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DIVERSITY AND REGENERATION OF WOODY PLANTS OF LOGONE BIRNI FLOODPLAIN VEGETATION IN THE FAR NORTH REGION OF CAMEROON

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Abstract: This study aims to contribute to the conservation and sustainable management of the Logone-Birni floodplains in Cameroon. In total, 27 plots of 100 m x 100 m plots of were laid out in 3 land use types (protected area, grazing area and agricultural area). Within each plot, all woody individuals having ≥ 10 cm circumference at breast height (> 1.3 m) were identified, and all the stems with a circumference ≤ 10 cm were considered as seedlings. A total of 43 timber species belonging to 35 genera and 21 families were harvested. Shannon-Weaver diversity ranged from 1.77-2.39 and the Pielou equitability index from 0.84-0.88 with low values in agricultural areas and higher values in protected and grazing areas. The distribution of stems according to diameter and height showed that all stands exhibit classic exponential decay distribution ‘‘L’’ or ‘‘J’’ inverted, reflecting the predominance of individuals with small diameters. The regeneration rates of the stand vary from 0.81 to 51.56%, indicating a difficult regeneration due partly to anthropogenic activities. It also appears that given the low diversity and the difficult regeneration of the stand, it is important, even crucial, to manage this plain to ensure the conservation and sustainable management of the biological resources that it hosts.

Keywords: Anthropogenic activities, Logone-Birni Floodplain, vegetation structure, woody plants.

Introduction

According to Article 1.1 of the Ramsar Convention, “wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres”. They are vital to livestock rearing, and to the life cycles of many animal and plant species. Therefore, the biodiversity and function should be preserved (Onana *et al*., 2003). The wetlands of northern Cameroon have been extensively exploited for agriculture and fishing. However, they are highly dependent on water resources and therefore extremely sensitive to climate variations (Onana *et al*., 2003). Floodplains are a major component of the Sahel, ranging from ponds in lowlands to river or lake basins, hence their classification as wetlands. These ecosystems of various sizes obey a cyclical and seasonal rhythm that triggers and modulates life through their plant, animal, and even mineral deployment: Pasture hatching, bird migrations, changes in soil conditions, etc. These are focal points for the concentration of complex phenomena that can lead either to food polyculture or large-scale monoculture (rice, sugar cane), but generally in the direction of concentration and intensification of yields (UICN, 2000).

It is this interface between several ecosystems, abundantly endowed with water, that makes floodplains places of dynamic complexity and opportunity. This is one of the reasons why the Cameroonian government joined the Ramsar Convention in 2006 on the conservation and sustainable use of wetlands. However, despite political efforts, floodplains are still victims of poor management, not because of a lack of will or resources, but because of limited knowledge of how they function and the overexploitation of animal and plant resources, which compromises, in the medium term, the preservation of biodiversity and the sustainable development of these regions (Kassi, 2006).

The Waza-Logone floodplain has undergone significant land degradation over the past decade. This degradation is manifested by changes in the floristic composition and structure of the vegetation (Bakhoum, 2013). This can add to the precariousness of the living conditions of rural populations (Diallo *et al*., 2011) and the accentuation of the desertification process (Adou Yao, 2005). This degradation of the natural environment is attributable to a combination of climatic, pedological, and human factors (Reeves, 2006; Sandjong *et al*., 2013). Anthropogenic factors include, among others, the combined effects of wood cutting, bush fires and overgrazing (Ntoupka, 1999), the poverty of the population and its strong demographic growth (Madi *et al*., 2003), and the overexploitation of natural resources (Gervais, 2008; Todou *et al.,* 2017).

However, it should be noted that the variability of vegetation in flood-prone areas is dependent on flood intensity (Delclaux *et al*., 2011). Studies by Sighomnou *et al*. (2002) show that the decrease or absence of flooding in the Yaere plains led to a transformation of vegetation, destruction of aquatic and terrestrial fauna habitats, and degradation of cropland productivity and pasture quality. When floods are exceptional, they can create property damage, destruction of crops and reduce yields of some cereals and vegetables. Because of its importance and the threats to floodplains, a study on floristic and structural diversity and vegetation regeneration is essential for the preservation and sustainable management of the resources of these ecosystems. Investigation of the diversity and regeneration of woody plants in the Logone-Birni floodplains was conducted to address the following questions: (1) What is the potential stock of woody plant species? (2) What does the vegetation structure look like? (3) How does vegetation regenerate itself? From this perspective, the general objective of this study is to contribute to the conservation and sustainable management of the Logone-Birni floodplains. Specifically, it will determine composition and floristic diversity (1); structural diversity of the stand (2); and the regeneration capacity of the stand (3).

Materials and Methods

Location and Description of the Study Site

The Logone-Birni council was created by decree No.082/455 of 20 September 1982. It is located in the Far North Region of Cameroon, Logone et Chari Division, Logone-Birni sub-division. It covers an area of 3,809 km^2 and it is made up of 56 villages. It is located between latitudes 11°13’ and 12°03’ North and longitudes 14°45’ and 15°10’ East (Figure 1). The Logone Birni council has a population of 75,833 in 2022 (adapted from the Bureau Central des Recensements et des Etudes de Population) with an annual growth rate of 2.6%. The Logone floodplain and its impact zone have been inhabited for centuries by a multitude of ethnic and cultural communities who eke out a living by fishing, livestock, handicrafts, tourism, and flood-recession crops. They are essentially composed of the Kotoko, who are traditionally fishermen, and the Mousgoum, who are usually farmers and fishermen. In addition to these settled populations in the flood-prone areas of the plain, some nomadic herders come from various countries in the region to graze their animals during the dry season (Sighomnou 2003).

The climate of Logone-Birni is of the Sudano-Sahelian type with two seasons: A rainy season that extends over a maximum of three months from July to September and a very long dry season that can last up to 10 months in some years from October to June (Mvondo *et al*., 2003). Rainfall has been quite low in recent years. The average annual rainfall based from 1984 to 2005 is 650.5 mm for 45 rains (Guianeng, 2010).

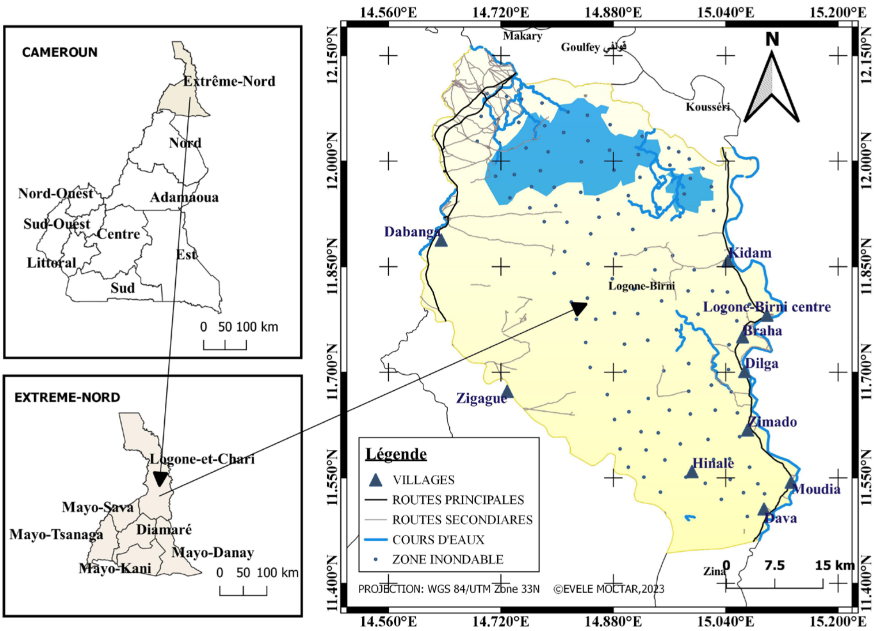


Figure 1: Location map of the study area (Logone-Birni sub-division)

Dendrometric Surveys

The method used for inventorying timber species is based on biodiversity study methods already developed, notably that of floristic surveys and dendrometric measurements used by Ndong *et al*. (2015) and Abakar *et al*. (2021) in the humid and Sahelian zones respectively. To inventory the timber species, three sites (site 1 Kidam village; site 2 Dilga and Braha village; site 3 Moudia and Dava villages) were selected. Plots 100 m x 100 m in size were set up in three land use types (grazing area, agriculture area and protected area) in each site in replicates of three for a total of 27 plots.

