

Annual Research & Review in Biology
7(5): 283-299, 2015, Article no.ARRB.2015.129
ISSN: 2347-565X



SCIENCEDOMAIN *international*
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Plant Species Characteristics and Woody Plant Community Types within the Historical Range of Savannah Elephant, *Loxodonta africana* Blumenbach 1797 in Northern Togo (West Africa)

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Authors' contributions

This work was carried out in collaboration between all authors. Author APA wrote the protocol, performed data analysis, interpreted the data and produced the initial draft. Authors KW, TY and KA designed the study. Authors AA, WA and MN anchored the field study and gathered the initial data. While authors YAW, SO and MC managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/ARRB/2015/19271

Editor(s):

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Reviewers:

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Complete Peer review History: <http://sciencedomain.org/review-history/10088>

Original Research Article

Received 1st June 2015
Accepted 22nd June 2015
Published 8th July 2015

ABSTRACT

Aims: Assessment of plant species diversity and habitat typology.

Study Design: Stratified random sampling design according to defined land categories of a land cover map.

Place and Duration of Study: Complex of protected areas Oti-Keran-Mandouri (Northern Togo) from March to December 2014.

Methodology: Floristic data, forest measurements (total height and diameter of woody species with diameter at breast height (DBH) greater than 10 cm) and 17 environmental variables were collected in plots of 50 m X 20 m; herbaceous species were recorded in subplot of 10 m X 10 m at the center of the big plot and juveniles (woody species with DBH<10 cm) were counted in three subplots of 5 m X 5 m installed diagonally. Floristic data were collected according to the phytosociological scale of Braun-Blanquet. After deletion of outliers, two different matrices were considered for canonical correspondence analysis (CCA) and .for hierarchical cluster analysis.

Results: A total of 320 plant species were recorded in 182 plots and grouped in 209 genera and 66 families. The most frequent species were *Piliostigma thonningii* (2.90%), *Pterocarpus erinaceus* (2.90%), *Combretum glutinosum* (2.34%), *Anogeissus leiocarpus* (2.09%), and *Terminalia laxiflora* (2.09%). The species' distribution was influenced by two major ecological gradients: habitat degradation and soil. The first four canonical axes of the CCA express 9.4% of the variance in species distribution and 50.4% of the variance in species-environment relation with a total inertia of 19.66%. Seven groups of woody plant communities were distinguished according to their species composition ($0.35 \leq H \leq 1.43$ and $0.37 \leq E \leq 0.83$).

Conclusion: Species composition and distribution are influenced by environmental variables especially anthropogenic activities. However, dominant species are relevant to large herbivores such as the African savannah elephant. Management system should be improved to maintain this important corridor.

Keywords: Biodiversity; habitat; conservation; Oti-Keran-Mandouri; Togo.

1. INTRODUCTION

Ecosystem and habitat assessment particularly in the face of the changing climate become important challenges in the fields of landscape ecology and conservation biology. Habitat lost and degradation is one of the most important threat to biodiversity conservation especially in developing countries. Habitat degradation appears to be related to the social and economic changes in rural areas across African continent in last decades [1] as well as to climate change [2,3].

The large wetlands of Oti River and its tributaries present important biotopes for migrating birds [4] and large mammals such as the African savannah elephant [5-7]. Therefore, large portions of this area have been put under protection for biodiversity conservation. Some of these protected areas are Oti-Keran National Park located 9°55'-10°20' North and 0°25'-1° East and Oti-Mandouri Wildlife Reserve located 10°18'-11° North and 0°30' - 0°47' East. They are part of the most important protected areas in Togo [8] and are listed as RAMSAR sites (Oti-Kéran in 1997 and Oti-Mandouri in 2007). They

have been recently considered as biosphere reserves in 2011. Oti-Keran National Park and Oti-Mandouri Wildlife reserve are currently considered as a complex of protected areas Oti-Keran-Mandouri (OKM) [9]. OKM is considered to be part of one of the most important corridors for elephant migration that lies across four countries: Burkina Faso, Benin, Niger and Togo [10]. At a wider range, OKM can be considered as a link between two large blocks of African elephant population including many protected areas. The first block, at the East, includes the protected areas of the tripartite WAP complex (Parks W, Arly and Pendjari) and the second block includes the protected areas of Po, Nazinga, and Sissili (PONASI) that are located in South-West Burkina Faso near the Northern boundary of Ghana. This area can be considered as one of the most important eco-geographical region for the West African elephant migration.

From 1970 to 1990, Oti-Keran-Mandouri (OKM) was considered as the largest and continuous habitat for savannah elephant in Togo [7]. Unfortunately, during social and political claims from 1990, natural resources within protected areas were the target of huge anthropogenic

pressure [1]. Therefore this historical range of elephant is converted into croplands and small patches of natural habitat. Recent studies in this area reported high fluctuations in rainfall [11] and an increasing pressure on protected areas [12,13]. However, OKM has been considered as a first priority corridor for elephant migration in West Africa [14]. On the other hand, this complex of protected areas has also been considered at the national level as a priority ecosystem to be managed to enhance biodiversity conservation in Togo [9].

Corridors provide the hope of reversing deleterious consequences of habitat fragmentation [15]. They are also of critical importance for maintaining the viability of isolated populations and conserving ecosystem functionality [16]. Since the African savannah elephant is considered as a keystone species of the savannah ecosystem [17], taking the elephant as a focal species in conservation planning will enable the designing of a management plan that will benefit other species as well. Therefore a better understanding of habitats characteristics and their species composition will enable a better planning.

The aims of nature conservation and planning can be partly met by scientific knowledge about hydrological processes, succession, isolation and population structure, and partly by field research directed at particular problems [18]. Biotic communities and environmental data are among the most important data needed in such planning.

Portions of OKM have been surveyed in previous studies [13,19]. However, ecological data of this habitat taken as a whole are still lacking. Thus, this study aims at improving biodiversity conservation within OKM by assessing plant species diversity and habitat typology through biodiversity indexes calculation and multivariate analysis.

2. MATERIALS AND METHODS

2.1 Study Area

Oti-Keran-Mandouri (OKM) is a complex of protected areas covering about 179 000 ha [9] and located in the northern flat plains of Oti river basin in Northern Togo (Fig. 1). It straddled three districts namely Kpendjal, Oti and Kéran. This

area belongs to the eco-floristic zone I of Togo [20]. It is characterized by a tropical climate with a rainy season from June to October and a dry season between November and May. The annual average rainfall is between 800 and 1000 mm and the temperature vary from 17 to 39°C during the dry season and from 22 to 34°C during the rainy season. The predominant vegetation is Sudanian savannah, with some dry forest patches and gallery forests along rivers.

