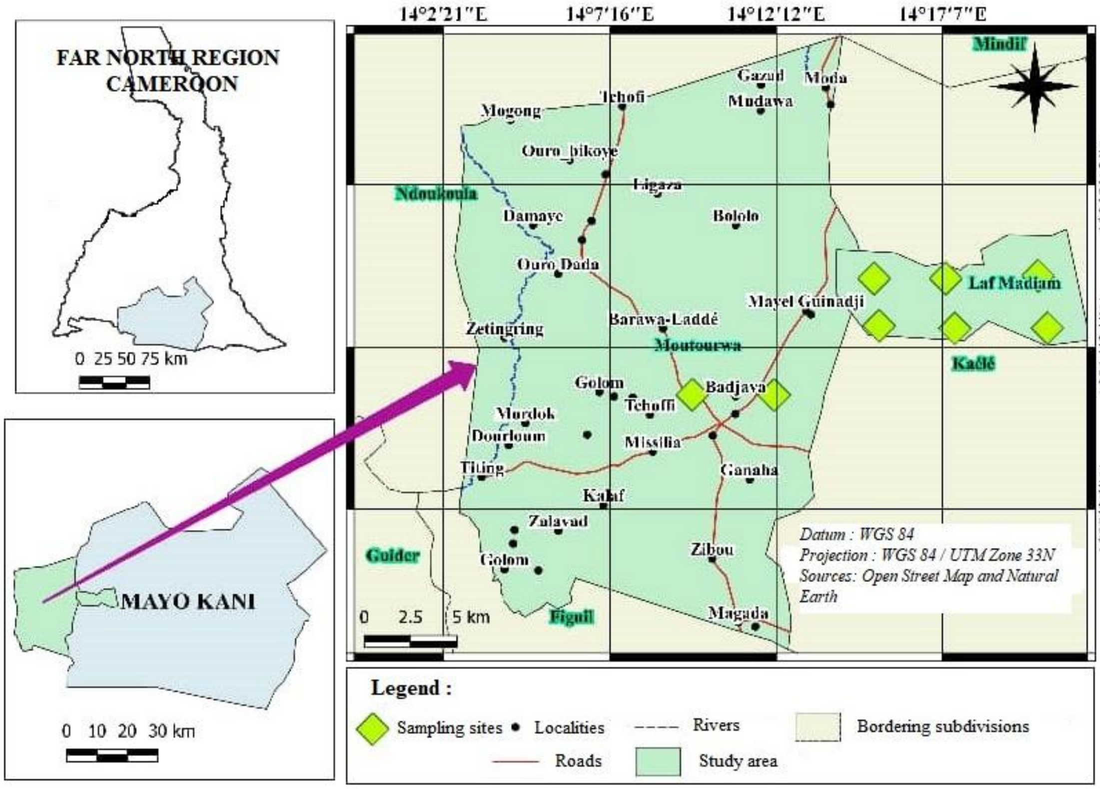

Figure 1. Localization of the study site.
Source: Author

by its scientific and/or local name. For unidentified species, samples were taken and then pressed to make the herbarium. Subsequently, these species could be identified with the help of appropriate documents such as the flora of Arbonnier (2009), but also by the botanists of the Faculty of Science. In addition to counting, dendrometric measurements (trunk circumference at 1.30 m from the ground and height) were taken for edible fruit trees.

Data processing and analysis

The species composition of the different plant formations was described using the following parameters and formulas: (i) The relative frequency (RFr) (Braun-Blanquet, 1932): RF = $(A_i/B) \times 100$, where A_i=number of plots containing the species i and B=total number of plots sampled; (ii) relative dominance (RDo) (Dona et al., 2016): RDo= $\pi D_i^2/4$, RD = relative dominance; Di = diameter at breast height of the specie i; π=3.14; (iii) relative density (RDe) (Ngom et al., 2013): RDe = $P_i \times 100$, where $P_i=n_i/N$, n_i is the number of individuals belonged to taxon i and N is total number of individuals of all sampled plots; (iv) relative diversity (RD_i): RD_i = number of species of one family×100/total number of species; (v) density (stems/ha) (Ngom et al., 2013): D = n_i/A where n_i is the number of individuals belonging to species i and A is the area in hectares; (vi) basal area (BA) (Devineau, 1984): BA= $(\sum \pi D_i)^2/4$, where D is diameter at breast height and S in m²/ha; (vii) importance value index (Cottam et Curtis, 1956): IVI=relative abundance + relative frequency + relative dominance; (viii) regeneration rate (Koulibaly, 2008; Konan, 2009): Tr = (n/N) × 100; n is the total number of juvenile individuals with a diameter less than or equal to 10 cm and N is the total number of individuals in the vegetation unit; (ix) species rarity index (Kokou et al., 2005): RI = (1-(ni/N)) ×100 with n_i: the number of records in which species i occurs and N the total number of records. The Fisher test was used to compare some of the different means.

Specific diversity of the site was described using the following indices: Shannon and Weaver index (Frontier and Pichod-Viale, 1995): $H' = -\Sigma\ ni/N \times \log_2 ni/N$ With ni is the proportion of a species i to the total number of species (N). Pielou evenness index (Dajoz, 1982): $E = H'/\log_2 N$ or H'/Hmax, with H' the Shannon diversity and N the species richness. Sorensen's coefficient of similarity (Dajoz, 1985; Krebs, 1999): Ks= (2c/a+b) × 100, where a is the number of species in a list belonging to site A; b is the number of species in a list belonging to site B; and c is the number of species common to the two sites (A and B).