This experimental set-up assumes that three plots are installed in each land use type, for nice plots per survey site (Table 1). The low density

Table 1: Experimental device

Villages/Area	Grazing Area	Agricultural Area	Protected Area
Kidam	GrA 1	AgA 1	PrA 1
	GrA 2	AgA 2	PrA 2
	GrA 3	AgA 3	PrA 3
Braha	GrA 4	AgA 4	PrA 4
	GrA 5	AgA 5	PrA 5
	GrA 6	AgA 6	PrA 6
Moudia	GrA 7	AgA 7	PrA 7
	GrA 8	AgA 8	PrA 8
	GrA 9	AgA 9	PrA 9

*Note: GrA = Grazing area: 1,2,3…………… 9 represents respectively the number of plots; AgA = Agricultural area: 1,2,3……….9 represents respectively the number of plots; PrA = Protected area: 1,2,3……….9 represents respectively the number of plots.

of woody plants in the study area explains the choice of installing 100 m x 100 m plots. These plots are randomly installed as suggested by Niang *et al*. (2014) and correspond to the minimum area for the study of Sahelian woody vegetation (Saleh *et al*., 2013).

In each plot, all woody species were inventoried and identified by their scientific names (Souare *et al*., 2020), or by their local names. The identification of species by their scientific names was done on-site. For unknown species, pictures were taken and then presented to resource personnel at the Botany and Ecology laboratory of the University of Maroua for identification with the help of reference books, such as Arbonnier.

For each woody species, the following dendrometric parameters were recorded:

- Circumference: This was done using a tape measure at chest height (1.30 m) according to the methods applied by Sawadogo (2006) and Tchobsala *et al*. (2018a). For multicoloured individuals, the diameter of all stems was measured. For sarment species, the average diameter was calculated using the formula:

$$D=\sqrt{\Sigma di^2} \quad (1)$$

(D = the average diameter and Σdi = sum of all stem diameters).

- Height: This was done using a 5 m graduated pole. For multi-cultivar individuals, the height of the tallest stem was estimated (Traoré, 2008).
- Identification and inventory of juvenile plants to assess the regeneration potential of the species (number of stump sprouts and seedlings). In this study, individuals with a diameter of less than 3.5 cm (i.e., 10 cm circumference) were considered as regeneration stems (Ouedraogo *et al*., 2006).
- Traces of anthropogenic activities (cutting, debarking, pruning, root removal, burning) in each plot were also recorded (Tchobsala *et al*., 2016a).

Data Processing and Analysis

Data processing was done with Microsoft Office 2016 Excel spreadsheet to evaluate floristic diversity, structure and stand regeneration. The list of inventoried species and their taxonomy was compiled to evaluate the floristic composition. The classification used in this study is that of APG IV. Species in the family *Fabaceae-Mimosoideae* have been updated using the revised phylogenetic classification of Kyalangalilwa *et al.* (2013). The Hierarchical Ascending Classification (HAC) of species grouping, based on their abundance, and families, based on the number of species, was performed using Xlstat 2016 software. Canonical Correspondence Analysis (CCA) was performed using Xlstat 2023.

Floristic Diversity Indices

Floristic diversity was assessed by calculating the following indices:

- Species richness (**S**), which is the total number of species in the community studied.
- The Shannon-Weaver diversity index (1949) is used to evaluate the weight of the species in the land cover. This index varies according to the number of species present. It is higher if a large number of species occupy the ground. It is expressed in bits per individual and varies from the lowest diversity (0 bits) to the highest diversity (4.5 bits) (Frontier *et al*., 1983). The formula used is:

$$ISH = -\Sigma\ (Ni/N)\ \log_2(Ni/N) \quad (2)$$

(Ni = number of individuals of each species i; N = total number of individuals across all species. ISH is the Shannon index expressed in bits).

- Pielou Equitability (Pielou 1966 cit. Jiagho 2018) is the ratio between the observed diversity and the maximum possible diversity of the number of species. The formula used is:

$$\mathbf{EQ = ISH/log_2S} \quad (3)$$

- Simpson's (1949) diversity index is a measure of dominance. It expresses the probability that two individuals drawn at random from a defined population belong to the same species.

$$\mathbf{D = \Sigma\ (\mathit{Ni/N})^2} \quad (4)$$

(Where Ni is the specific contribution of species i to the recovery. Simpson's index varies between 0 and 1).

Structural Parameters

The assessment of stand structure was based on the interpretation of histograms of woody species distribution in diameter (horizontal structure) and height classes (vertical structure). The spectrum of biological types was also used to describe the different morphological characteristics resulting from plant adaptations to environmental conditions. The stratification profiles of Amougou (1986) and Jiagho (2018) were used for the vertical structure. The biological types were studied according to the classification of Raunkaier (1934) and adapted to tropical regions by Schnell (1971). In this study, we limited ourselves to the "height" criterion represented by the Phanerophytes.

Regeneration Capacity of Vegetation

To evaluate the regeneration of the stand, the following parameters were calculated:

- Regeneration Rate of the Stand: The regeneration potential of woody species in a biotope (Konan *et al*., 2015). The formula of Poupon, (1980) used by Ngom *et al.* (2013) was chosen to calculate the stand regeneration rate.

$$\mathbf{TRP} = \frac{\textit{total number of seedings}}{\textit{total stand size}} \times \mathbf{100} \quad (5)$$

According to Rothe's (1964) scale,

{*regeneration is difficult if TRP* < 100%
regeneration is good for 100% < *TRP* < 1000%
regeneration is very good when TRP > 1000%)}

- Mortality Rate: The mortality rate is given by the percentage ratio between the number of dead standing or felled individuals and the total number of individuals in the stand (Ibrahima *et al*., 2020).

$$\mathbf{TM} = \frac{\textit{number of dead individuals}}{\textit{total stand size}} \times \mathbf{100} \quad (6)$$

- Dynamics Rate: The dynamics are considered as the difference between the regeneration rate and the mortality rate. The formula of Baggnian *et al.* (2013) will be used in the calculations.

$$\mathbf{DR\ (\%) = TRP - TM} \quad (7)$$

- Specific Importance of Regeneration: This is obtained from the percentage ratio of the number of seedlings of a species over the total number of seedlings (Ngom *et al*., 2013).

$$\mathbf{ISR} = \frac{\textit{total number of seedlings of a species}}{\textit{total number of trees in the stand}} \times \mathbf{100} \quad (8)$$

- Indicators of Anthropogenic Pressures: The analysis of anthropogenic pressures is calculated based on the damage suffered by the flora. In this study, the cutting or felling, pruning, fire or burning and debarking are considered anthropogenic damage. The anthropisation index of a species (Id), expressed as a percentage, was calculated according to the formula used by Ngom *et al*. (2018):

$$\mathbf{Id} = \frac{\textit{number of adult individuals with at least one damage}}{\textit{total number of individuals}} \times \mathbf{100} \quad (9)$$

Results

Floristic Inventory

Specific Richness

The values of species richness and taxonomic abundance in the land use types according to the different sites are summarised in Table 2. It appears that (i) in the grazing area, 26 species distributed in 23 genera and 13 families have been inventoried with a density of 86 stems/ha; (ii) in agricultural area, 21 species distributed in 17 genera and 11 families have been inventoried with a density of 32 stems/ha; and (iii) in

Table 2: Specific richness and taxonomic abundance in the different sites

Stands	Grazing Area				Agricultural Area				Protected Area			
Parameters	**Ni**	**S**	**G**	**F**	**Ni**	**S**	**G**	**F**	**Ni**	**S**	**G**	**F**
Kidam	97	16	15	7	32	15	13	8	342	28	23	13
Braha	141	19	16	9	39	16	15	9	228	22	19	13
Moudia	21	10	11	7	26	11	11	7	203	22	19	12
Total area	86	26	23	13	32	21	17	11	258	41	34	19

*Note: Ni = number of individuals/ha; S = species; G = Genera; F = family.

protected area, 41 species distributed in 34 genera and 19 families have been inventoried with a density of 258 stems/ha.