Agriculture is the principal activity in the surrounding area and occupies around 70 to 80% of the active population in these districts [21]. The most cultivated crops are sorghum (*Sorghum bicolor* (L.) Moench.), maize (*Zea mays* L.), rice (*Oryza sativa* L.), yams (*Dioscorea* sp), and cassava (*Manihot esculenta* Crantz.). There is currently increasing interest in cash crop production that is cotton (*Gossypium hirsutum* L.). Consequently, there is a great pressure to access fertile lands. This leads to over-exploitation and degradation of soils and natural habitats even within protected areas. Other rural activities in this area include collection of timber and fuelwood [22,23] and non-timber products (fruits, medicinal plants, straw), charcoal production [12,24], hunting and fishing [25]. International livestock transhumance constitutes also an important threat to biodiversity in this area.

2.2 Data Collection

Vegetation survey was based on a land cover map derived from a supervised classification of Landsat 8 image of October 2013. Land categories were defined and ground truth data were collected during field prospection in November 2013. Therefore, a stratified random sampling was designed according to defined land categories. Fieldworks were done from March to December 2014. Floristic data, dendrometric measurements (total height and diameter of woody species with diameter at breast height (DBH) greater than 10 cm) and 17 environmental variables were collected in plots of 50 m X 20 m; herbaceous species were recorded in subplot of 10 m X 10 m at the center of the big plot [26] and juveniles (woody species with DBH<10 cm) were counted in three subplots of 5 m X 5 m installed diagonally. Floristic data were collected according to the phytosociological scale of Braun-Blanquet [27]. Dendrometric

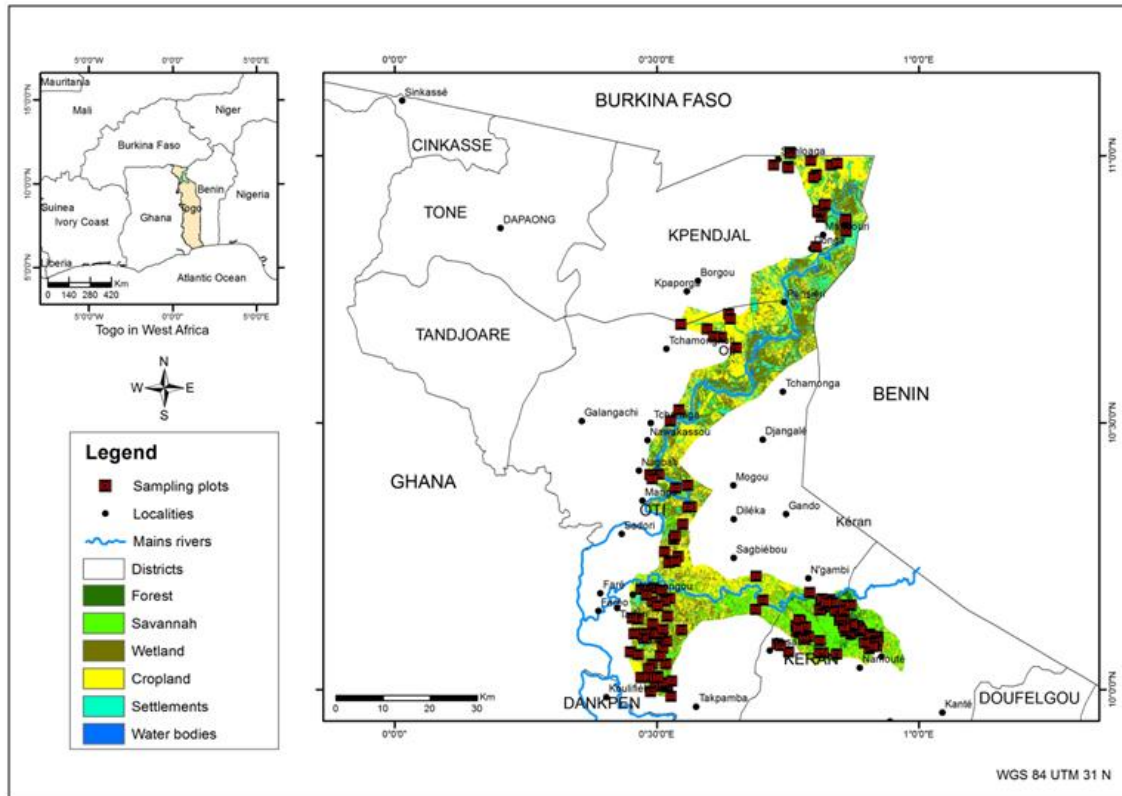


Fig. 1. Study area: distribution of sampling plots

measurements concerned total height and diameter of woody species with diameter at breast height equal or greater than 10 cm (DBH ≥ 10 cm) [13,26]. Three 5 m X 5 m subplots were installed diagonally to assess plant regrowth (two at the angles and one at the center of the 50 m X 20 m plot). Environmental variables described canopy cover, topographic position, slope, soil type, water availability and anthropogenic footprints such as cropping, wood cutting, fire, charcoal production etc. The geographic coordinates of each sample and any relevant environmental or ecological feature were recorded using a handheld Global Positioning System receiver (GPS GARMIN GPS Map 62stc).

2.3 Data Analysis

All plant species encountered in the overall 182 sampling plots of this study were named and categorised into their respective genera and families according to those set by [28,29]. EstimateS (version 9) was used to estimate the total species richness by constructing sample-based species accumulation curves using Chao

2 estimator with 100 randomization as recommended by the user's guide [30]. Plant species were furthermore classified according to their phytogeographical types [31] and their life forms [32]. Major ecological gradients in species distribution and species-environment relationship were assessed by a direct gradient analysis using Canoco software (Canonical Correspondence Analysis (CCA)) [33]. After the first run, outlier samples were deleted and this analysis was finally performed on a matrix of 161 samples X 312 species with 17 environmental variables. The analysis was performed using a log transformed plant species abundance data recorded according to the scale of Braun-Blanquet with inter-species scaling, Hill's distance and downweighting of rare species.

The habitats were distinguished based on woody species. Therefore, a matrix of 123 plots x 94 woody species was submitted to a hierarchical clustering using presence-absence data following Ward's method and Euclidian distance measure with the Community Analysis Package (CAP 2.15) software [34].

Alpha diversity indices were computed for each woody plant community identified. These are species richness (S), Shannon-Wiener diversity index (H) and Pielou evenness index (E). The Pielou's evenness measures the similarity in the abundance of the different woody species sampled. Its value varies between 0 and 1. The value tends to 0 when one or few species have higher abundance than others and 1 in the situation where all species have equal abundance. High values of H would be representative of more diverse communities [35].

