Hindawi Publishing Corporation
Journal of Botany
Volume 2016, Article ID 9523685, 11 pages
http://dx.doi.org/10.1155/2016/9523685

Research Article

Effects of Climate and Land Use on Herbaceous Species Richness and Vegetation Composition in West African Savanna Ecosystems

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Received 28 September 2015; Accepted 17 January 2016

Academic Editor: Guang S. Zhou

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West African Savanna ecosystems are undergoing severe changes in their vegetation composition due to the impact of human land use and changes in climatic conditions. This study aims to examine the effect of climate, land use, and their interaction on species richness and composition of West African herbaceous vegetation. Plot based vegetation sampling was done in Burkina Faso. Specific richness and diversity indices were used to determine the effect of land use, climate, and their interaction. An importance value was computed to determine herbaceous species dominating the communities. Frequency of species is used to examine their distribution pattern. The results showed that climate significantly influenced herbaceous specific richness more than land use. However, land use had a significant effect on herbaceous vegetation composition. Herbaceous species diversity changed with environmental conditions. The floristic composition of dominant species is driven by both climate and land use. The frequency of distribution demonstrated that herbaceous species occurrences were more influenced by the mixed effect of climate and land use than their separate effects. Occasional and rare species are the most important part of herbaceous vegetation. Thus heterogeneity of Savanna ecosystem and vulnerability of herbaceous species are high.

1. Introduction

West African Savanna ecosystems are undergoing severe changes in their vegetation composition and species cover due to the impact of human land use and changes in climatic conditions. Indeed, African Savannas represent a fundamental environment for people practicing stock breeding and agriculture [1] and collecting nontimber forest products (NTFP) for multiple purposes [2–4]. In recent decades, the most dramatic changes were increasing human population and consequently an increase in land use intensity often related to increased livestock density and the extension of agricultural lands, or a shortening of fallow periods [5, 6]. Climate change and human activities (land use, chopping, fire, and grazing) are leading to the degradation of these ecosystems [3, 7–13]. These changes threaten biodiversity and sustainable land use [6].

Several studies predicted dramatic changes for West Africa vegetation for the next 50 years: for example, Savannas are predicted to expand in the next few centuries at the expense of tropical forests, mainly as a result of deforestation and human fires [14]. On the contrary, a tendency to greening is predicted because of the increase in precipitation in West Africa [15]. The main question is how climate and land use interact to affect West African herbaceous vegetation?

Many authors studied the effect of land use and climate on West African Savannas vegetation separately. Most of these studies showed that anthropogenic activities affect woody vegetation composition [16–20] and climate influences its species richness and stand structures [21–25]. Other studies revealed that land use and climate affect vegetation composition [12, 26–30]. Authors who studied the herbaceous vegetation demonstrated that grazing, fire, and selected cutting [5, 9, 10, 31, 32] influenced herbaceous biomass. Devineau and Fournier [33] pointed out that the characteristics of the top soil horizon are most important for herbaceous species installation. Among these studies, none focused implicitly on the impact of climate, land use, and their interaction on Savanna herbaceous species richness and composition. Given that herbaceous species are the most sensitive ecosystem components of Savanna ecosystems [25, 33] and climate change, it is essential to study the effect of the interaction of land use and climate.

The scope of this study is to determine the effect of climate, land use, and their interaction on herbaceous species richness and composition in Savanna vegetation. We assume that investigating these factors and their interaction may clarify which change may take place in West African Savanna herbaceous diversity. With this study we will test the following hypotheses:

(i) The specific richness or taxonomic richness of herbaceous vegetation is more driven by climate than by land use.

(ii) The composition of herbaceous vegetation varies due to climate and land use conditions.

(iii) The frequency of herbaceous species depends more on the interaction between climate and land use than on their individual effects.

2. Methods

2.1. Study Sites. The study was conducted along a climatic gradient in three protected areas and their surroundings used by local people for multiple purposes (fallows, grazing, collecting of nonforest product, etc.). The three study sites are representative for the phytogeographical zoning of Burkina Faso described by Guinko [34] (Figure 1).

(i) The Sylvopatoral Reserve and Partial Fauna Reserve of Sahel: it is a protected area of IUCN category VI [35]. It is located in the Sahelian zone with a mean annual rainfall ranging between 300 mm and 600 mm. Mean annual temperature ranges from 23.5°C to 35°C.

(ii) The Northern part of National W Biosphere Reserve: W Biosphere Reserve is a protected area of IUCN category II [35]. The study site is located in the North Sudanian zone. The mean annual rainfall ranges between 600 mm and 900 mm. Mean annual temperature ranges from 25.5°C to 33°C.