RESULTS

Medicinal plants reported and diseases treated

The ethnobotanical surveys among the local populations showed that 24 species divided into 23 genera and 17 families were cited as being used by the local people (Table 1). The most represented families were Anacardiaceae (3 species), Annonaceae, Arecaceae, Bombacaceae, Moraceae and Rubiaceae (2 species each). Some organs cited by these populations are

Table 1. Edible fruit species and products consumed during the ethnobotanical surveys.

Families	Species	Local names	Parts used
Anacardiaceae	*Lannea acida*	lebew (guiziga)	Pulp, seed
	Haematostaphis barteri	trousse (guiziga)	Leaves, pulp, seed
	Sclerocarya birrea	eedi (foufouldé)	Pulp, seed
Annonaceae	*Annona senegalensis*	gonokoy (guiziga)	Pulp
	Hexalobus monopetalus	tubulubum (guiziga)	Pulp
Arecaceae	*Borassus aethiopium*	doubbi (foufouldé)	Pulp, root of young trees
	Hyphaene thebaïca	gellehi (foufouldé)	Pulp, seed
Balanitaceae	*Balanites aegyptiaca*	tanni (foulfouldé)	Pulp, seed, leaves
Bombacaceae	*Bombax costatum*	djohi (foulfouldé)	Immature fruits
	Adansonia digitata	bokki (foulfouldé)	Pulp, seed, leaves
Caesalpiniaceae	*Tamarindus indica*	djabbi (foulfouldé)	Pulp, seed
Ebenaceae	*Diospyros mespiliformis*	huwung (guiziga)	Pulp
Loganiaceae	*Strycnos spinosa*	narbatanahi (foulfouldé)	Pulp, seed
Mimosaceae	*Parkia biglobosa*	narehi (foulfouldé)	Pulp
Moraceae	*Ficus platiphylla*	doundéhi (foulfouldé)	Whole fruits
	Ficus sycomorus	ibbi gorki (foulfouldé)	Whole fruits
Olacaceae	*Ximenia americana*	tchabboulli (foulfouldé)	Pulp
Rhamnaceae	*Ziziphus mauritiana*	djabi (foulfouldé)	Pulp
Rubiaceae	*Feretia apodanthera*	bouhebehi (foulfouldé)	Pulp
	Sarcocephalus latifolius	bakurehi (foulfouldé)	Pulp
Sapotaceae	*Vitellaria paradoxa*	sougoum (guiziga)	Pulp, seed
Sterculiaceae	*Sterculia setigera*	bobori (foulfouldé)	Seed
Tiliaceae	*Grewia flavescens*	kolehi (foulfouldé)	Pulp, seed
Verbenaceae	*Vitex doniana*	galbihi (foulfouldé)	Pulp

Source: Author

consumed directly while others are first processed before use. These include whole fruits, roots, leaves, seeds and pulp. The results showed that the pulp is the part of the fruit tree most used by the local people.

Edible plants used in traditional pharmacopoeia

For medicinal purposes, the local population uses several fruit trees. The organs used and the method of preparation vary according to the species and the diseases. The most used species in the traditional pharmacopoeia was *Balanites aegyptiaca* (85.47%), followed by *Annona senegalensis* (76.92%), *Ximenia americana* (73.50%) and *Tamarindus indica* (72.64%) (Table 2). The most frequent diseases in the study area encountered were: typhoid, diarrhoea and jaundice (1.12% each). The most used method of preparation was decoction (4.48%), followed by infusion and maceration (1.12% each). As for the organs, bark (4.34%) and leaves (1.55%) were the most used in the recipes (Table 2).

Floristic composition of woody plants

A total of 2134 individuals were inventoried in the Laf-Madjam forest reserve and its surroundings with a total density of 133.37 individuals/ha (Table 3). These individuals are subdivided into 69 species divided into 43 genera and 27 families. The Combretaceae family has the highest number of species (10 species), followed by the Mimosaceae (8 species) and the Anacardiaceae with

Table 2. Edible fruit organs used in traditional pharmacopoeia.

Family	Scientific names	Local names	Exploited organ	Mode of preparation	Treated diseases	% of respondents
Anacardiaceae	*Haematostaphis barteri*	trouss (guiziga)	Bark	Decoction	Anaemia	53.84
	Sclerocarya birrea	eedi (foufouldé)	Bark	Decoction	Rheumatism	67
			Bark	Decoction	Dysentery	
			Bark	Decoction	Tooth ache	
			Leaves	Infusion	Hypertension	
Annonaceae	*Hexalobus monopetalus*		Leaves	Decoction	Yellow fever	58.11
	Annona senegalensis	gonokoy (Guiziga)	Roots	Maceration	Typhoid	76.92
			Bark	Decoction	Diarrhea	
			Bark	Powder	Wounds	
Balanitaceae	*Balanites aegyptiaca*	tagwar (Guiziga)	Seeds	Maceration	Yellow fever	85.47
			Roots, bark	Decoction	Diarrhea	
			Seeds	Maceration	Typhoid	
			Leaves	Expression	Eye pain	
Bombaceae	*Adansonia digitata*	bokki (foufouldé)	Leaves	Powder	Diarrhea	59.82
Caesalpiniaceae	*Tamarindus indica*	djabbi (foufouldé)	Flowers	Infusion	Yellow fever	72.64
			Fruits	Infusion	Fever	
			Fruits	Decoction	Typhoid	
			Flowers	Decoction	Rubeola	
Ebenaceae	*Diospyros mespiliformis*	nelbi (foufouldé)	Seeds, roots, bark	Decoction	Stomach ache	69.23
			Leaves	Infusion	Eye pain	
Mimosaceae	*Parkia biglobosa*	narehi (foufouldé)	Bark	Decoction	Dysentery	58.97
Moraceae	*Ficus platiphylla*.	doundéhi (foufouldé)	Bark	Decoction	Diarrhea	56.41
Olacaceae	*Ximenia americana*	toumbour (guiziga)	Roots	Decoction	Yellow fever	73.50
Rhamnaceae	*Ziziphus mauritiana*	hilvid (guiziga)	Bark	Decoction	Malaria	58.97
Rubiaceae	*Sarcocephalus latifolius*	bakurehi (foufouldé)	Bark	Maceration	Typhoïd	66.66
			Bark	Decoction	Malaria	
Sapotaceae	*Vitellaria paradoxa*	sougoum (guiziga)	Seeds	Oil extraction	Rheumatism	58.11
Verbenaceae	*Vitex doniana*	zougoui (guiziga)	Bark	Decoction	Itchiness	63.24

Source: Author

Table 3. Comparison of the taxonomic richness of the different plant formations.