The formulas of these indexes are:

$$H = -\sum_{i=1}^s p_i \log_2 p_i \text{ with } p_i = \frac{r_i}{r} \quad (1)$$

Where r_i is the number of individuals belonging to the species i , r the total number of all individuals in the considered plot and s is the species richness in the plot.

$$E = \frac{H}{H_{max}} \text{ with } H_{max} = \log_2 s \quad (2)$$

Where H represents the Shannon-Wiener's diversity index, H max is the maximum value of the diversity index and S is the number of species recorded in the considered plant community.

Furthermore, a thorough characterization of each plant community was done by computing the Indicator value index (IndVal) and the species Importance Value Index (IVI).

The indicator analysis was computed using R package "Indicspecies" [36]. This package provide a set of functions to assess the strength and statistical significance of the relationship between the species occurrence or abundance and site groups, which may represent habitat types, community types, disturbance states, etc. The indicator value index is the product of two components, referred to as 'A' and 'B' [37]. Component 'A' is the probability that the surveyed site belongs to the target site group given the fact that the species has been found. This conditional probability is called the specificity or the positive predictive value of the species as indicator of the site group. Component 'B' is the probability of finding the species in sites belonging to the site group. This second conditional probability is called the fidelity or sensitivity of the species as indicator of the target site group [38].

The Importance Value Index (IVI) [39] characterizes the place occupied by each species within vegetation, compared with the other species. Its formula is:

$$IVI = \text{FREQesp} + \text{DENSesp} + \text{DOMesp} \quad (3)$$

The relative frequency of a species (FREQesp) is the ratio of its specific frequency (a number of plots in which it is present) over the sum of the specific frequencies of all species. The relative density of a species (DENSesp) is the ratio of its absolute density over the sum of the absolute densities of all species. Relative dominance of a species (DOMesp) is the quotient of its basal area with the sum of basal areas of all species.

The basal area of the stand (G) is the sum of the cross-sectional area at 1.3 m above the ground level of all trees on a plot, expressed in m² per ha:

$$G = \frac{\pi}{4} \sum_{i=1}^n 0.0001 d_i^2 \quad (4)$$

Where n is the number of trees found on the plot, and d_i the diameter (in cm) of the i -th tree. Species regeneration rate was estimated for each woody plant species in each plant community.

3. RESULTS

3.1 Floristic Analysis

The floristic inventory in 182 plots (18.2 ha) revealed 320 plant species grouped in 209 genera and 66 family. The most frequent plant species are *Ptilostigma thonningii* (Schumach.) Milne-Redhead (2.90%), *Pterocarpus erinaceus* Poir. (2.90%), *Combretum glutinosum* Perr. ex DC. (2.34%), *Anogeisus leiocarpus* (DC.) Guill. & Perr. (2.09%), and *Terminalia laxiflora* Engl. & Diels (2.09%) (Fig. 2). The most important families in term of percentage of species richness are Poaceae (9.69%), Fabaceae (9.06%), Rubiaceae (6.25%), Euphorbiaceae (5.31%) and Combretaceae (5%). The most diversified genera in term of species richness are *Combretum* (2.81%) and *Acacia* (2.5%).

The estimation of the species richness based on Chao 2 estimator gives a total of 433±30 species for the study area (Fig. 3). There is a high variation between the observed and the estimated species richness.

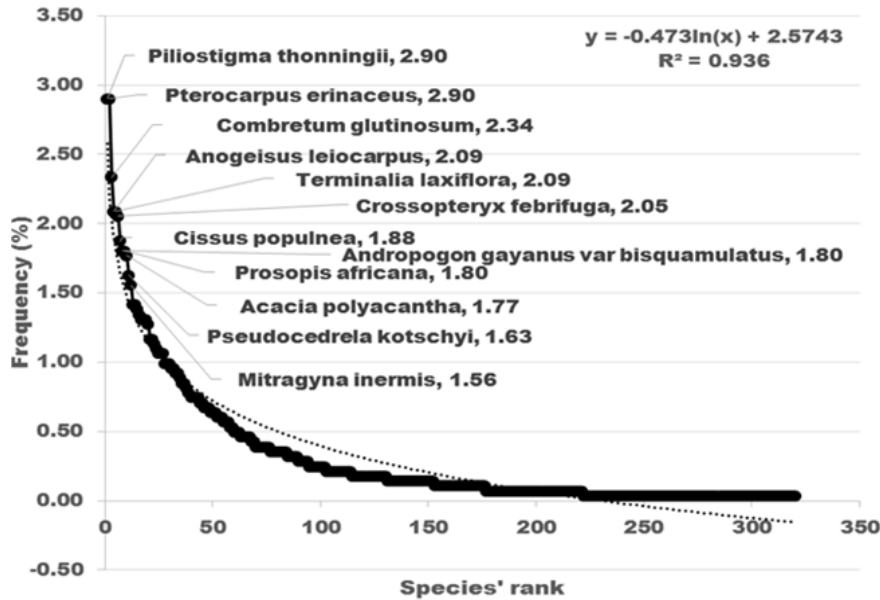


Fig. 2. Species-rank curve of all species recorded in 182 plots within OKM

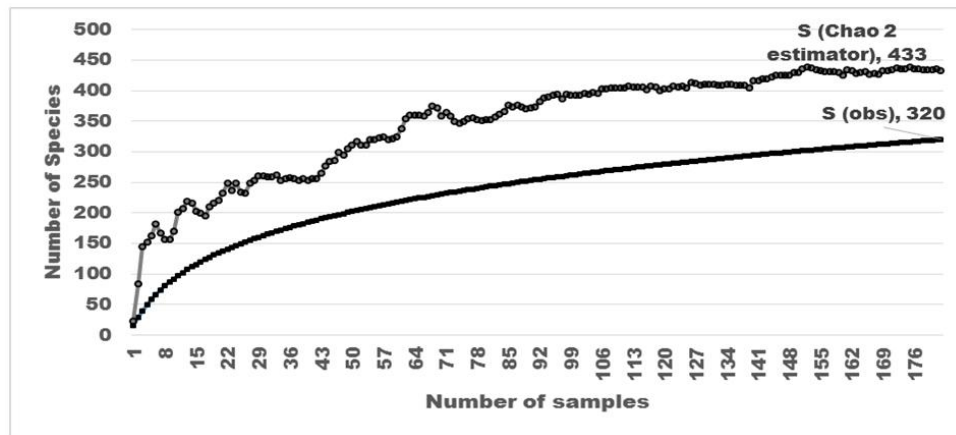


Fig. 3. Species accumulation curve

The most important plant species in the recorded data are phanerophytes (50.52%) followed by therophytes (26.30%) and geophytes (8.65%). The least represented plants are hydrophytes (0.34%) and epiphytes (0.69%) (Fig. 4).