The Principal Component Analysis (PCA) was applied to the different species according to the different land use types. The three axes explain 94.88% of the total variance (Figure 2). The figure shows that the species form a cloud of points in the centre of the axes. However, we note a rather distant dispersion of other species such as *Piliostigma reticulatum, Vachellia seyal* and *Borassus aethiopum*. This could be justified by their high abundance and diversity in the different land use types (*Borassus aethiopum* in the protected area (PrA) and *Piliostigma reticulatum* in the grazing area).

Taxonomic Richness in Different Stands

After grouping all the plots, a total of 19 families were counted. The most represented families in terms of the number of species are: Fabaceae with 15 species (*Faidherbia albida, Senegalia ataxacantha, Vachellia nilotica, Senegalia polyacantha, Senegalia senegal, Vachellia seyal, Vachellia sieberiana, Dichrostachys cinerea, Entada africana, Mimosa pigra, Bauhinia rufescens, Piliostigma reticulatum, Tamarindus indica, Dalbergia melanoxylon, and Dalbergia sisoo*), Rubiaceae with four species (*Feretia apodanthera, Gardenia aqualla, Gardenia erubescens,* and *Mitragyna inermis*), the families Arecaceae, Apocynaceae, Capparaceae, Meliaceae, Moraceae, Myrtaceae, and Rhamnaceae with 2 species each; and Anacardiaceae, Zygophyllaceae, Bignoniaceae, Combretaceae, Convolvulaceae, Ebenaceae, Phyllanthaceae, Cannabaceae, Lamiaceae, and Vitaceae all represented by a single species (Figure 3).

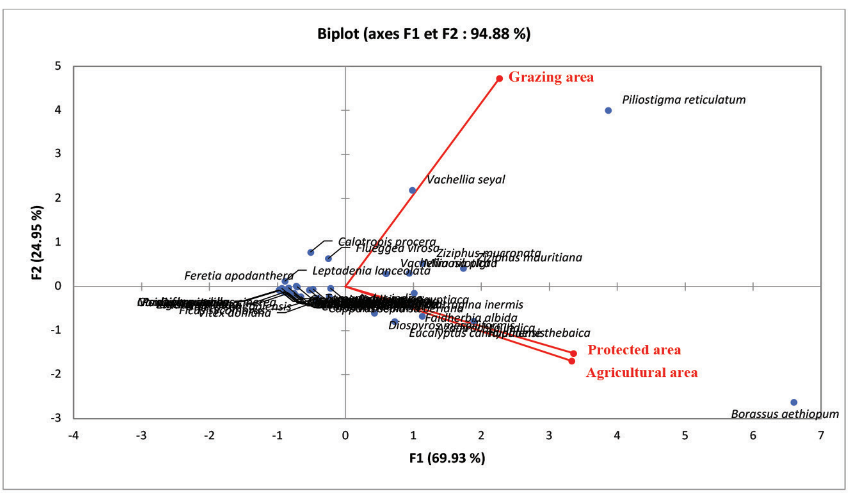


Figure 2: PCA shows the dispersion of species according to land use types

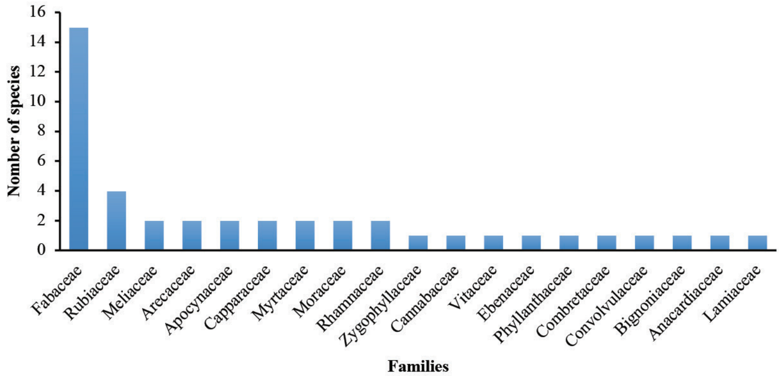


Figure 3: Distribution of species in families in all the sites

Table 3 presents a list of plant species recorded from the Logone-Birni floodplain according to the land use types. The table shows that the Fabaceae family is the most represented in protected, grazing and agricultural areas. Table 3 also shows that *Borassus aethiopum* is the species most represented in protected areas and agricultural areas; in grazing areas, *Piliostigma reticulatum* is the most represented species.

Table 3: Family richness in different stands

Families	**Species**	**Abundance**		
		PrA	**GrA**	**AgA**
Fabaceae	*Faidherbia albida*	86	19	21
	senegalia ataxacantha	9	0	0
	Vachellia nilotica	92	37	8
	Senegalia polyacantha	26	1	0
	Senegalia senegal	15	0	0
	Vachellia seyal	70	106	3
	Vachellia sieberiana	34	7	8
	Bauhinia rufescens	33	7	2
	Dalbergia melanoxylon	16	0	0
	Dalbergia sissoo	18	0	0
	Dichrostachys cinerea	3	0	0
	Entada africana	19	0	0
	Mimosa pigra	96	43	13
	Piliostigma reticulatum	163	212	21
	Tamarindus indica	4	7	0
Rubiaceae	*Feretia apodanthera*	22	7	0
	Gardenia aqualla	3	0	0
	Gardenia erubescens	3	2	0
	Mitragyna inermis	59	30	24

Meliaceae	*Azadirachta indica*	179	13	10
	Khaya senegalensis	3	0	0
Arecaceae	*Borassus aethiopum*	423	36	76
	Hyphaene theabaica	176	22	24
Apocynaceae	*Calotropis procera*	6	36	0
	Leptadenia lanceolata	0	8	0
Capparaceae	*Capparis sepiaria*	40	0	0
	Crataeva adansonnii	16	0	2
Myrtaceae	*Eucalyptus camaldulensis*	204	2	0
	Psidium guajava	1	0	0
Moraceae	*Ficus platyphylla*	10	0	0
	Ficus sycomorus	30	3	6
Rhamnaceae	*Ziziphus mauritiana*	98	60	25
	Ziziphus mucronata	81	54	17
Zygophyllaceae	*Balanites aegyptiaca*	68	13	1
Cannabaceae	*Celtis integrifolia*	14	9	6
Vitaceae	*Cissus quadrangularis*	2	0	0
Ebenaceae	*Diospyros mespiliformis*	76	5	15
Phyllanthaceae	*Flueggea virosa*	39	35	0
Combretaceae	*Guiera senegalensis*	30	0	0
Convolvulaceae	*Ipomoea fistulosa*	12	4	0
Bignoniaceae	*Kigelia africana*	6	0	1
Anacardiaceae	*Mangifera indica*	1	0	0
Lamiaceae	*Vitex doniana*	38	0	5

*Note: PrA = protected area, GrA = grazing area and AgA = agricultural area.

Hierarchical Ascending Classification (HAC)

The Hierarchical Ascending Classification (HAC) of species according to the different land use types and their absolute abundance in the entire study area formed six classes C1, C2, C3, C4, C5, and C6 at the Euclidean dissimilarity threshold of about 100% [Figure 4 (a)]. C1 is composed of 8 species (*Faidherbia albida, Vachellia nilotica, Balanites aegyptiaca, Diospyros mespiliformis, Mimosa pigra, Mitragyna inermis, Ziziphus mauritiana,* and *Ziziphus mucronata*); C2 is composed of 29 species (*Senegalia ataxacantha, Senegalia polyacantha, Senegalia senegal, Vachellia sieberiana, Bauhinia rufescens, Calotropis procera, Capparis sepiaria, Celtis integrifolia, Cissus quadrangularis, Crataeva adansonii, Dalbergia melanoxylon, Dalbergia sissoo, Dichrostachys cinerea, Entada africana, Feretia apodanthera, Ficus platyphylla, Ficus sycomorus, Flueggea virosa, Gardenia aqualla, Gardenia erubescens, Guiera senegalensis, Ipomoea fistulosa, Khaya senegalensis, Kigelia africana, Leptadenia lanceolata, Mangifera indica, Psidium guajava, Tamarindus indica, Vitex doniana*); C3 is composed of *Acacia seyal*; C4 is composed of 3 species: *Azadirachta indica, Eucalyptus camaldulensis,* and *Hyphaene thebaica*; C5 is composed of *Borassus aethiopum*; C6 is composed of *Piliostigma reticulatum*.