(iii) The Southern part of Classified Forest and Partial Fauna Reserve of Pama: Pama Reserve is a protected area of IUCN category IV [35]. The study site is located in the South Sudanian zone. The mean annual rainfall ranges between 900 mm and 1200 mm. Mean annual temperature ranges from 25.9°C to 31.4°C.

We distinguished between two types of land use (communal area and protected area); in "protected areas" all human activities are strictly prohibited, while in "communal areas" all kinds of human land use activities are allowed (like grazing, agriculture, and harvest of nontimber forest products).

2.2. Data Collection. Per study site, two contrasting land use types were compared: protected and communal areas. Per land use type and study site, herbaceous vegetation composition was sampled during the rainy season (September to November) on plots of 10 m × 10 m. Additionally, we distinguished between four different habitats (dry, bowal, fresh, and wet). For each habitat 10 plots were sampled. Thus, vegetation sampling resulted in 240 plots (2 land use types × 4 habitats × 3 study areas × 10 repetitions). Per plot the percentage of cover occupied by each herbaceous species was visually estimated using the method of Braun-Blanquet [36] with the cover classes r (rare species): cover less than 1%, +: cover less than 1%, 1a: cover between 1 and 3%, 1b: cover between 3 and 5%, 2a: cover between 5 and 15%, 2b: cover between 15 and 25%, 3: cover between 25 and 50%, 4: cover between 50 and 75%, and 5: cover between 75 and 100%.

2.3. Data Analysis. Specific richness or taxonomic richness of an ecosystem is defined as the number of species or taxa that can be found there regardless of the number of individuals or the biomass of each taxon [37]. To examine the effect of climate gradient and land use on specific richness, we considered family richness, genera richness, and species richness as the number of families or genera or species occurring in a given climate zone or land use type. To estimate the effect of the explanatory variables climate and land use on specific richness, species richness, genera richness, and family richness (response variables) we used Generalized Linear Models with Poisson errors [21].

There are several numbers of diversity which differ greatly and make comparisons difficult and confusing, which hampers also a sound interpretation [38]. To describe the effect of the interaction of climate and land use on herbaceous vegetation composition, we used the series of diversity numbers and evenness presented by Hill [39], which is well indicated for ecological interpretation. Hill's family of diversity numbers are

(i) $N0 = S$, where S is the number of species in a plot;

(ii) $N1 = e^{H'}$, where $H' = -\mathrm{Sum}(P_i * \ln(P_i))$ is Shannon's index;

(iii) $N2 = 1/D$, where $D = \mathrm{Sum}(P_i^2)$ is Simpson's index, with P_i relative abundance of species in a plot.

$N0$ is the effective number of species in the sample regardless of their abundance. $N1$ measure the number of abundant species in the sample. $N2$ is the number of very abundant species.

Evenness $(E) = H/\ln(S)$. It is an expression of the balance in the distribution of individuals among the species. Its value approaches 0 when one species is

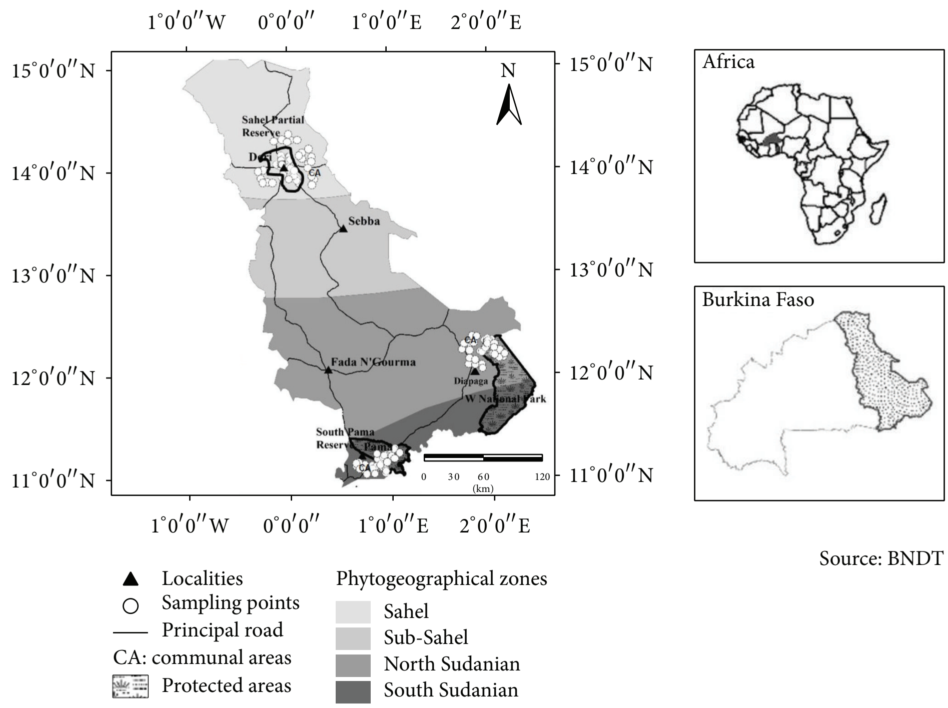

Figure 1: Study sites.