The phytogeographical spectrum is dominated by species from the Sudano-Zambesian (SZ) (21.94%) and the Sudanian endemism centre (S) (18.35%) types (Fig. 5). There is a good representation of a large distribution scale species: Pan-tropical (12.23%), Paleotropical (10.07), and Afro-American (1.44%). Species

with a continental scale distribution are also well represented. These are, Afro-Tropical (14.39%), African multi-regional (11.15%), Sudano-guinean (4.32%), Guineo-Congolian (3.60%), Afro-Malgach (1.08%), and Guinean (1.08%).

3.2 Species-environment Relationship

There is a significant relationship between canonical axes, species, and ecological factors. The first four canonical axes of the CCA express 9.4% of the variance in species distribution and 50.4% of the variance in species-environment

relation. The total inertia is 19.66%. The most important variance in species data (3.5%) and in species-environment relation (37.7%) are only expressed by the first axis (Table 1).

axes (trace) are highly significant ($P = 0.002$ with 499 permutations). However, the F value is much higher for the test on the first axis ($F=5.263$) than for the test on the trace ($F=1.927$) meaning that the first axis explains more than the second, third, and fourth axes combined.

Both of the performed significance test (Monte Carlo permutation) on the first axis and on all

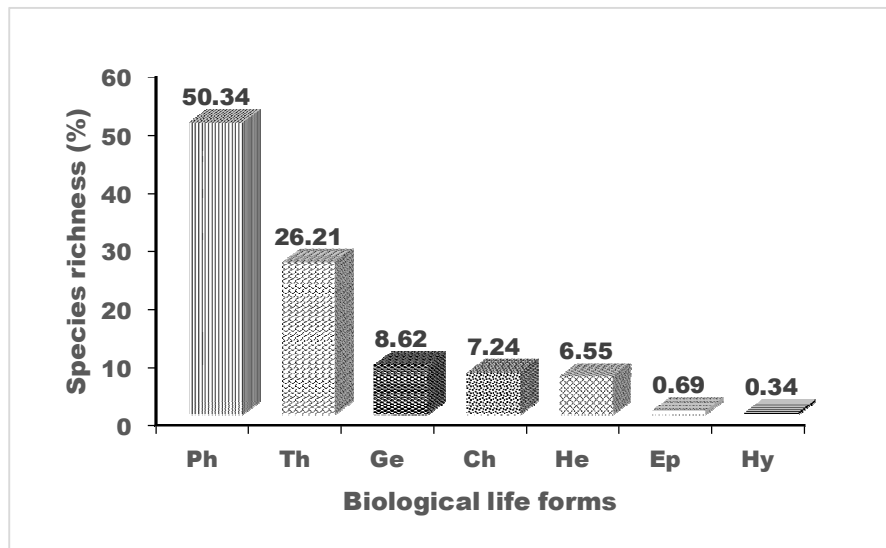


Fig. 4. Life forms spectrum of recorded plant species in 182 plots within OKM (Ph: Phanerophytes, Th: Therophytes, Ge: Geophytes, Ch: Chamaephytes, He: Hemicryptophytes, Ep: Epiphytes and Hy: Hydrophytes)

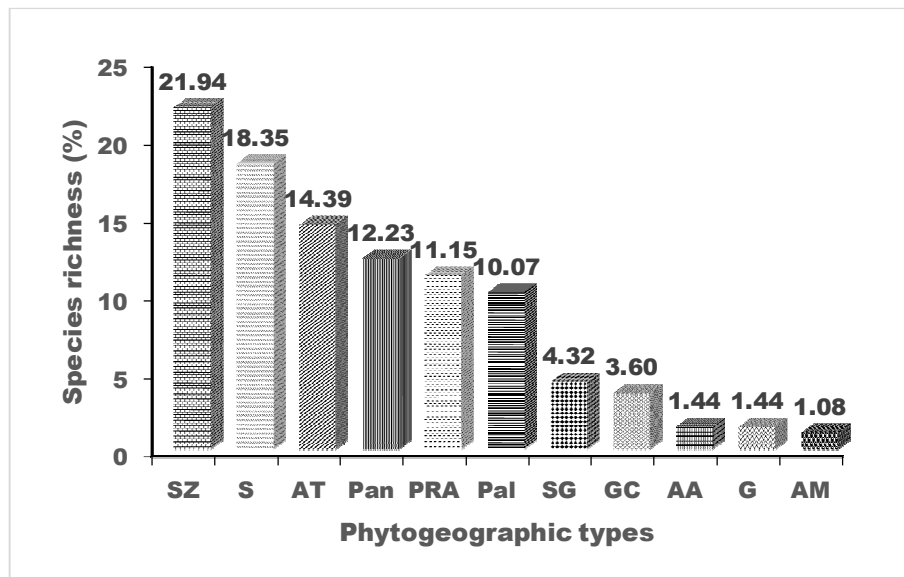


Fig. 5. Phylogeographical types of plant species (SZ: Sudano-Zambesian, S: Sudanian, AT: Afro-tropical, Pan: Pan-tropical, PRA: Pluri-regional in Africa, Pal: Paleo-tropical, SG: Sudano-Guinean, GC: Guineo-Congolian, AA: Afro-American, G: Guinean and AM: Afro-Malgash)

Table 1. Statistical synthesis of the CCA (161sample X 312 species X 17 environmental variables)

Axes	1	2	3	4	Total inertia
Eigenvalues :	0.698	0.439	0.395	0.313	19.656
Species-environment correlations :	0.903	0.777	0.773	0.751	
Cumulative percentage variance					
of species data :	3.5	5.8	7.8	9.4	
of species-environment relation:	19	31	41.8	50.4	
Sum of all eigenvalues					19.656
Sum of all canonical eigenvalues					3.663

Table 2. Weighted correlation between environmental variables and ordination axes of the CCA