The HAC of the families according to the number of species revealed three main groups at the dissimilarity threshold (with the Euclidean distance) of 15% and distributed in five (05) classes [Figure 4 (b)]: Class C1 consisting of the families of Anacardiaceae, Bignoniaceae, Capparaceae, Combretaceae, Lamiaceae, Vitaceae, and Zygophyllaceae, C2 consisting of Apocynaceae, Cannabaceae, Convolvulaceae, Ebenaceae, Meliaceae, Moraceae, Myrtaceae, Phyllanthaceae; C3 consisting of Arecaceae and Rhamnaceae; class C4 consisting of family of Fabaceae; and class C5 consisting of family of Rubiaceae.

Floristic Diversity

The values of the Shannon-Weaver diversity index, Pielou Equitability as well as Simpson diversity index are represented in Table 4. The Shannon-Weaver Diversity Index (ISH) ranges from 2.56 to 3.04 bits; it is 2.58 bits in the grazing area, 2.56 bits in the agricultural area and 3.04 bits in the protected area. Across all plots, this index (ISH) is 3.06 bits, indicating that diversity is moderate across plots. Pielou's equitability (EQ) across all plots is 0.81 indicating that a

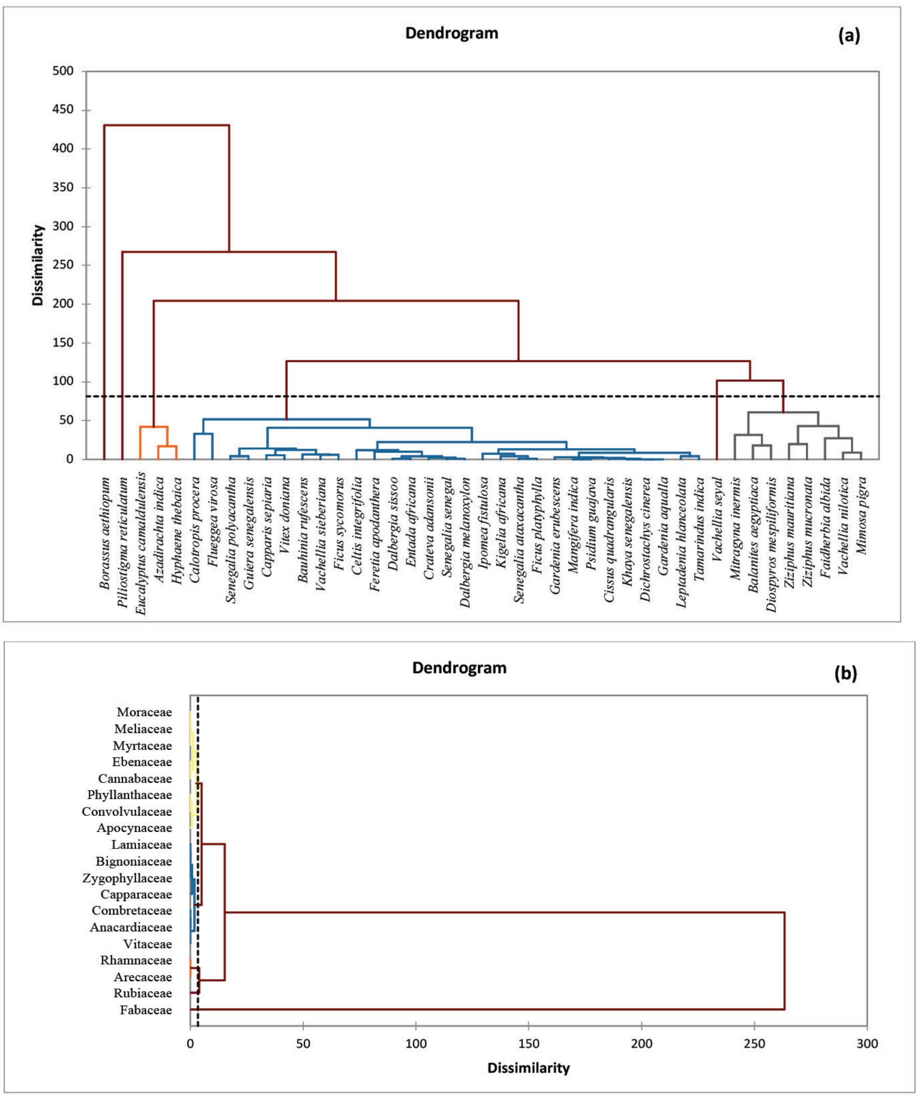


Figure 4: Dendrogram of species grouping by abundance (a) and Families by number of species (b)

maximum number of species participate in the stand with approximately the same abundance. Taking the formations individually, Pielou's equitability (EQ) does not differ too much: It is 0.79 in the grazing area; 0.84 in the agricultural area and 0.82 in the protected area. Simpson's diversity index (D) in all plots is 0.007, which would indicate that the probability of randomly drawing two individuals of different species is very high. In the different formations, the Simpson diversity index increases from the protected area (0.07) to the agricultural area (0.11) and then to the grazing area (0.12). It also appears from this table that, in general, site 1 (Kidam) is more diverse than site 2 (Braha) and site 3 (Moudia). However, in the Moudia site, the species are more evenly distributed than in the Kidam and Braha sites. This could be explained by the fact that the number of species inventoried in Moudia is lower than those obtained in the other sites.

Structural Analyses

Vertical Structure

The distribution of stems in height classes according to land use types shows that the size of individuals is between 0 and 5 m in all plots [Figure 5 (a)], which corresponds to the shrub layer. By analysing this stratum according to the stratification profile, in the protected area, 33% of the individuals have a height between 1.5 and 3 m, which corresponds to the medium stem class; in the grazing area, 62% of the individuals have a height between 1.5 and 3 m corresponding to the medium stem class; in the agricultural area, 25% of the individuals have a height between 1.5 and 3 m which corresponds to the medium stem class. An "L" structure was observed in these distributions reflecting a sign of degradation.

The distribution of stems by height class according to the different villages shows globally an "L" pattern with a dominance of shrubs (height between 0 and 5 m) except the grazing area and the agricultural area of the Moudia site which indicates a "bell" distribution. This distribution characterises an abundance of stems of height between 5 and 10 m, which reflects the shrub class [Figure 5 (b)], thus indicating that this ecosystem is in a state of degradation. Analysis of variance shows that there is a statistically significant difference (p-value < 0.0001) between the different heights.

Horizontal Structure

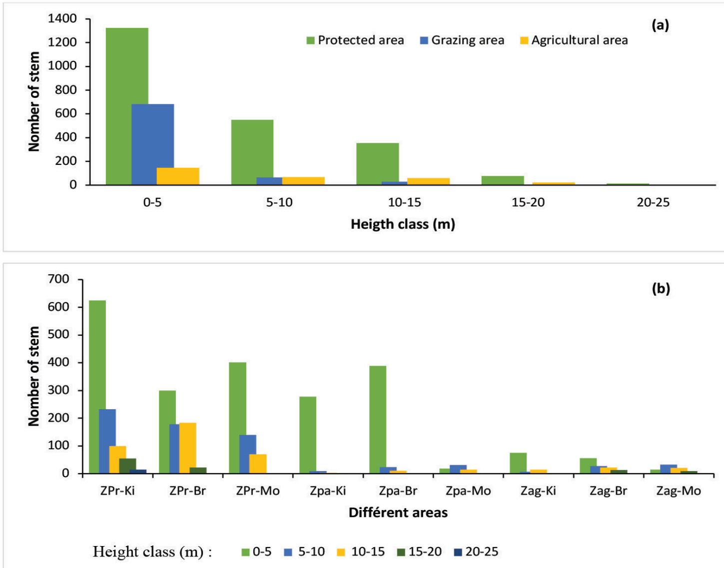
The distribution of individuals of woody species by diameter class shows an overall "L"-shaped structure characterised by an abundance of small-diameter individuals [Figure 6 (a)]. An abundance of small-diameter individuals (between 0-20 cm) was observed in all three communities (63% in the protected area, 89% in the grazing area and 54% in the agricultural area).