highly dominant and 1 when all species have similar densities. E is independent from species numbers occurring on a plot.

Diversity indices were analyzed with the linear model ($\alpha = 0.05$) [21, 37] because they fulfilled the assumptions of normality and variance homogeneity. In all cases climate and land use conditions are treated as explanatory variables and diversity indices as response variables. Student's t-test at 5% of significance was used as host-post test to detect difference between combinations.

To evaluate β-diversity (similarity between climate-land use conditions), Sorensen similarity index based on species data abundance and presence/absence was used to evaluate similarity between each climate and land use condition. This index potentially varies between 0 and 1: a value close to 1 indicates greater similarity between plots and hence low beta-diversity [40].

The importance value of each species was calculated per climate and land use combination to identify dominant herbaceous species. The importance value index was considered as the sum of Relative Frequency and Relative Dominance according to the following parameters:

(i) Frequency = number of plots in which the species occurs/total plot number × 100.

(ii) Relative Frequency = frequency of a species/sum of all frequencies × 100.

(iii) Relative Dominance = total cover of a species/total cover of all species × 100.

(iv) Importance value = Relative Frequency + Relative Dominance.

In order to determine the effect of climate, land use, and their interactions on the occurrence of herbaceous species, the frequency of each species was computed and compared [41]. An χ^2-test was used to observe the significance of the variation of species frequency [41]. In addition relative abundance of species and rank-frequency diagrams [37, 42] were used to determine herbaceous vegetation structure between climate-land use conditions. Frequent species are those that are widely distributed within all climate-land use conditions. Occasional and rare species are those that are confined to one type of climate-land use conditions or which are accidentally found in an environment:

(i) Frequency ≥ 50%: frequent species.

(ii) 25 ≥ Frequency < 50%: fairly frequent species.

(iii) 5 ≥ Frequency < 25%: occasional species.

(iv) Frequency ≤ 5%: rare species.

All statistical analyses were done using R.3.0.2 [43].

3. Results

3.1. Richness of Herbaceous Vegetation along Climatic and Land Use Gradient. The inventoried flora of the three sites included 374 species of which 307 are herbaceous species and 67 juveniles of woody species. The herbaceous species belong to 152 genera and 39 families. Overall, herbaceous vegetation is dominated by the families of Poaceae (31.8%), Fabaceae (13.2%), Cyperaceae (9.5%), and Malvaceae (6.4%).

Specific richness increased along the climatic gradient from the Sahel to the South Sudanian vegetation zone

Table 1: Climate effect on specific richness of herbaceous vegetation (GLMs analysis).

		Sahel	North Sudanian	South Sudanian	F	p
Families	Overall	24	33	34	2.0800	0.3535
	Protected area	15	30	28	5.9071	0.0522
	Communal area	25	27	33	1.2019	0.5483
Genus	Overall	74	117	125	15.1200	0.0005*
	Protected area	31	100	102	49.2051	<0.0001*
	Communal area	74	95	105	7.6152	0.0403*
Species richness	Overall	130	198	208	21.2500	<0.0001*
	Protected area	41	147	161	87.9035	<0.0001*
	Communal area	128	150	168	7.4399	0.0459*

*Significant effect of the statistic test.

Table 2: Land use effect on specific richness of herbaceous vegetation (GLMs analysis).

		Protected area	Communal area	F	p
Families	Overall	33	37	0.2287	0.6325
	Sahel	12	25	4.6665	0.0308*
	North Sudanian	30	27	0.1580	0.6910
	South Sudanian	28	33	0.4103	0.5218
Genus	Overall	125	145	1.4828	0.2233
	Sahel	31	74	18.1381	<0.0001*
	North Sudanian	100	95	0.1282	0.7203
	South Sudanian	102	105	0.0435	0.8348
Species richness	Overall	223	263	3.2959	0.0695
	Sahel	41	128	47.0106	<0.0001*
	North Sudanian	147	150	0.0303	0.8618
	South Sudanian	161	168	0.1489	0.6995

*Significant effect of the statistic test.