Label	Significance	Axe 1 (species)	Axe 2 (species)	Canonical axe 1 (environmental variables)	Canonical axe 2 (environmental variables)
VegeOpen	Vegetation openness	-0.0566	0.1645	-0.0627	0.2119
TreeC20m	Tree cover of individual with at least h=20 m	0.6557	-0.311	0.726	-0.4004
TreeC720	Tree cover of individual with at least h between 7-20 m	0.419	0.0459	0.464	0.0591
TreeC.7m	Tree cover of individual with at least h=7 m	-0.1509	-0.2809	-0.167	-0.3617
HerbC	Herbaceous cover	-0.6234	-0.2147	-0.6902	-0.2765
HTree	Tree height	0.3403	-0.106	0.3768	-0.1365
Hshrub	Shrub tree height	-0.1433	-0.2842	-0.1587	-0.366
Hherb	Herbaceous plant height	-0.4194	-0.2943	-0.4643	-0.379
Topograp	Topography	-0.2957	0.3063	-0.3274	0.3944
EdaphSub	Edaphic substratum	-0.2142	-0.2021	-0.2371	-0.2602
Submers	Submersion (presence of water)	-0.2983	-0.2406	-0.3303	-0.3098
Fire	Fire occurrence	-0.3154	0.2502	-0.3493	0.3222
Grazing	Pastureland of grazing activity	-0.3753	0.2154	-0.4156	0.2773
Cropping	Existence of cropland	-0.0368	0.3695	-0.0407	0.4758
Wood-cut	Wood cutting activity	-0.1007	0.4424	-0.1115	0.5697
Swab	Bark or other plant organ harvesting	0.0226	0.4193	0.025	0.5399
Charcoal	Charcoal production	-0.0191	0.1433	-0.0211	0.1846

The analysis of Table 2 above shows that the first axis is positively correlated with high tree cover and negatively with shrubs and small trees. It is also correlated with the edaphic substratum.

Here the soil varies from clayed soil on the right to sandy soil on the left. The latter is favourable to the bottom. The canopy cover increases as

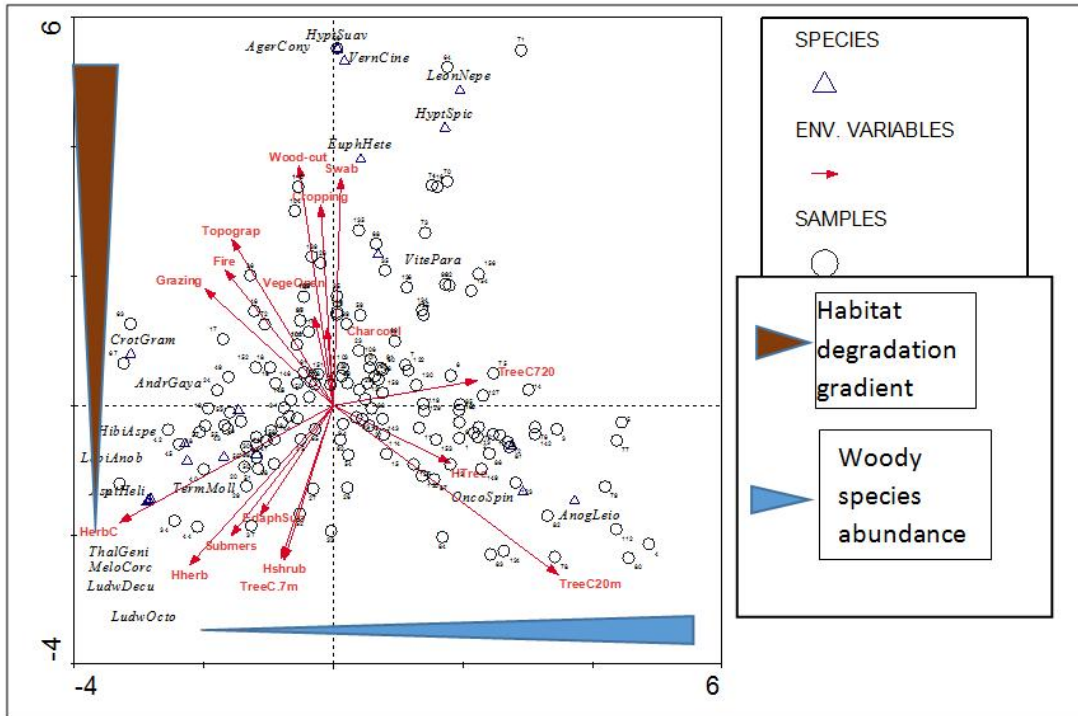


Fig. 6. CCA diagram of 161 samples X 312 species X 17 environmental variables

well as woody species abundance from the left to the right of the diagram. This indicates a gradient of soil enabling the establishment of perennial plants. This second gradient is linked to the first axis (horizontal axis).

The analysis of Table 2 shows that the first axis is positively correlated with high tree cover and negatively with shrubs and small trees. It is also correlated with the edaphic substratum. Here the soil varies from clayed soil on the right to sandy soil on the left. The latter is favourable to the establishment of woody vegetation type, usually a dry forest characterized by the abundance of *Anogeisus leiocarpus* (DC.) Guill. & Perr. The second axis is positively correlated to vegetation openness, topography and all the anthropogenic activities but it is negatively correlated with herbaceous cover and water availability (submersion).

3.3 Habitat Typology

The cluster analysis distinguished seven groups of woody plant communities (Fig. 7). The first group (G1) is composed of samples from gallery forests distributed along the major rivers, the second one (G2) is composed of samples from dry forests and woodland savannahs mostly on dry and sandy soil. The third group (G3) is

composed of samples from shrub savannahs mostly on wet and clayed soil, the fourth (G4) is composed of samples from tree savannahs that is widely distributed, the fifth group (G5) is another group of gallery forests along minor rivers or tributaries. The sixth group (G6) is a mosaic group composed of samples from thorny woodland savannahs, samples from gallery forests and some shea tree parklands that are mostly located in periodically flooded areas and well represented in the North-Eastern part of OKM. The last group (G7) is composed of samples from *Borassus aethiopicum* Mart. stands that are almost all the time in monospecific bands and usually transformed into parklands by surrounding residents.

Table 3. Alpha diversity in the different woody plant communities discriminated within OKM

	S	H (bits)	E
G1	49	1.06	0.63
G2	49	1.27	0.75
G3	33	1.18	0.78
G4	54	1.43	0.83
G5	33	1.25	0.82
G6	29	1.14	0.78
G7	9	0.35	0.37

The species diversity in each of these groups is reflected by the value of the species richness (S), Shannon-Wiener diversity index (H) and Pielou evenness index (E) (Table 3 above). The species richness range from 9 woody plant species in *B. eathiopum* parklands (G7) to 54 woody plant species in tree savannahs (G4). Both Shannon-Wiener diversity index and Pielou's evenness showed low species diversity within *B. eathiopum* parkland (G7) (H=0.35 and E=0.37) whereas the species diversity and distribution were more or less even in the other

woody plant communities ($1.06 \leq H \leq 1.43$ and $0.63 \leq E \leq 0.83$). The gallery forest along major rivers (mostly Oti River) was more diverse (S=49; H=1.06 and E=0.63) than the second one (S=33; H=1.25 and E=0.82) which is located along tributaries (mostly Koumongou River). However, species are more evenly distributed in the latter than in the former. Since anthropogenic activities are the main factor influencing species composition in these habitats, the gallery forests along Oti River are more pressured than those along Koumongou River.