The distribution of stems according to the different villages shows globally an "L" shape, with a dominance of stems between 0 and 20 cm in diameter, except in the Moudia site, where the distribution is an "inverted L" shape with the dominance of stems with diameters of between 20 and 40 cm [Figure 6 (b)]. The analysis of variance shows that there is a statistically significant difference ($p < 0.0001$) between the different diameters recorded.

Table 4: Floristic diversity in different stands

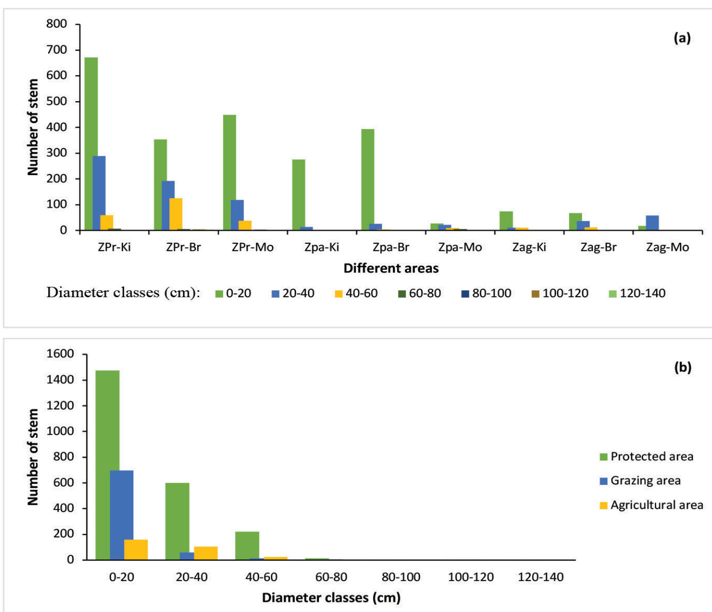
Stands	Grazing Area			Agricultural Area			Protected Area		
Index	**ISH**	**EQ**	**D**	**ISH**	**EQ**	**D**	**ISH**	**EQ**	**D**
Kidam	2.00	0.72	0.20	2.39	0.88	0.10	2.66	0.80	0.10
Braha	2.35	0.80	0.13	2.37	0.86	0.13	2.30	0.74	0.17
Moudia	2.06	0.89	0.17	1.77	0.84	0.22	2.60	0.84	0.11
Total	**2.58**	**0.79**	**0.12**	**2.56**	**0.84**	**0.11**	**3.04**	**0.82**	**0.07**

*Note: ISH = Shannon diversity index, EQ = Pielou equitability index, D = Simpson diversity index.



Note: *Caption- ZPr-Ki = protected area Kidam; ZPr-Br = protected area Braha; ZPr-Mo = protected area Moudia; Zag-Ki = agricultural area Kidam; Zag-Br = agricultural area Braha; Zag-Mo = agricultural area Moudia; ZPa-Ki = grazing area Kidam; ZPa-Br = grazing area Braha; ZPa-Mo = grazing area Moudia.

Figure 5: Distribution of individuals by height class according to land use types (a) and according to villages (b)



Note: *Caption- ZPr-Ki = protected area Kidam; ZPr-Br = protected area Braha; ZPr-Mo = protected area Moudia; Zag-Ki = agricultural area Kidam; Zag-Br = agricultural area Braha; Zag-Mo = agricultural area Moudia; ZPa-Ki = grazing area Kidam; ZPa-Br = grazing area Braha; ZPa-Mo = grazing area Moudia.

Figure 6: Distribution of individuals in diameter classes according to villages (a) and according to land use types (b)

Spectrum of Biological Types

Figure 7 (a) shows the biological spectrum of the flora of the floodplains of the Logone Birni according to land use types. The figure shows that: First, three biological types were recorded in the set of land use types; second, micro-phanerophytes (2 m < height < 10 m) are the most represented with a density of 132.11 individuals/ha in the protected area, 22.44 individuals/ha in the grazing area, and 14.33 individuals/ha in the agricultural area (the plants belonging to this group are *Senegalia ataxacantha, Vachellia nilotica, Vachellia seyal, Vachellia sieberiana, Senegalia senegal, Balanites aegyptiaca, Bauhinia rufescens, Crataeva adansonii, Celtis integrifolia, Dichrostachys cinerea, Entada africana, Kigelia africana, Ziziphus mauritiana,* and *Psidium guajava*); third, meso-phanerophytes (10 m < height < 30 m) are the least represented with a density (in individuals/ha) of 49.33; 3.33; and 8.89 respectively for the protected, grazing and agricultural areas. The plants belonging to this group are *Khaya senegalensis, Eucalyptus camaldulensis, Borassus aethiopum, Ficus platyphylla, Ficus sycomorus, Faidherbia albida, Vachellia sieberiana, Mitragyna inermis, Celtis integrifolia, Vitex doniana,* and *Azadirachta indica*. The analysis of variance shows that there is a significant difference between the biological types in the protected area and those in the agricultural area ($p < 0.05$). Throughout the study areas, micro-phanerophytes were observed to be dominant, with a percentage of species of 45%, followed by the class nanophanerophytes (39%) and Mesophanerophytes (16%) as seen in Figure 7 (b).

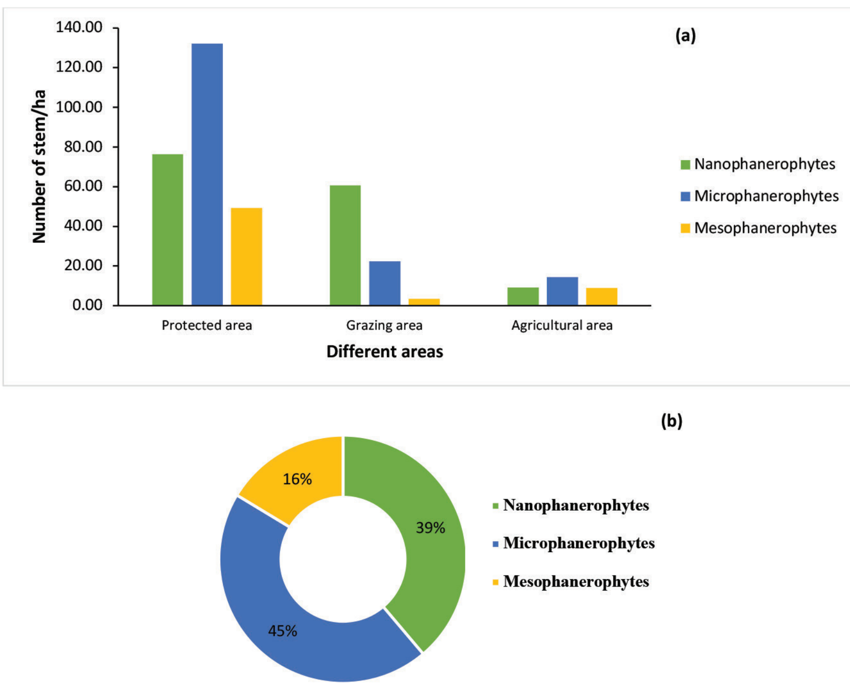


Figure 7: Spectrum of biological types based on land use types (a) and across the study area (b)

Regeneration of Vegetation

Stand Regeneration Rate, Mortality Rate, and Dynamics Rate

Table 5 shows the values of the regeneration rate of the stand, the mortality rate and the rate of the dynamics observed in the different communities. The result shows that the regeneration rate of stand varies from 0% in the agricultural area of Kidam to 51.66% in the Moudia grazing area, indicating a difficult regeneration in all plots according to the Rothe scale. The mortality rates are 6.46%, 2.04%, and 1.34% respectively in the grazing areas of Kidam, Braha, and Moudia. In the agricultural areas, this rate was 1.21%, 1.81%, and 0.82% respectively for the Kidam, Braha, and Moudia sites. In protected areas, the mortality rate was 2.51%, 2.47%, and 2.17% for Kidam, Braha, and Moudia sites respectively. The rate of dynamics reflects the difference between regeneration and mortality of individuals in the population. The dynamic rate (DR) in all plots varies from -1.21 to 50.22%. In general, the grazing areas have a higher dynamic rate than the other areas. The dissemination of diaspores by animals (epizoochory and endochory) and even by humans (anthropochory) could be one of the explanations for these values.