(Table 1). The number of families did not vary significantly between the three climatic zones (Table 1). On the contrary the number of genera and specific richness were significantly lower in the Sahel than in the Sudanian zones ($p < 0.05$). The same pattern was found overall and for communal area and protected area.

Analyzing the influence of land use, species, genera, and family richness did not vary significantly between protected and communal areas ($p > 0.05$) except for the Sahel where we observed higher diversities in the communal areas (Table 2).

3.2. Diversity and Similarity of Herbaceous Species between Climate and Land Use Conditions. The analysis of diversity of herbaceous vegetation by Hill numbers allowed underlining the variations of mean species numbers ($N0$), abundant species numbers, and very abundant species numbers between climate and land use types (Table 3).

Mean species numbers by plot ($N0$) showed that the South Sudanian zone was more diverse than North Sudanian zone which was also more diverse than the Sahelian zone (d.f. = 5, $F = 20.01$, $p < 0.0001$). Besides, in each climate zone, there is a significant difference between communal and protected areas. Mean species number varies from 14.34 ± 4.71 in the Sahel communal area to 25.58 ± 6.34 species in the South Sudanian communal area.

The analysis of herbaceous vegetation by $\mathrm{Exp}(H')$ ($N1$) revealed that the number of abundant species increases significantly (d.f. = 5, $F = 28.65$, $p < 0.0001$) with the precipitation gradient from the Sahel to the South Sudanian zone. Besides, in the Sahelian zone, there are no significant differences between communal and protected areas. In contrast, in the North and South Sudanian zone, we observed that the number of abundant species in communal areas is significantly high compared to that in protected areas. The number of abundant species varied from 8.23 ± 3.15 species in the Sahel communal area to 18.00 ± 4.60 in the South Sudanian communal area.

By considering $1/D$ ($N2$), the number of very important species decreases significantly from the Sahel to the South Sudanian zone (d.f. = 5, $F = 12.14$, $p < 0.0001$). But in each climate zone there are no significant differences between communal and protected areas in terms of numbers of very abundant species. The number of very abundant species does not exceed two (1.09 ± 0.04 in the South Sudanian communal area to 1.27 ± 0.23 in the Sahelian communal area).

The evenness pattern increased significantly (d.f. = 5, $F = 28.56$, $p < 0.0001$) with the precipitation gradient from the Sahel to the South Sudanian zone. Evenness index is high in each climate and land use combination but does not differ significantly between communal and protected areas

Table 3: Herbaceous vegetation diversity indices along climate-land use conditions.

Climatic zone	Land use	Mean richness $N0$	$\exp(H')$ $N1$	$1/D$ $N2$	Evenness (E)
Sahel	Communal area	14.34 ± 4.71^{d}	8.23 ± 3.15^{d}	1.27 ± 0.23^{a}	0.77 ± 0.09^{c}
	Protected area	19.50 ± 4.74^{bc}	10.05 ± 3.12^{cd}	1.20 ± 0.06^{abc}	0.77 ± 0.05^{c}
North Sudanian	Communal area	21.67 ± 7.90^{b}	13.31 ± 5.43^{b}	1.15 ± 0.08^{bc}	0.83 ± 0.06^{b}
	Protected area	15.86 ± 5.90^{cd}	10.58 ± 4.14^{c}	1.19 ± 0.12^{b}	0.84 ± 0.06^{b}
South Sudanian	Communal area	25.58 ± 6.34^{a}	18.00 ± 4.60^{a}	1.09 ± 0.04^{cd}	0.89 ± 0.03^{a}
	Protected area	19.51 ± 6.35^{b}	14.63 ± 4.96^{b}	1.11 ± 0.04^{d}	0.90 ± 0.03^{a}

Superscript letters indicate significant differences according to Student's t-test. The numbers with the same letters indicate that there is no significant difference.

Table 4: Sorensen similarities of climate and land use types.

Climatic zone	Land use	Sahel		North Sudanian		South Sudanian	
		Communal	Protected	Communal	Protected	Communal	Protected
Sahel	Communal	1					
	Protected	0.25	1				
North Sudanian	Communal	0.23	0.17	1			
	Protected	0.16	0.07	**0.50**	1		
South Sudanian	Communal	0.20	0.07	**0.50**	0.45	1	
	Protected	0.16	0.07	0.31	0.48	**0.53**	1

regardless of the climate zone. Its value ranges from 0.77 ± 0.09 in the Sahel to 0.90 ± 0.03 in the South Sudanian protected area.