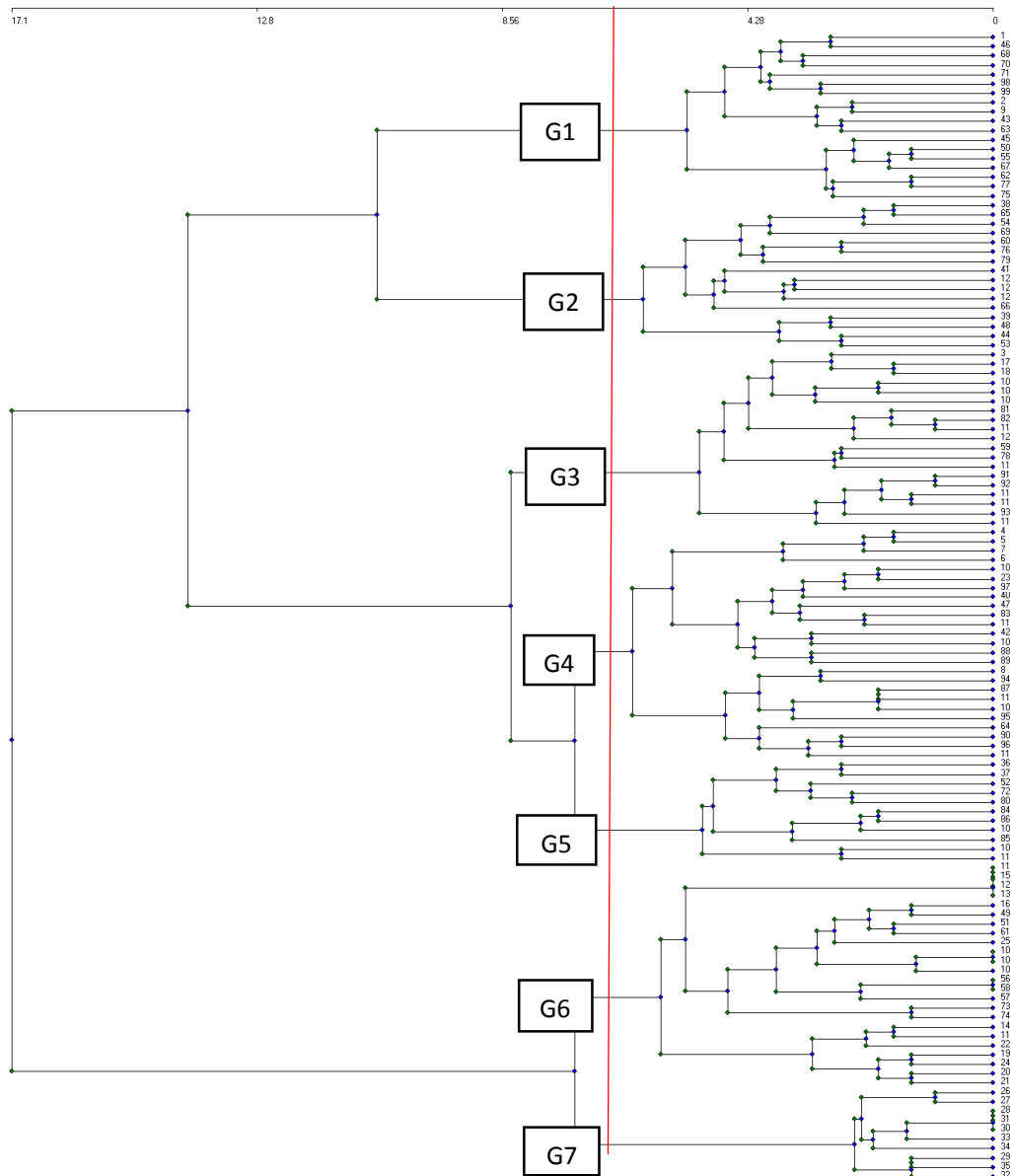


Fig. 7. Dendrogram of the Hierarchical Cluster Analysis (HCA) performed on woody plant species from 123 samples within OKM

Table 4. Most important woody plant species in each group and their estimated regrowth rate

Group	Species	Rde	Rdo	CVI	RF	IVI	Reg/ha
G1	<i>Anogeisus leiocarpus</i> (DC.) Guill. & Perr.	31.88	1.83	33.72	12.14	45.86	4156
	<i>Diospyros mespiliformis</i> Hochst. ex A. DC.	12.91	1.66	14.57	10.71	25.28	3100
	<i>Tamarindus indica</i> L.	14.93	1.14	16.07	7.14	23.21	544
	<i>Mitragyna inermis</i> (Willd.) O. Kuntze.	11.98	1.08	13.05	8.57	21.62	200
	<i>Pterocarpus santalinoides</i> DC.	0.31	13.76	14.07	0.71	14.79	0
G2	<i>Bombax costatum</i> Pellegr. & Vuill.	0.74	43.58	44.32	2.16	46.48	31
	<i>Anogeisus leiocarpus</i> (DC.) Guill. & Perr.	20.19	2.24	22.43	7.03	29.45	1005
	<i>Crossopteryx febrifuga</i> (G. Don) Benth.	18.15	0.70	18.85	7.03	25.88	431
	<i>Pterocarpus erinaceus</i> Poir.	7.59	2.32	9.92	5.95	15.86	595
	<i>Vitellaria paradoxa</i> C. F. Gaertn.	8.15	1.53	9.68	4.86	14.54	1477
G3	<i>Acacia gourmaensis</i> A. Chev.	29.29	4.66	33.95	6.59	40.55	1032
	<i>Pseudocedrela kotschy</i> (Schweinf.) Harms	11.62	13.67	25.29	5.49	30.78	688
	<i>Combretum glutinosum</i> Perr. ex DC.	8.59	6.11	14.70	14.29	28.99	3039
	<i>Lannea acida</i> A. Rich.	5.56	7.62	13.17	7.69	20.87	84
	<i>Balanites aegyptiaca</i> (L.) Del.	7.07	6.28	13.36	3.30	16.65	196
G4	<i>Pterocarpus erinaceus</i> Poir.	7.05	3.22	10.27	9.66	19.93	47
	<i>Prosopis africana</i> (Guill. & Perr.) Taub.	7.81	4.37	12.18	4.35	16.53	63
	<i>Terminalia macroptera</i> Guill. & Perr.	11.05	2.15	13.20	2.90	16.09	973
	<i>Lannea microcarpa</i> Engl. & K. Krause	6.48	2.55	9.03	4.83	13.86	55
	<i>Pseudocedrela kotschy</i> (Schweinf.) Harms	6.48	2.02	8.49	5.31	13.81	361
G5	<i>Anogeisus leiocarpus</i> (DC.) Guill. & Perr.	23.28	4.43	27.71	4.76	32.47	1947
	<i>Lannea barteri</i> (Oliv.) Engl.	5.29	8.73	14.02	9.52	23.54	293
	<i>Parkia biglobosa</i> (Jacq.) R. Br. ex G Don f.	4.76	8.85	13.61	7.14	20.75	0
	<i>Prosopis africana</i> (Guill. & Perr.) Taub.	4.23	6.33	10.57	8.33	18.90	133
	<i>Pterocarpus erinaceus</i> Poir.	8.47	3.82	12.28	5.95	18.24	27
G6	<i>Adansonia digitata</i> L.	0.61	48.48	49.10	3.28	52.38	12
	<i>Mitragyna inermis</i> (Willd.) O. Kuntze.	12.68	1.00	13.68	11.48	25.16	909
	<i>Anogeisus leiocarpus</i> (DC.) Guill. & Perr.	13.50	5.33	18.83	4.92	23.75	0
	<i>Acacia polyacantha</i> Willd. ssp. <i>campylacantha</i> (Hochst. ex A. Rich.) Brenan	11.04	0.82	11.87	11.48	23.34	12
	<i>Pterocarpus santalinoides</i> DC.	13.91	1.44	15.34	3.28	18.62	0
G7	<i>Borassus aethiopum</i> Mart.	82.35	8.54	90.89	47.62	138.51	381
	<i>Adansonia digitata</i> L.	1.18	61.42	62.60	4.76	67.36	0
	<i>Parkia biglobosa</i> (Jacq.) R. Br. ex G Don f.	3.53	8.62	12.15	9.52	21.67	0
	<i>Vitex doniana</i> Sweet	4.71	4.51	9.21	9.52	18.74	19
	<i>Lannea microcarpa</i> Engl. & K. Krause	1.18	11.92	13.09	4.76	17.86	0