Specific Importance of Regeneration

Table 6 shows the values of the specific index of regeneration in the different formations. In all, in the protected area, seedlings belonging to 26 species were inventoried and distributed as follows: 17 seedlings in Kidam; 9 seedlings in Braha, and 16 seedlings in Moudia. The importance of regeneration is more significant in the following species: *Azadirachta indica* and *Eucalyptus camaldulensis* (15.23%) and *Vachellia sieberiana* (13.33%) in Kidam site; *Borassus aethiopum* (30.39%), *Mitragyna inermis* (19.6%), and *Hyphaene thebaica* (17.6%) in the Braha site; and *Hyphaene thebaica* (19.31%), *Borassus aethiopum* (12.44%), and *Ziziphus mauritiana* (10.30%) in the Moudia site.

In all, seedlings belonging to 19 species were inventoried in the grazing area in all plots. The specific importance of regeneration is more significant in the following species: *Piliostigma reticulatum* (36.99%), *Vachellia seyal* (7.53%), and *Guiera senegalensis* in the Kidam grazing area; *Ziziphus mauritiana* (15.03%), *Piliostigma reticulatum* (12.5%), and *Vachellia seyal* (13.15%) in the Braha grazing area; and *Borassus aethiopum* (48.48%) in the Moudia grazing area.

Among the 21 species inventoried in the agricultural area, the seedlings of seven species were found. The specific importance of regeneration is significant in the following species: *Borassus aethiopum* (47.22%) and *Hyphaene thebaica* (52.78%) in the agricultural

Table 5: Stand regeneration rate (TRP), mortality rate (TM) and dynamics rate (DR) in the different sites

Villages	Treatments	TRP (%)	TM (%)	DR (%)
	Grazing area	36.08	6.46	29.62
Kidam	Agricultural area	0	1.21	-1.21
	Protected area	14.22	2.51	11.71
	Grazing area	35.93	2.04	33.89
Braha	Agricultural area	47.46	1.82	45.64
	Protected area	14.93	2.47	12.46
	Grazing area	51.56	1.34	50.22
Moudia	Agricultural area	46.75	0.82	45.93
	Protected area	38.20	2.17	36.03

Table 6: Specific importance of regeneration in all land use types (in%)

Species	Protected Area			GrazingArea			Agricultural Area		
	Ki	Br	Mo	Ki	Br	Mo	Ki	Br	Mo
Faidherbia albida	0.95	8.82	9.87	-	-	-	-	-	-
Vachellia nilotica	1.9	10.78	-	-	9.21	-	-	-	-
Senegalia polyacantha	-	-	3			-	-	-	-
Vachellia seyal	3.81	-	9.01	7.53	13.15	-	-	-	-
Vachellia sieberiana	13.33	-	7.29	-	3.28	-	-	-	-
Azadirachta indica	15.23	-	-	-	9.86	-	-	-	-
Balanites aegyptiaca	6.67	-	-	-	3.28	-	-	-	-
Bauhinia rufescens	-	-	-	-	5.92	-	-	-	-
Borassus aethiopum	0.95	30.39	12.44	4.79	3.28	48.48	-	41.07	47.22
Calotropis procera	-	-	-	19.86	-	-	-	-	-
Capparis sepiaria	3.81	-	-	-	-	-	-	-	-
Celtis integrifolia	2.85	-	-	-	-	-	-	-	-
Crataeva adansonii	-	-	2.14	-	-	-	-	5.36	-
Dalbergia melanoxylon	-	-	2.14	-	-	-	-	-	-
Dichrostachys cinerea	2.85	-	-	-	-	-	-	-	-
Diospyros mespiliformis	-	-	7.29	1.37	11.84	-	-	17.85	-
Entada africana	-	-	4.72	-	-	-	-	-	-
Eucalyptus camaldulensis	15.23	-	-	-	-	-	-	-	-
Feretia apodanthera	0.95	-	-	-	-	-	-	-	-
Ficus platyphylla	-	4.9	-	-	-	-	-	-	-
Ficus sycomorus	-	1.96	2.14	-	-	-	-	3.57	-
Flueggea virosa	-	-	-	-	3.29	-	-	12.5	-
Gardenia aqualla	-	-	-	4.11	-	-	-	-	-
Guiera senegalensis	-	-	4.72	6.85	-	-	-	-	-
Hyphaene thebaica	2.85	17.64	19.31	2.05	-	45.45	-	1.78	52.78
Khaya senegalensis	0.95	0.98	-	-	-	-	-	-	-
Leptadenia lanceolata	-	-	1.72	-	1.97	-	-	-	-
Mitragina inermis	6.67	19.6	-	2.74	-	6.06	-	-	-
Piliostigma reticulatum	-	4.9	7.72	36.99	12.5	-	-	-	-
Tamarindus indica	-	-	-	-	0.65	-	-	-	-
Vitex doniana	-	-	3.43	-	-	-	-	-	-
Ziziphus mauritiana	1.9	-	10.3	6.167.53	15.03	-	-	17.85	-
Ziziphus mucronata	12.38	-	-	-	6.57	-	-	-	-

*Note: Ki = Kidam, Br = Braha , Mo = Moudia, (-) = absence of regeneration.

zone of Braha; and *Hyphaene thebaica* (52.68%) in the agricultural zone of Moudia. However, in the agricultural zone of Kidam, no regeneration stems were observed in the agricultural area.

Mechanisms of Regeneration

Three regeneration mechanisms were identified in all the plots (Table 7). Regeneration by seedling is the most observed at 67.05%,

Table 7: Species density (stems/ha) by regeneration type across the study area

Species	Seedling	Stump Sprouts	Suckers
Faidherbia albida	0.74	0.48	0
Vachellia nilotica	0.56	0.44	0
Senegalia polyacantha	0.15	0.11	0
Vachellia seyal	1.11	0.96	0
Vachellia sieberiana	1.15	0.52	0
Azadirachta indica	0.63	0.52	0
Balanites aegyptiaca	0.44	0	0
Bauhinia rufescens	0.33	0	0
Borassus aethiopum	3.48	0	0
Calotropis procera	0.89	0	0
Capparis sepiaria	0.15	0.33	0
Celtis integrifolia	0.11	0	0
Crataeva adansonii	0	0	0.74
Dalbergia melanoxylon	0.19	0	0
Diospyros mespiliformis	0.67	1.07	0
Dichrostachys cinerea	0.11	0	0
Entada africana	0.41	0	0
Eucalyptus camaldulensis	0.26	1.11	0
Feretia apodanthera	0.04	0.59	0
Ficus sycomorus	0.33	0	0
Ficus platyphylla	0.19	0	0
Flueggea virosa	0.41	0	0
Gardenia sp	0.22	0	0
Guiera senegalensis	0.63	0.52	0
Hyphaene thebaica	3.11	0	0
Khaya senegalensis	0.07	0	0
Leptadenia lanceolata	0.26	0	0
Mitragyna inermis	1.11	0.78	0
Piliostigma reticulatum	1.33	0.44	0
Tamarindus indica	0.04	0	0
Vitex doniana	0.15	0.41	0
Ziziphus mauritiana	1.44	1.04	0
Ziziphus mucronata	0.74	0.44	0
Total (%)	**67.05**	**30.65**	**2.3**

followed by stump sprouts (30.65%) and suckers (2.30%). We observed that most of the species (16 species) that regenerate by seedling also regenerate by stump sprouting since stump regeneration is often induced by endogenous actions. The abundance of species such as *Borassus aethiopum* and *Hyphaene thebaica* could then explain the dominance of seedlings over other regeneration types. Indeed, these species are the most exploited for construction and cannot regenerate after being cut. The matrix of species dispersal according to regeneration modes also shows *Borassus aethiopum* and *Hyphaene thebaica* in relation to seedlings, then *Crataeva adansonii* in relation to the suckering mode of dispersal, and finally a scatterplot of the other species in the centre of the axes (Figure 8).

Regeneration by suckers was observed only on *Crataeva adansonii* stems (0.74 stems/ha) in all plots. In addition, for some species, an absence of seedlings was noted; this could be explained on the one hand by the difficulties of these species to produce viable seeds or stump sprouts (or any other type of multiplication) and on the other hand by the systematic collection of seeds and fruits. The grazing of young plants by animals may also be a reason.