Taxonomic groups	Shrubby savannah	Woody savannah	Gallery forest	Hills	Total
Species number	35	34	38	45	69
Genera number	25	24	24	31	43
Families number	16	17	17	21	27
Individuals number	369	642	603	372	2134
Density	92.25	160.50	150.75	93	133.37

Source: Author

Table 4. Comparison of the taxonomic richness of fruit trees in different plant formations.

Taxonomic groups	Shrubby savannah	Woody savannah	Gallery forest	Hills	Total
Species number	6	7	12	16	24
Genera numbers	6	7	12	12	18
Families number	5	6	10	9	14
Individuals number	67	113	115	154	449

Source: Author

Table 5. Diversity indices of different plant formations in the study area.

Plant formations	Diversity indices		
	Maximum diversity	Shannon-weaver index	Pielou evenness
Woody savannah	5.09	3.66	0.72
Shrubby savannah	5.13	3.80	0.74
Forestry gallery	5.25	4.00	0.76
Hills	5.49	4.22	0.77
Study area	6.11	4.53	0.74

Source: Author

7 species.

Taxonomic richness of edible fruit trees

A total of 449 individuals of edible fruit trees were recorded and divided into 24 species, 18 genera and 14 families (Table 4). The richest plant formation was hillside with 16 species followed by gallery forest with 12 species.

Species diversity

The Shannon-Weaver diversity index value was 4.53 bits for the study area and varied from 3.66 bits for the woody savannah to 1.22 for the hills (Table 5). The Pielou’s evenness index was 0.74 for the study site and varied from 0.78 for woody savannah to 0.77 for the hills.

For edible fruit trees, the Shannon diversity index calculated in all formations was 3.10 bits. This value varied from 1.10 in the shrubby savannah to 2.03 bits in the hills (Table 6). The Pielou evenness index was 0.67 in the study area. This value varied from 0.43 for the shrubby savannah to 0.50 for the hills and the tree savannah.

Sorensen's coefficient of similarity for all woody plants was ≥ 50% for all plant formations (Table 7) while for fruit trees only (Table 8), these values were ≤ 50% all plant formations.

Rarity index and species importance value index

The calculation of the rarity index of the species encountered in the different formations of Moutourwa and its surroundings shows that 2 species have a rarity index higher than 80%, *Diospyros mespiliformis* and *Gardenia ternifolia* rarity index of 87.5%. Among the species, *Sclerocarya birrea* was found in all 8 transects and had a rarity index of zero (RI = 0). The high abundance of certain species could be considered as a response of the rural society which considers them as a priority species

Table 6. Diversity indices of edible fruit trees in different plant formations of the study site.

Plant formations	Diversity indices		
	Maximum diversity	Shannon-weaver index	Pielou evenness
Woody savannah	2.81	1.40	0.50
Shrubby savannah	2.58	1.10	0.43
Forestry gallery	3.58	1.68	0.47
Hill	4	2.03	0.50
Study area	4.64	3.10	0.67

Source: Author

Table 7. Coefficient of similarity of woody species in the study area.

Coefficient of similarity	Plant formations			
	Woody savannah	Shrubby savannah	Forestry gallery	Hillside
Woody savannah	-	63.77	72.22	40.51
Shrubby savannah	-	-	65.75	50
Forestry gallery	-	-	-	53.01

Source: Author

Table 8. Coefficient of similarity of edible fruit trees in the study area.

Coefficient of similarity	Plant formations			
	Woody savannah	Shrubby savannah	Forestry gallery	Hillside
Woody savannah	-	46.15	63.16	26.09
Shrubby savannah	-	-	44.44	18.18
Forestry gallery	-	-	-	28.57

Source: Author

(Sigaud and Eyog-Matig, 2001).

The ecological importance of the species here is assessed by the high value of their IVI. The species with high IVI values were: *B. aegyptiaca* (72.56), *S. birrea* (37.54), *Ziziphus mauritiana* (23.36) and *Hexalobus monopetalus* (22.38) (Table 9).

Density and basal area of fruit trees

The highest density value (38.24 stems/ha) and the lowest value (16.77 stems/ha) and the highest basal area (1.95 m^2/ha) and the lowest value (0.94 m^2/ha) were found, respectively in the hills and shrubby savannah (Table 10). Analysis of variance of absolute density and basal area showed a highly significant difference between formation types (p=0.05).

Horizontal structure of edible fruit trees

The distribution of individuals by diameter class in the study area shows some structural divergences clearly discriminated by the number of stems. In the present study, the structure of edible fruit trees in the savannah shrubland and edible fruit trees in the hillside showed 'inverted L' curves (Figure 2). The structure of edible fruit trees in the forest gallery and in the tree savannah showed a bell-shaped curve.

Vertical structure of edible fruit trees

The vertical structure of the plant population showed "L" curves with high proportion of individuals in the class height [←; 10[- in the different formations (Figure 3). This structure showed high proportion of young plants and low proportion of adult individuals.