Rde=Relative density; Rdo=Relative dominance; CVI=Cover Value Index; RF=Relative Frequency; Reg/ha=Regrowth rate per hectare

According to the indicator species analysis (multilevel pattern analysis using R) 22 species are significantly associated to just one group on a total of 94 species. Thus the discriminated habitats share many species. Among these 22 species, 4 species are associated to G1, 8 species to G2, 1 species to G3, 2 species to G4,

5 species to G5, and 1 species to both G6 and G7. The list of species associated to each group is presented below. The most important species in each of these groups are presented in Table 4 above with their relative values of density (Rde), dominance (Rdo) and frequency (RF) and their regrowth rate.

Multilevel pattern analysis

 Association function: IndVal.g
 Significance level (alpha): 0.05
 Total number of species: 94
 Selected number of species: 40
 Number of species associated to 1 group: 22
 Number of species associated to 2 groups: 9
 Number of species associated to 3 groups: 8
 Number of species associated to 4 groups: 1
 Number of species associated to 5 groups: 0
 Number of species associated to 6 groups: 0

List of species associated to each combination:

Group 1 #sps. 4	Group 4 #sps. 2
<i>Diospyros mespiliformis</i> 0.789 0.001 ***	<i>Grewia venusta</i> 0.600 0.001 ***
<i>Tamarindus indica</i> 0.721 0.001 ***	<i>Lannea microcarpa</i> 0.548 0.002 **
<i>Khaya senegalensis</i> 0.394 0.027 *	Group 5 #sps. 5
<i>Feretia apodentera</i> 0.333 0.043 *	<i>Oncoba spinosa</i> 0.568 0.002 **
Group 2 #sps. 8	<i>Acacia sieberiana</i> 0.554 0.002 **
<i>Crossopteryx febrifuga</i> 0.748 0.001 ***	<i>Parkia biglobosa</i> 0.540 0.003 **
<i>Combretum collinum</i> 0.589 0.001 ***	<i>Ficus gnaphalocarpa</i> 0.471 0.004 **
<i>Hymenocardia acida</i> 0.569 0.003 **	<i>Securidacca longepedunculata</i> 0.386 0.030 *
<i>Vitellaria paradoxa</i> 0.548 0.002 **	Group 6 #sps. 1
<i>Bridelia ferruginea</i> 0.473 0.007 **	<i>Acacia amythetophyla</i> 0.408 0.02 *
<i>Tectona grandis</i> 0.433 0.013 *	Group 7 #sps. 1
<i>Gardenia aqualla</i> 0.383 0.018 *	<i>Borassus aethiopum</i> 1 0.001 ***
<i>Grewia carpinifolia</i> 0.368 0.046 *	
Group 3 #sps. 1	
<i>Terminalia avicenioides</i> 0.397 0.029 *	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

While the indicator species analysis shows the specific relationship between species and site groups, the importance value index (IVI) shows well the physiognomy of each group. The abundance of shared species is revealed and indicates that at a certain level the habitats within Oti-Keran-Mandouri are more or less fuzzy. Some species such as *Anogeisus leiocarpus* (DC.) Guill. & Perr. and *Pterocarpus erinaceus* Poir. are well distributed in this area. The former is well distributed with high regrowth rate in gallery forests while the latter is present in gallery forests as well as in dry forests.

4. DISCUSSION

4.1 Floristic Diversity

The number of species (320) found in this study is higher than what has been recorded in the same ecological zone I by [19] who reported 274 plant species for three protected areas including Oti-Keran. However, both studies are

complementary since the diversity at genera and family taxonomic levels are quite different. This study recorded 66 families and 209 genera whereas [19] reported 63 families and 247 genera. This variation can be linked to the sampling design. [19] based his study on line transect and plot size of 30 m X 30 m and 50 m X 10 m whereas the present study was based on a stratified random sampling and the standardized plot size defined by BIOTA project for large scale environmental monitoring in tropical vegetation especially for Africa [40]. This same sampling design has been successfully used by [26] in Pendjari reserve of biosphere (Benin) where 183 species were recorded from 61 sample plots. The most important families are similar to those reported by other studies within the Sudanian ecological zone. Poaceae, Fabaceae and Rubiaceae were the most reported by [41] for the vegetation of Atakora mountain at the Eastern part of our study area whereas Fabaceae, Poaceae and Combretaceae were the most reported by [19]. The importance

of Fabaceae reflects the existence of a transition to the Guinean forest condition, while the importance of Combretaceae family is typical to Soudanian Endemism Center [42]. The high diversity in Poaceae reflects one of the fundamental characteristic of tropical savanna ecosystem characterized by a continuous layer of grasses [43]. The relative abundance of Rubiaceae can be explained by the relative density of hydrography in the study area allowing the establishment of species well adapted to Guinean forest in riparian forest along rivers. The same remark was done by previous studies [13, 44] in the same ecological zone.