Indicators of Anthropogenic Pressures

Table 8 presents the rate of anthropisation in the study sites. The table shows that the highest index is cutting (40.29%), followed by burning (23.17%), pruning (22.55%), and peeling (13.99%). The high rate of burning and cutting observed in agricultural areas can be explained by the clearing of plots by the populations.

The canonical correspondence analysis (CCA) between the structural parameters, the sites and the various anthropogenic pressures (Figure 9) showed that the site-structural parameters data are linearly related to the sites – anthropogenic pressures data (p-value = 0,049). This means that anthropogenic pressures (debarking, pruning, cutting, burning) have a significant impact on the floristic composition (density of stems) and vegetation structure of the sites.

Discussion

An analysis of the plot sets indicates that a total number of 43 timber species belonging to 35 Genera and 19 Families were inventoried. These results are slightly higher than the 35 species obtained by Ousmane *et al*. (2013) and closer to

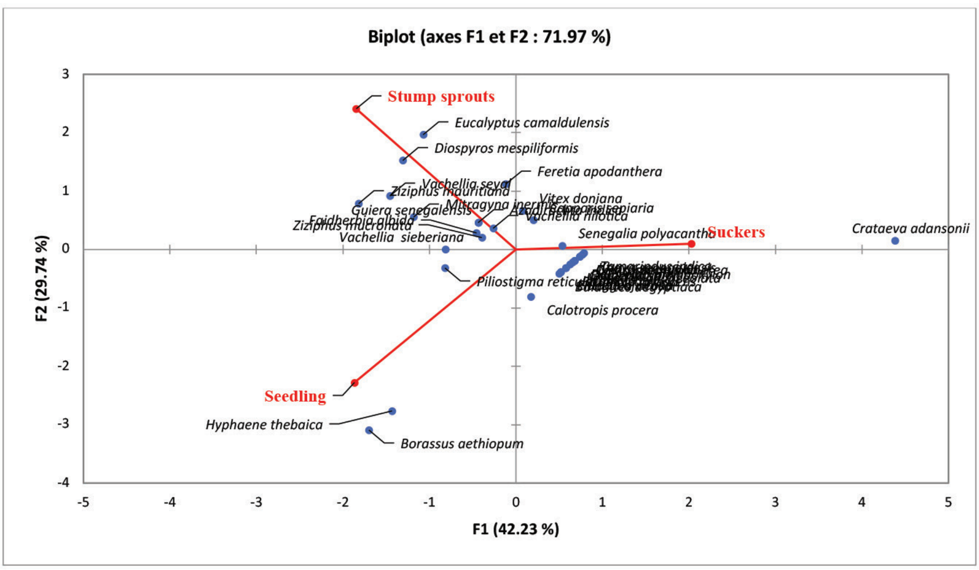
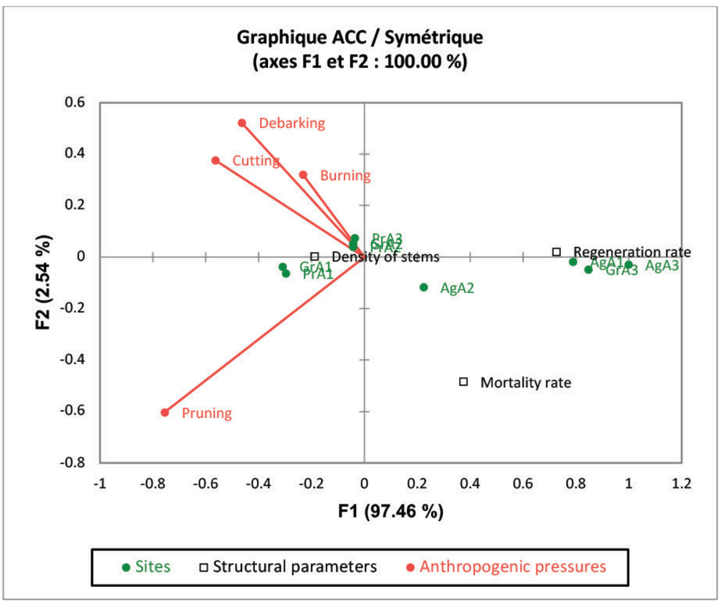


Figure 8: Dispersion of species according to the mode of regeneration

Table 8: Indicator of anthropogenic pressures (%) according to the different villages

Villages	Treatment	Pruning	Cutting	Burning	Debarking
Kidam	Protected area	5.85	8.35	1.04	2.09
	Grazing area	4.18	2.51	7.72	0.42
	Agricultural area	0.84	3.55	1.46	0.00
Braha	Protected area	2.51	7.10	2.09	3.76
	Grazing area	1.67	4.18	5.85	2.51
	Agricultural area	4.18	1.25	0.84	1.88
Moudia	Protected area	2.51	11.06	2.09	2.51
	Grazing area	0.84	1.04	1.46	0.21
	Agricultural area	0.00	1.25	0.63	0.63
Total (overall plots)		**22.55**	**40.29**	**23.17**	**13.99**



Note: *Caption-AgA1 = agricultural area Kidam; AgA 2 = agricultural area Braha; AgA3 = agricultural area Moudia; GrA1 = grazing area Kidam; GrA2 = grazing area Zimado; GrA3 = grazing area Moudia; PrA1 = protected area Kidam; PrA2 = protected area Zimado; PrA3 = protected area Moudia.

Figure 9: Canonical correspondence analysis diagram showing the correlation of anthropogenic pressures and structural parameters with the land use types

the 52 species recorded by Jiagho (2018) located in the same agroecological zone. However, these results are lower than those obtained by some authors in other wetlands. 100 species obtained by Faye *et al*. (2018) and 132 species obtained by Noba *et al*. (2010). These results show the advanced state of degradation of the woody species in the Logone floodplains compared to other important wetlands. Our findings also reveal that the protected area is richer in several species (41), genera (31), and families (19) than the grazing and agricultural areas. This could be linked to human activities, such as overgrazing and the expansion of agricultural land. Some authors made this same observation (Dan Guimbo, 2011; Soulama *et al.,* 2015; Tchobsala *et al.*, 2016b). In managing this plain, particular attention must, therefore, be paid to agricultural and grazing areas.

The density of stems obtained varies from 32 stems/ha in the agricultural area to 258 stems/ha in the protected area, giving an average density of 125 stems/ha in all sites. The average densities obtained are lower than those found by other authors (Ngom *et al*., 2013; Téwéché *et al*., 2016; Sambou *et al.,* 2021); however, they are still higher than those obtained by Abakar *et al*. (2021) in two sites of the Great Green Wall of Chad. The low density of stems in the Logone-Birni floodplain could be explained by the low representativeness of adult trees, due in part to uncontrolled logging but also due to the harshness of climatic conditions. According to Ngnignindiwou *et al.* (2021), the difference in density between the two sites would be due to abiotic factors (soil, rainfall and competition) which determine the diversity and structure of the vegetation in relation to the biotic parameters.

The most represented families are Fabaceae and Rubiaceae. These families are those with species that are resistant to the lack of rainfall and also to high temperatures (Savadogo *et al*., 2016). Indeed, the Fabaceae family is one of the most represented families in tropical Africa, particularly in the Sudano-sahelian zone, and they are generally fodder, with zoochorous seeds, disseminated by the herbivores that consume them. The abundance of Rubiaceae can be explained by the fact that the Logone-birni subdivision is located in an area that is periodically flooded, which is the ideal growth zone for this family. Kabore *et al.* (2013) have shown that the predominance of Rubiaceae in an environment reflects better flooding of the site, thus creating good conditions for the growth of species belonging to this family. These results were in line with those of Laminou *et al.* (2017) and Ousmane *et al*. (2013), who identified the Mimosaceae and Caesalpiniaceae (Included in the Fabaceae family in this study) and Combretaceae as the most represented families.