Regeneration of species

A total of 141 individuals grouped into 11 species were recorded in the different formation types. In the shrubby

Table 9. Species with high Ecological importance of edible fruit trees.

Family	Species	Relative dominance	Relative density	Relative frequency	IVI
Anacardiaceae	*Haematostaphis barteri*	10.01	5.12	3.12	18.26
	Lannea acida	7.52	2.45	4.68	14.65
	Lannea fructicosa	3.27	8.68	3.12	15.08
	Sclerocarya birrea	18.80	6.23	12.5	37.54
Annonaceae	*Annona senegalensis*	1.03	11.58	4.68	17.29
	Hexalobus monopetalus	5.88	8.69	7.81	22.38
Balanitaceae	*Balanites aegyptiaca*	29.78	33.40	9.37	72.56
Caesalpiniaceae	*Tamarindus indica*	4.36	2.22	4.68	11.27
Ebenaceae	*Diospyros mespiliformis*	2.08	3.12	10.33	15.53
Rhamnaceae	*Ziziphus mauritiana*	2.86	11.13	9.37	23.36
Ulmaceae	*Celtis integrifolia*	7.94	0.44	1.56	9.94

Source: Author

Table 10. Density and basal area by formation type in the study area.

Plant formations	Dendrometrical parameters	
	Density (trees/ha)	Basal area (m^2/ha)
Woody savannah	28.24 ± 0.01^c	0.70 ± 0.01^d
Shrubby savannah	16.77 ± 0.02^d	0.94 ± 0.01^b
Forestry gallery	28.76 ± 0.01^b	0.81 ± 0.01^c
Hills	38.24 ± 0.02^a	1.95 ± 0.01^a

Source:Author

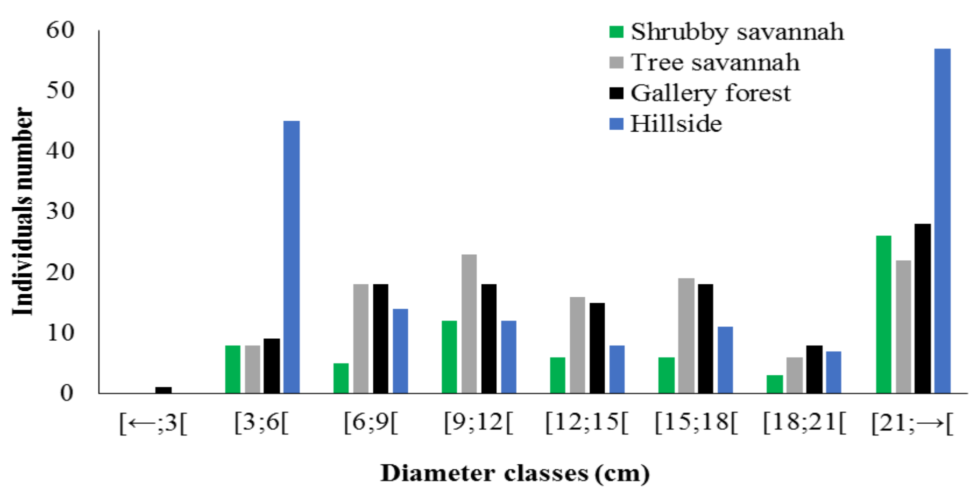

Figure 2. Horizontal structure of all edible fruit trees in different plant formations.
Source: Author

and tree savannahs, the highest rate is observed in *B. aegyptiaca* (44 and 68.75%, respectively) (Table 11). In the forest gallery, the highest value is found in *Z. mauritiana* (66.67%), whereas in the hill, the highest regeneration rate is observed in *A. senegalensis* (74.04%).

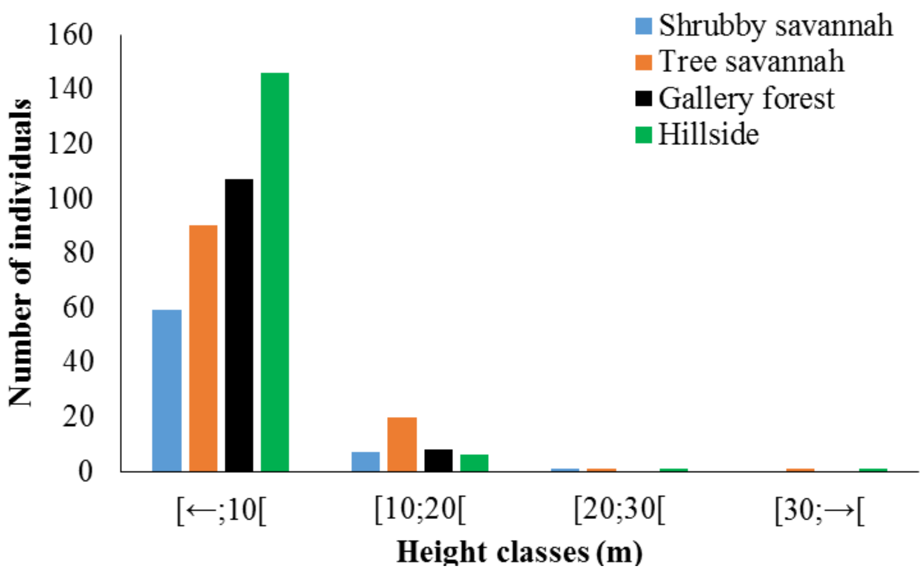

Figure 3. Vertical structure of all edible fruit trees in the different plant formation.
Source: Author

DISCUSSION

Medicinal plants reported and diseases treated

The high use of the pulp by the local people can be explained by the fact that fruits in the form of pulp are the most represented in the study site. Moreover, the fruits most suitable for preservation are in pulp form. These different results corroborate those of Todou et al. (2017) who found 50 species used by local populations in the Mandara Mountains in Cameroon. Nyakabwa (1994) in the DRC also found that the pulp is the most used part of the fruit.