The periods of fieldworks were set to take into account grasses. However, due to some species phenology and some fire events, most of the grass could not be identified reducing the total number of species recorded. Nevertheless, the sampling effort, the sampling design and the collaboration among scientists should be improved for a better estimation of species richness within the study area.

The analysis of the life forms spectrum gives an idea on the phytocenosis dynamic [41] and provides information on the response of plants to local environmental conditions [45]. The predominance of phanerophytes reflects the general physiognomy of the vegetation in the study area that is structured by woody plant species. It indicates also the good condition of the soil that enables the establishment of perennial plant species. However, the importance of therophytes reveals a floristic change due to anthropogenic activities. Indeed, the conversion of savannahs into cropland decreases the proportion of perennial while promoting the installation of ruderal species [41]. On the other hand, the presence of therophytes can be linked to the large areas of wetlands within Oti-Keran-Mandouri since [45] explained their abundance in Wadi M'Zab (North-East of Algeria) by the strong presence of water favourable to the development of annual plant species. The relative dryness of the study area is shown by the presence of geophytes and chamaephytes. These species are well adapted to semi-arid ecosystems, drought and fire events [46, 47] whereas the presence of hemipterophytes indicates the presence of open vegetation types [41].

The abundance of Sudano-Zambesian (SZ) and Sudanian endemism centre (S) species is characteristic of savannah ecosystems and

indicate the originality of the vegetation since the study area is located in the Sudanian endemism centre according to [31]. However, the presence of species with large scale distribution that are Pan-tropical (12.23%), Paletropical (10.07), and Afro-American (1.44%) indicates the anthropogenic action in transforming the ecosystem. This has been also reported by [41]. Within these species, Guinean and Guineo-Congolese are refugee species from Guinean and Congolese forests that are well distributed along rivers in riparian forest as reported by [48].

The two major ecological gradients in species distribution revealed in this study are almost the same described by [41] in the Atakora mountain area where anthropogenic activities, especially agriculture, were reported as the main factors leading to change in the composition and the structure of vegetation. Another study focusing on woody vegetation in three protected areas including the southern part of our study area points out the effect of human selective practices on species composition (traditional agroforestry system) [49]. The relation between community and environmental variables could be used to assess climatic impact on a given habitat using the indirect modelling approach [50].

4.2 Habitat Types

The community types identified are very similar to the different habitat types or woody plant communities described in several studies in the Sudanian zone in terms of their floristic composition and the vegetation type [13,41,49]. However, there is variation in term of the number of groups described. This variation is mainly due to the difference in methodological framework. Some studies were based on unconstrained ordination (indirect gradient analysis, ex. DCA) or constrained ordination (direct gradient analysis, ex. CCA) and some other on cluster analysis (agglomerative and Ward's method or TWINSpan). All these methods are good for community data analysis but they are not based on the same statistical computation [18,33]. There is a need to standardize the methodological framework in landscape ecological research within this area and then enable the development of habitat mapping and monitoring program at local, regional and national levels such as the Natura 2000 habitats [51] or a comprehensive framework of ecological land units [52].

The values of alpha diversity described in this study are similar to what previous studies in this area have found [13,49]. *Anogeisus leiocarpus* (DC.) Guill. & Perr. and *Pterocarpus erinaceus* Poir. are reported as typical of dry forest in the Sudanian and Sudano-Guinean zones [22,49, 53,54]. Usually, the abundance of *Mitragyna inermis* (Willd.) O. Kuntze; *Pseudocedrela kotschyi* (Schweinf.) Harms; and *Terminalia sp.* indicates that the area is periodically flooded. Their importance in 4 out of 7 site groups confirms the large distribution of wetlands within Oti-Keran-Mandouri. This is consistent with the classification of this area as Ramsar site and as Important Bird Area [4]. All the important species and almost all the indicator species have been reported as species browsed by elephant (*Loxodonta africana*, Blumenbach, 1797) in the hunting zone of Djona (North Benin) [55] and in Nazinga Game Ranch (South Burkina Faso) [56]. *B. aethiopum*, *L. acida*, *M. inermis*, *T. macroptera*, and *V. paradoxa* were reported as browsed by elephant in the Red Volta valley [57]. Moreover, *A. gourmaensis*, *V. paradoxa*, *A. digitata*, *B. aegyptiaca*, and *A. leiocarpus* have been reported in different groups of species occurring in habitat with high elephant concentration in Pendjari reserve of biosphere (North Benin) [26]. Therefore, habitats in Oti-Keran-Mandouri are well suitable for elephant because of food and water availability. This explains the seasonal occurrence of elephant within this area reported by several studies despite increasing anthropogenic pressure [7,8]. The influence of anthropogenic activities in plant species composition is well illustrated in G7. All the species listed in this group are multipurpose trees that are useful to farmers for food, medicine or fiber [58,59]. These species are intentionally left on the field while other species are cut down or burnt to produce charcoal. It creates a cultural landscape well distributed in the Sudanian zone of West Africa and described by several studies in Togo, Benin and Burkina Faso [23,60-64]. Since these species are also browsed by elephant, this sharpens human-elephant-conflict (HEC) around protected areas. Another example of human influence on species composition is the presence of *Tectona grandis L.* among indicator species in Group 2. This species has been introduced as plantation tree but it is currently invading natural habitats of the reserve.

5. CONCLUSION

A total of 320 plant species belonging to 66 families and 209 genera was recorded within Oti-

Keran-Mandouri. A total of 7 woody plant communities derived from 94 woody plant species was discriminated. The defined habitat types and their indicators or most important plant species are typical to the vegetation of the Sudanian zone in Africa and very similar to habitats currently used by the remaining population of elephants in West Africa. This explains the seasonal occurrence of these large mammals within OKM. However, habitats seem fuzzy due to anthropogenic activities leading to change in species composition. The management system of this area should be improved to enhance biodiversity conservation. A good management of this area could enable a repopulation of large mammals such as elephant and this would be beneficial for the restoration of the ecosystem since this species is known to be a very good seed dispersal. Findings from this study may be used for better conservation planning. They provide also the mean to assess climate change impacts on these habitats by indirect modelling using their species composition.

ACKNOWLEDGEMENTS

This study was funded through the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) by the German Federal Ministry Department of Education and Research (BMBF). We gratefully acknowledge the Laboratory of Botany and Plant Ecology of the University of Lomé (Togo), the Department of Geography and Urban Planning of the University of Wisconsin, Oshkosh (USA) and the Ministry of environmental resources of Togo for their technical assistance and all the local communities for their hospitality. We are also grateful to all the anonymous reviewers who improved the quality of the first draft of this paper.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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