The Simpson diversity index, Pielou equitability and Shannon-Weaver diversity index show that agricultural areas are less diverse (ISH 1.77 to 2.39 bits) and more equitable (EQ 0.84 to 0.88) than protected and grazing areas. In all the plots, the mean value of the Shannon index was 2.72 bits, indicating a low level of diversity. These results are lower than the 3.80 recorded by Jiagho (2018) in the Waza National Park. However, they are still similar to those of Tchobsala *et al.* (2018a, 2018b) in Minawao Camp and the anthropised savannah of the canton of Lara respectively, both located in the same phyto-geographical subdivision of Cameroon. According to Tamiru *et al*. (2023), the medium value of the Shannon diversity index suggests that there are various factors contributing to this result, including illegal harvesting, agricultural expansion, overpopulation, and livestock intervention.

The distribution of stems by height class according to the different villages shows globally an “L” pattern, with a dominance of shrubs (height between 0 and 5 m). This structure results from anthropogenic pressure, such as wood collection and timber harvesting, which contributed to the height reduction of individuals. It is, therefore, imperative under these conditions to make measures that favour conservation and the sustainable management of these species (Mbaiyetom *et al.,* 2021). These results are similar to those of Ngom *et al*. (2013), Jiagho (2018) and Ngnignindiwou *et al.* (2021), who also obtained an L-shaped structure and have deduced that this is a sign of degradation.

The distribution of individuals of woody species by diameter class shows an overall L-shaped structure characterised by an abundance of small-diameter individuals. Tchobsala *et al*. (2018a) in Minawao camp and Nyasiri (2018) in the forest landscapes of the Ngaoundéré cliff (Adamaoua-Cameroon) observed a similar diametric structure in their studies. The abundance of small-diameter individuals in the plots can be explained, on the one hand, by the abundance of small-diameter plants in the plots as a whole: This is the case, for example, of *Piliostigma reticulatum* and *Mimosa pigra*; but also, by the arid climatic conditions of the area, which hinder the growth and development of the species, on the other hand. According to Ousseina *et al*. (2015), the scarcity of large-diameter individuals in tropical Africa can be explained by water deficits that influence the growth in thickness of plants.

Microphanerophytes are the most representative biological types. According to Thiombiano (2005), the strong representation of micro-phanerophytes shows a preponderance of shrubby formations in an environment. The dominance of micro-phanerophytes, thus, confirms the most widespread physiognomic type in the study area, namely shrub savannahs. These results agree with those of Faye *et al*. (2018) who obtained a dominance of phanerophytes in the Gueumbeul Wildlife Reserve (Senegal River Delta). The scarcity of meso-phanerophytes in the study area can be explained, on the one hand, by the overexploitation of trees and, on the other hand, by the inability of trees to grow normally in thickness following the cumulative water deficit (Diallo, 2011).

Concerning the regeneration of the stand, it appears from the results obtained that regeneration is difficult in all the plots. However, in the agricultural area of the Kidam site, no regeneration stems were observed. This could be explained by the fact that the population of the area clears the land before cultivating, giving preference only to mature plants. However, little regeneration was observed in the protected area, as compared to the agricultural and grazing areas. These results are lower than those of Ngom *et al.* (2013) who obtained regeneration rate values of between 36% and 79% in the Ferlo reserve in Senegal. This could be explained by the fact that the Ferlo Reserve is a fully protected area and is less subject to anthropogenic actions, unlike the Logone-Birni floodplain vegetation, which is subject to anthropogenic actions on an almost permanent basis. According to Jiagho (2018), the poor regeneration of the vegetation cover, particularly in the floodplain, can be the consequence of environmental factors, such as irregular and deficient rainfall, excessive concentration of livestock, flood recession agriculture, systematic exploitation and cutting of woody species, rapid withdrawal of flood waters, pastoralism and transhumance.

These results also show that deadwood is most common in grazing areas, which could be partly explained by the low protection of grazing areas compared to protected and agricultural areas, but also by the ecological conditions of the environment. These results are in line with those of Sist *et al.* (1987), which showed that the presence or absence of seedlings and their densities depend not only on the viability of the seed but also on the ecological conditions it encounters. In this same vein, Tchobsala *et al.* (2016b) demonstrated that the important number of dead stems would be due to the repeated wood cutting each year or the grazing of young suckers and the trampling by animals in pasture sites. These results are similar to those of Baggnian *et al*. (2013) in south-central Niger, where the average mortality rate is minimal (2.11%) in sites benefiting from protection compared to unprotected sites.

Regeneration by seedling is the most observed with a contribution of 67.05%, followed by stump sprouts (30.65%) and suckers (2.30%). These results are similar to those of Adjonou *et al*. (2009), who found 88.9% seedlings versus 10.8% shoots and 0.4% suckers in the open forests of the Oti-Kéran National Park in northern Togo intersected by the River Koumongou. However, these results differ from those of Nyasiri (2018), who noted 66.88% of stump sprouts, 31.94% of seedlings and 1.98% of suckers. This difference could be due in part to grazing in the plots, which considerably reduces the seeding rate compared with that of stump sprouts, thus explaining the high seeding rate reported in our findings.

In all the plots, the species with the high regeneration index are *Borassus aethiopum* (ISR = 23.57%) and *Hyphaene thebaica* (ISR = 20.26%). The high regeneration rate observed in some species is probably related to their mode of multiplication. The same observation was made by Régis *et al*. (2008), who found that *Hyphaene thebaica* develops a horizontal network of vegetative organs tens of centimetres below the soil surface that grow 10 cm to 20 cm in diameter, with the appearance of rhizomes. The latter ensures the production of shoots, which densely colonise the environment. Different results were obtained by Ngom *et al.* (2013) in the Ferlo Biosphere Reserve in northern Senegal, who obtained *Guiera senegalensis* (ISR = 62.37%) and *Boscia senegalensis* (ISR = 16.38%) as the species with better regeneration potential. The observed difference could be related to the degree of anthropisation, which is greater in the Logone Valley than in the Ferlo Reserve. 15 woody tree species in the protected areas lacked a seedling stage, while another seven woody species lacked a seedling stage in grazing areas. The absence of seedlings in these species indicated a discontinuity in their population structure according to Gebeyehu *et al.* (2020). These species with few or no seedlings must, therefore, be given special attention in terms of conservation and management.

Regarding the anthropisation index, cutting is the main anthropogenic action of the population of the Logone-Birni flood plain. This could be explained by the need for firewood. Indeed, the investigation carried out by the PAN-LCD (2006) showed that more than 80% of households in the Far North region of Cameroon is dependent on firewood. Wood cutting has been identified as the main anthropogenic action by several authors (Baiyabe *et al.*, 2018; Aboubakar, 2022). Human disturbances have a direct influence on tree density and diversity, and the specific composition of the vegetation. Similar results were obtained by Ngom *et al.* (2018), Ngueguim *et al.* (2018) and Tchobsala *et al.* (2016a; 2016b). It is, therefore, necessary to set up a local structure for the management of the site.

The results of this study can be seen as the starting point for operations to conserve and restore the vegetation of the Logone-Birni floodplain.

Conclusions

The present study is aimed at contributing to the sustainable management of the Logone-Birni floodplain, which has been degraded for a long time by anthropic activities. It is also aimed at determining the composition and floristic and structural diversities of the stand, and at evaluating the regeneration capacity of the vegetation. The main results obtained are: The inventory of the woody flora enabled the identification of 43 species distributed in 35 genera and 19 families in all the plots. The values of the Shannon diversity index and Pielou equitability show that the agricultural areas are less diverse and more equitable than the protected grazing areas. The most important family is the Fabaceae, while the most important species in terms of abundance are *Borassus aethiopum* in agricultural and protected areas; and *Piliostigma reticulatum* in grazing areas. The distribution of stems of woody species in diameter and height classes showed a general "L" shape marked by an abundance of small diameter and height stems. The spectrum of biological types showed a dominance of micro-phanerophytes in the Logone-Birni floodplain. These species are under permanent threat from anthropogenic actions and it was observed that the regeneration rate of the stand is low in all the plots, partly due to anthropogenic factors (cutting or felling being the most observed factor). In the long term, this would lead to the disappearance of the vegetation cover to bare soil and consequently to an increase in the release of carbon into the atmosphere, which is the cause of climate change. There is thus the need to raise awareness of this threat and to launch a process of management of the periodically flooded plains of Logone-Birni to ensure the sustainability of the goods and services provided by this ecosystem.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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