Edible plants used in traditional pharmacopoeia

The interest in leaves and bark can be explained by the fact that these plant organs are the seat par excellence of biosynthesis and even storage of secondary metabolites which is responsible for the plant's pharmaco-biological properties (Nacoulma Ouedraogo, 1996). Furthermore, Bitsindou (1986) attests that the high frequency of use of leaves is due to the ease of harvesting. These results are similar to those obtained by Ngbolua et al. (2019) who showed that leaves and bark were the most used. In addition, Saotoing et al. (2011) obtained 34% of the leaves commonly used in recipes. On the other hand, Gueye (2012) found in their respective works a high frequency of use of barks and roots. In general, all organs of medicinal plants relieve and cure diseases or ailments but uncontrolled use of certain organs such as roots and bark could cause damage to the plant and even its ecosystem. So, it would be better to use good harvesting techniques to preserve it for us and even for future generations.

Floristic composition of woody plants

The highest number of species, genera and families is found in the hills while the lowest number is found in the shrubby and tree savannas. This difference may be due to the existence of permanent anthropic actions in the shrub and tree savannahs while the hills are difficult to access. The dominance of Combretaceae can be explained by the fact that it is a characteristic family of savannahs and easily adapt to water stress. Oumarou (2012) has shown that the Combretaceae family represents the most diverse and abundant family in the savannahs. Considering the high number of species and individuals inventoried in the Laf-Madjam forest reserve and its surroundings, it can be said that this locality is rich in woody species. These results are similar to those of Todou et al. (2016) who found 75 species, divided into 54 genera and 28 families in the same locality. Similarly, Teicheugang (2000) recorded 75 species, divided into 46 genera and 24 families in the Zamay reserve. Froumsia et al. (2019) also found 66 species in 46 genera and 26 families in the unprotected Sudano-Sahelian zone in Cameroon. The similarity of these results may be due to similar microclimatic factors and anthropogenic pressures.

Taxonomic richness of edible fruit trees

The variation in species richness in the different plant formation observed can be explained by climate variation

Table 11. Regeneration of edible fruit species in different plant formation.

Species	Shrubby savannah	Woody savannah	Forestry gallery	Hillside
Balanites aegyptiaca	44.44	68,75	25.00	0.00
Ximenia americana	11.11	0.00	0.00	0.00
Ziziphus mauritiana	22.22	12,50	66.67	0.00
Capparis sepiaria	11.11	6,25	0.00	0.00
Sclerocarya birrea	11.11	0.00	0.00	0.00
Hexalobus monopetalus	0.00	0.00	8,33	0.00
Annona senegalensis	0.00	12,50	0.00	74.04
Sarcocephalus latifolius	0.00	0.00	0.00	0.96
Diospyros mespiliformis	0.00	0.00	0.00	0.96
Ficus platyphylla	0.00	0.00	0.00	0.96
Hexalobus monopetalus	0.00	0.00	0.00	23.08

Source: Author

(Sarr, 2008), interspecific competition, resource availability and the level of disturbance (Palmer, 1994). It is also observed following the existence of permanent anthropic actions in the shrubby and tree savannahs while the hill is difficult to access. This specific richness was similar to the work of Todou et al. (2017) who found 38 wild edible fruit species grouped into 29 genera and 19 families in the Far North of Cameroon. These results showed a significant wealth of edible fruit trees in the Laf-Madjam forest reserve, hence the need to valorise them in order to use them rationally.

Species diversity

Based on the calculated diversity indices, the study area had high diversity because the Shannon index was high and the Pielou evenness is near to 1. These values indicate a homogeneity of the stand. In the different vegetation formations, it can be seen that diversity is important everywhere because the Shannon index varies from 3.66 to 4.22 with the hill having a higher diversity.

Considering the values of the different diversity indices, it appears that the diversity of edible fruit species is moderate in the study area, but in each plant formation it is found to be very low, slightly less in the hills. This index is different from that found by Mapongmetsem et al. (2016) in the agroforests of the peri-urban area of the city of Bafia in the Central Cameroon Region (3.33 bits). In terms of Pielou equitability, it is 0.67 across the study area (0.50 for hill and tree savannah, 0.47 for forest gallery and 0.43 for shrub savanna). These values are lower than those of Todou et al. (2016) who found 0.82 in the uncultivated plain of Moutourwa located in the Sahelo-Sudanese sector of Cameroon. These results suggest that edible fruit species are equitable in the study area. Sorensen's coefficient of similarity for all woody plants was ≥ 50% for all plant formations and confirmed that these plant formations belong to the same plant communities while for fruit trees only, the values were ≤ 50% all plant formations and confirmed that these plant formations belong to different plants communities.

Rarity index and species importance value index

In the North Cameroon Region, 55 indigenous edible fruits were identified by Mapongmetsem et al. (2012). Among these fruits, *B. aegyptiaca* was one of them. These 55 fruits were among the most prized and traded in the region. Similarly, Kristensen and Balslev (2003) in Gourounsi, Burkina Faso, note that the availability of most fruits coincides with a decline in food supplies. At this time, the availability and consumption of wild fruits is a considerable contribution to household diets. Furthermore, Guinko and Pasgo (1992) state that wild fruits contribute to a varied diet in terms of vitamin intake. These results suggest that the consumption of these fruits therefore saves on very low agricultural produce to ensure year-round feeding. For this reason, it would be important to preserve the reserve's highly endangered fruit trees.

Density and basal area of fruit trees

These results are confirmed by Birnbaum (2017) who indicated that savannah tree formations are subject to anthropic influences. The high human pressure in the formations could explain the low presence of breeding individuals due to abusive logging. Comita et al. (2007) agree, saying that the higher the number of breeding individuals, the higher the overall density.

Horizontal structure of edible fruit trees

The general diametric distribution of edible fruit trees in the Laf-Madjam reserve showed that individuals with a diameter ≥21 cm were in the majority. It shows an "inverted L" distribution in some plant formations and a bell-shaped distribution in others. This type of distribution is similar to that obtained by Mapongmetsem et al. (2011) in Vitellaria paradoxa in the high Guinean savannahs. In the first case, this type of distribution shows that individuals with a large diameter are in the majority; this can be explained by anthropogenic actions such as bush fires and grazing, as juvenile species are destroyed at the expense of adults. In the second case, there is a dominance of individuals with a small diameter; this may show the good regeneration of these species. This may also be due to the strong anthropic pressure on this group and therefore the death of adult plants as a result of poor management or overexploitation. Thus, numerous studies carried out in the Sahelian and Sudanian zones have also confirmed this structural variability of species (Rabiou et al., 2015; Idrissa et al., 2017; Amadou et al., 2020). According to Sandjong et al. (2018), adaptations to ecological conditions, competition for resources and exploitation would underlie this structural variability. The low presence of adult individuals with a diameter greater than 15 cm was observed in species with an inverted J-shape that embodies secure regeneration. This indicates that large individuals are heavily exploited as highlighted by Idrissa et al. (2017). The 'inverted J' shape type has been observed in *T. indica* (Fandohan et al., 2011), *Dialium guineense* (Assongba et al., 2013), *Prosopis africana* (Houètchégnon et al., 2015) and *Lophira lanceolata* (Lankoandé et al., 2017). The predominance of young individuals can be explained by the relationship between the temperament of the species and their diameter distribution. However, the survival of these young individuals is problematic due to bushfires and overgrazing. On the contrary, species that are resistant to bushfires have a high proportion of mature individuals (Nkongmeneck et al., 2010) in their distribution, such as species with a bell-shaped distribution. This type of distribution is characteristic of mono-specific stands with very low regeneration potential.

Vertical structure of edible fruit trees

These results are in agreement with those of Sani (2009), in a revegetated site and a degraded site in the department of Mirriah and confirm one of the characteristics of savannah ecosystems. However, the L-shaped structure is a sign that the whole ecosystem is in a state of degradation as concluded by Jiagho et al. (2016) who worked in Waza National Park. In addition, Tchobsala et al. (2010) found the same structure in the peri-urban area in Ngaoundéré, Cameroon. These results are also in line with those of Faber-Langendeon and Gentry (1991), who obtain decreasing distributions of structural parameters in a hut field and justify that these distributions are characteristic of formations containing mature stands with many small individuals and a low representation of large trees.

Regeneration of species

This result can be justified by the adverse effects of man whose actions impact on the survival of many seedlings. In addition, several authors report that the regeneration of many woody species is made difficult by the harmful action of bush fires and grazing (Mbaiyetom et al., 2021, Nangndi et al., 2021). The species with a high regeneration rate were: *A. senegalensis*, *H. monopetalus*, *B. aegyptiaca* and *Z. mauritiana*, which together represent more than 80% of the regeneration rate of edible fruit trees. However, it should be noted that some species, although well present at the adult stage, have a low regeneration rate, or even none at all, at the seedling stage, while others are only present at the seedling stage and absent at the adult stage. According to Froumsia (2013), three quarters of seedlings live only 3 months at most. The results showed that the higher regeneration rate, the better the regeneration. The decrease in the overall regeneration rate of the species in the forest reserve would be attributed to the high density of species in this location negatively influencing the survival of natural regeneration due to insufficient light. Several research studies have indicated that the high regeneration rate is recorded in species suitable for suckering and layering (Douh et al., 2014).

Conclusion

The availability of edible fruit trees was highlighted in the Laf-Madjam forest reserve and its surroundings. The inventory revealed that Combretaceae, Mimosaceae and Anacardiaceae are the most represented families in the plant formations studied. The diversity of edible fruit species is moderate in the study area, but very low in some plant formations, somewhat less so in the hills. The highest basal area is observed in the hills and the lowest in the shrubby savannah. The highest rate of natural regeneration is found in *B. aegyptiaca* in the shrubby and tree savannahs, the highest value in the forest gallery is found in *Z. mauritiana* and in the hill it is observed in *A. senegalensis.* The analysis of diametric structure of the edible fruit trees in the Laf-Madjam reserve shows us that individuals with a diameter ≥21 cm is the most represented. It shows an "inverted L" distribution in some plant formations and a bell shape in others. The vertical structure of the plant population in the different formations, as well as in the formations as a whole, shows L-shaped curves. Strategies need to be developed to ensure conservation, survival of natural regeneration and to enable low-cost propagation activities of wild edible fruit species to improve their availability.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Akbari H, Huang J, Martien P, Rainer L, Rosenfeld A, Taha H (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Solar Energy 70(3):295-310.

Amadou MK, Ismaila D, Rabiou H (2020). Composition floristique, diversité et structure des espèces forestières alimentaires de la Région de Sikasso au Sud du Mali. European Scientific Journal 16(12):156-178.

Arbonnier M (2009). Arbres, arbustes et lianes d'Afrique de l'Ouest (3e édition). CIRAD MNHN-UICN, Paris 573 p.

Arrif T, Blanc N, Clergeau P (2011). Trame verte urbaine, un rapport Nature-Urbain en géographie et écologie, Cybergo. European Journal of Geography 17:5-18.

Assongba YF, Djègo GJ, Sinsin B (2013). Distribution des habitats de *Dialium guineense* (wild) (Fabaceae: Caesalpinioideae) dans les phytodistricts Est du Sud-Bénin. Bulletin Scientifique de l'Institut National pour l'Environnement et la Conservation de la Nature 12:1-16.

Barbault R (2007). « Espaces protégés : stratégie dépassées ou dispositifs d'avenir ? » Pour les sciences 35(9):14-17.

Birnbaum P (2017). Spatialisation de la diversité et de la structure: un enjeu pour la conservation des forêts tropicales. Biodiversité et Ecologie. Université de Montpellier. France 79 p.

Bitsindou M (1986). Enquête sur la phytothérapie traditionnelle à Kindamba et Odzala (Congo) et analyse de convergence d'usage des plantes médicinales en Afrique Centrale. Mémoire Doc (ined.), Université libre de Bruxelles, Belgique 482 p.

Comita LS, Condit R, Hubbell SP (2007). Developmental changes in habitat associations of tropical trees. Journal of Ecology 95(3):482-492.

Douh C, Daïnou K, Loumeto JJ, Fayolle A, Doucet JL (2014). Explorer la banque de graines du sol pour mieux comprendre la dynamique de régénération des forêts tropicales africaines (synthèse bibliographique). Biotechnologie, Agronomie, Société et Environnement 18(4):558-565.

Eba'a RA, Lescuyer G, Jonas NP (2011). Etude de l'importance économique et sociale du Secteur forestier et faunique dans les Etats d'Afrique Centrale 9 p.

Faber-Langendoen D, Gentry AH (1991). The Structure and diversity of Rain Forests at Bajo Calima, Choco Region, Western Colombia. Biotropica 23(1):2-11. Https://doi.org/10.2307/2388682

Fandohan B, Assogbadjo AE, Glèlè Kakai R, Sinsin B (2011). Geographical distribution, tree density and fruit production of *Tamarindus indica* L. (Fabaceae) across three ecological regions in Benin. Fruits 66(2):53-62.

Fotsing J, Ntoupka M, Boubaoua A (2003). Etat de la réserve forestière de Laf et Perspective d'aménagement et de gestion de l'espace. In jamin J.Y. SEIN Y. Boukar L. et Floret C. (Eds), Savane africaine : des espaces en mutation, des acteurs face à de nouveaux défis. Actes du colloque, Garoua, Cameroun 10 p.

Fotsing J, Verburg P, Wouter TG, Cheylan JP, Tchuente M (2009). Un modèle intégré pour explorer les trajectoires d'utilisation de l'espace en Zone de Savanes Sèches du Cameroun. Savanes africaines en développement : innover pour durer, Garoua, Cameroun 12 p.

Froumsia M (2013). Impact des activités anthropiques sur le couvert ligneux de la réserve de Kalfou, Cameroun. Thèse doctorat Université de Yaoundé I 151 p.

Froumsia M, Djosebe A, Souare K, Hamawa Y, Todou G, Tchobsala (2019). Structure, dynamics and impact of the exploitation of the woody plants of woodlands in the Sudano-sahelian zones, North Cameroon. International Journal of Advanced Research in Biological Sciences 6(3):201-220.

Gueye M, Cisse A, Diatta CD, Diop S, Koma S (2012). Étude ethnobotanique des plantes utilisées contre la constipation chez les Malinkés de la communauté rurale de Tomboronkoto, Kédougou, Sénégal. International Journal of Biology and Chemistry Science 6(2):778-779.

Guinko S, Pasko LJ (1992). Haversting and marketing of edible products from local woody species in Zitenga, Burkina Faso. UNASYLVA n°168. Aride Zone Forestry 43(1):47-56.

Idrissa S, Habou R, Machi II, Mahamane A, Mahamane S (2017). Biodiversity and Structure of Woody Plants of Sahelian Rangelands of Baban Rafi, Niger. International Journal of Biology 9(4):1-9.

Jiagho ER, Zapfack L, Banoho LPRK, Tsayem-Demaze M, Corbonnois J, Tchawa P (2016). Diversité de la flore ligneuse à la périphérie du Parc National de Waza (Cameroun). Vertigo 16(1).

Jim CY, Chen WY (2008). Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). Journal of Environmental Management 88(4):665-676.

Kristensen M, Balslev H (2003). Perceptions, use and availability of woody plants among the Gourounsi in Burkina Faso. Biodiversity and Conservation 12(8):1715-1739.

Lankoandé B, Ouédraogo A, Boussim JI, Lykke AM (2017). Natural stands diversity and population structure of *Lophira lanceolata* Tiegh. ex Keay, a local oil tree species in Burkina Faso. West Africa. Agroforestry Systems 9(1):85-96.

Laporte G, Cordeau JF (2007). The dial-a-ride Problem: models and algorithms. Annals of Operations Research 153(1):29-46.

Letouzey R (1968). Etude phytogéographique du Cameroun. Eds. Paul Lechevalier, Paris 511 p.

Mapongmetsem PM, Guidawa F, Noubissie TJB, Nkonmeneck AB, Bidou HSS, Ronald B (2016). Propagation végétative de *Vitex doniana* sweet à partir des sections de racines. Bois et Forêts des Tropiques 327(327):29-37.

Mapongmetsem PM, Kapchie VN, Tefempa BH (2012). Diversity of local fruit trees and their contribution in sustaining the rural livelihood in the Northern Cameroon. Ethiopian Journal of Environmental Studies and Management 5(1):32- 46.

Mapongmetsem PM, Nkongmeneck AB, Romgoumi G, Dongock ND, Dongmo B (2011). Impact des systèmes d'utilisation des terres sur la conservation de *Vitellaria paradoxa* Gaertn. F. (Sapotaceae) dans la région des savanes soudano-guinéennes. International Journal of Environmental Studies 68(6):851-872.

Mbaiyetom H, Avana TML, Tchamba NM, Wouokoue TJB (2021). Diversité floristique et structure de la végétation ligneuse des parcs arborés de la zone soudanienne du Tchad. International Journal of Biological and Chemical Sciences 15(1):68-80.

MEA (2005). Ecosystem Wealth and Human Well-being. Island Press 135 p.

Nacoulma-OG (1996). Plantes médicinales et Pratiques médicales traditionnelles au Burkina Faso : cas du plateau central. Thèse de Doctorat d'Etat ès Sciences Naturelles, Université de Ouagadougou, tome II, 285 p.

Nangndi B, Avana TML, Wouokoue TJB, Etchike DAB, Wolwai DT, Fonkou T (2021). Floristic and structural diversity of woody vegetation in the Sudano-guinean zone of Larmanaye, Chad. Journal of Ecology and the Natural Environment 13(3):63-72.

Ngbolua KN, Inkoto CL, Mongo NL, Ashande CM, Masens YB, Mpiana PT (2019). Étude ethnobotanique et floristique de quelques plantes médicinales commercialisées à Kinshasa, République Démocratique du Congo. Revue marocaine des Sciences agronomiques et vétérinaires 7(1):118-128.

Nkongmeneck BA, Kemeuze VA, Mapongmetsem PM, Ibrahima A, Jiofack RT (2010). Distribution des Combretums en rapport avec l'aridité au Cameroun. International Journal of Environmental Studies 67(1):41-50.

Nowak DJ, Hoehn RE, Crane DE, Stevens JC, Walton JT (2006). Assessing Urban Forest, Effects and Values: Chicago's Urban Forest. Resource Bulletin, NRS-37. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station 27 p.

Oumarou S (2012). Caractéristiques de la végétation ligneuse et impact des traitements sylvicoles dans la dynamique évolutive des forêts naturelles : cas de la forêt classée du Nazinon dans le Centre - Ouest du Burkina-Faso, Mémoire de fin du cycle à l'Institut du développement rural à l'Université Polytechnique de Bobo-Dioulasso. 91 p.

Rabiou H, Diouf A, Bationo BA, Segla KN, Adjonou K, Kokuste AD, Radji R, Kokou K, Mahamane A, Saadou M (2015). Structure des peuplements naturels de *Pterocarpus erinaceus* Poir. dans le domaine soudanien, au Niger et au Burkina Faso. Bois et Forêts des Tropiques 3(325):71-83.

Rusterholz HP (2003). Biodiversité en milieu urbain : Protection de la nature en milieu urbain et rôle des espaces verts affectés à un entretien extensif. Institut pour la protection de la nature, du paysage et de l'environnement, Paris 24 p.

Sandjong SRC, Ntoupka M, Vroumsia T, Ibrahima A (2018). Caractérisation structurale de la végétation ligneuse du Parc National de Mozogo-Gokoro (Cameroun). Flora et Vegetatio Sudano-Sambesica 21:7-24.

Sani R (2009). Caractérisation biophysique des ressources dans un site reverdi et un site dégradé dans le département de Mirrah. Mémoire de fin d'études d'ingénieur des eaux et forêt, Université de Abdou Moumouni, Niger 2. 53 p.

Saotoing P, Vroumsia T, Tchobsala, Tchuenguem FFN, Njan NAM, Messi J (2011). Medicinal plants used in traditional treatment of malaria in Cameroon. Journal of Ecology and the Natural Environment 3(3):104-117.

Sarr MA (2008). Variabilité climatique en Afrique de l'Ouest. Dynamique des espaces végétaux à partir d'images satellites. Exemple du Bassin versant du Ferlo (Sénégal). Journée climatologique-Nantes pp. 57-76.

Sigaud P, Eyog-Matig O (2001). Situation des ressources génétiques forestières de la zone sahélienne et nord-soudanienne. Plan d'action sous-régional pour leur conservation et utilisation durable. Note thématique sur les ressources génétiques forestières. Document de travail FGR/2F. FAO. 111 p.

Suchel JB (1987). Rainfall patterns and regimes rainfall in Cameroon. Doc. Geographic tropical, N° 5, CEGET-CNRS, Talence 287 p.

Tchobsala, Amougou A, Mbolo M (2010). Impact of wood cuts on the structure and floristic diversity of vegetation in the peri-urban zone of Ngaoundere, Cameroun. Journal of Ecology and Nature Environment 2(11):235-258.

Tieguhong CJ, Betti JL (2008). Forest and Protected Areas in Cameroon: Progress has been significant but Challenges remain. International Tropical Timber Organisation (ITTO) Tropical Forest Update pp. 6-9.

Todou G, Doudou K, Vroumsia T (2017). Diversity and local transformation of indigenous edible fruits in Sahelian domain of Cameroon. Journal of Animal and Plant Sciences 26(2):5289-5300. Available at http://www.m.elewa.org/JAPS; ISSN 2071-7024

Todou G, Froumsia M, Souaré K, Nnanga JF (2016). Woody plants diversity and type of vegetation in non-cultivated plain of Moutourwa, Far North, Cameroon. Journal of Agriculture and Environment for International Development 110(2):217-227.

Véron J (2007). La moitié de la population mondiale vit en ville. Population and Sociétés 435:4.

Wafo TG (2008). Les aires protégées de l'Extrême-Nord Cameroun entre politiques de conservation et pratiques locales. Thèse de doctorat en Géographie–Amenagement- Environnement, Université d'Orléans. 332 p.

Wolff A (2005). La problématique de l'environnement urbain vue par une écologue. Le cas de l'Île de France. In Ville et environnement, Paris: Ellipses édition pp. 204-223.

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