The composition of herbaceous vegetation varied according to the climate and land use conditions. Sorensen coefficient of similarity reveals that similarity is low between all climate and land use conditions (Table 4). There was a higher difference between the Sahelian and Sudanian zones than between South Sudanian and North Sudanian zone. The difference between communal and protected area was higher in the Sahel and lower in the Sudanian zones.

3.3. Dominant Herbaceous Species according to Climate-Land Use Conditions. In the Sahelian zone, four herbaceous species were found as new for the flora of Burkina Faso. They are *Digitaria fuscescens* (Presl) Henrard (Poaceae) on wet habitat; *Trichoneura mollis* (Kunth) Ekman (Poaceae) on sand dune; *Sporobolus spicatus* (Vahl) Kunth (Poaceae) on wet habitat, and *Abutilon macropodum* Guill. & Perr. (Malvaceae) on sand dune.

We identified the dominant herbaceous species per climatic zone and land use type on the basis of their importance value index (IVI ≥ 5) (Table 5). In the communal area of the Sahel, the dominant species were *Zornia glochidiata*, *Schoenefeldia gracilis*, *Panicum laetum*, *Cassia obtusifolia*, and *Alysicarpus ovalifolius*. The protected area was characterized by a dominance of *Digitaria horizontalis*, *Zornia glochidiata*, *Eragrostis tremula*, *Alysicarpus ovalifolius*, and *Cenchrus biflorus*. In the communal area of the North Sudanian zone, *Microchloa indica*, *Loudetia togoensis*, *Pennisetum pedicellatum*, *Tripogon minimus*, and *Zornia glochidiata* are the most dominant species. In the protected area, important species are *Loudetia togoensis*, *Hyparrhenia involucrata*, *Andropogon pseudapricus*, *Microchloa indica*, and *Andropogon gayanus*. In the South Sudanian communal area, *Andropogon pseudapricus*, *Pennisetum pedicellatum*, *Microchloa indica*, *Tephrosia pedicellata,* and *Spermacoce stachydea* are the most dominant species. In the protected area, the most important ones are *Andropogon gayanus*, *Andropogon pseudapricus*, *Hyparrhenia involucrata*, *Chamaecrista pratensis*, and *Sorghastrum bipennatum*.

3.4. Impact of Climate, Land Use, and Their Interaction on Herbaceous Species Frequency. The occurrence of 23.6% of all species was affected by land use type and 59.8% by climate (Figure 2). Interestingly, for 84.5% of the species, the interaction between climate and land use was important.

In all climate zone and land use combinations, herbaceous vegetation is dominated by occasionally occurring and rare species excepted in the protected area of the Sahel (Figure 3). The abundance of occasional species ranged from 41.6% (South Sudanian protected area) to 57.1% (North Sudanian protected area). That of rare species varied from 28.0% (North Sudanian communal area) to 45.3% (South Sudanian protected area). In the Sahel protected area, frequent species (51.2%) and occasional species are abundant (36.6%).

The rank-frequency diagram allows distinguishing frequent species, fairly frequent species, occasional species, and rare species. Figure 4 illustrated only some herbaceous species among several.

In the Sahel communal area, *Schoenefeldia gracilis*, *Zornia glochidiata*, and *Cassia obtusifolia* were the most frequent species (Figure 4). *Alysicarpus ovalifolius* and *Enteropogon prieurii* were found among fairly frequent species. Among

Table 5: Herbaceous species with an importance value ≥ 5 according to climate and land use conditions.

Climatic zone	Sahel		North Sudanian		South Sudanian	
Land use	Communal area	Protected area	Communal area	Protected area	Communal area	Protected area
Alysicarpus ovalifolius	**6.24**	**9.70**	4.64	2.82	6.16	2.99
Andropogon gayanus	3.72	—	—	**7.54**	3.37	**11.64**
Andropogon pseudapricus	—	—	—	**8.37**	**9.91**	**10.09**
Aristida adscensionis	5.44	—	—	—	—	—
Cassia obtusifolia	**7.76**	4.38	—	—	3.24	—
Cenchrus biflorus	3.19	**9.79**	—	—	—	—
Cenchrus prieurii	—	7.22	—	—	—	—
Ceratotheca sesamoides	—	5.87	—	—	—	—
Chamaecrista pratensis	2.79	6.51	3.28	2.86	4.55	**6.26**
Corchorus tridens	4.03	6.87	3.55	—	—	—
Digitaria gayana	—	5.18	—	—	—	—
Digitaria horizontalis	—	**33.61**	—	—	—	—
Eragrostis tremula	5.41	**9.87**	—	—	—	—
Hyparrhenia involucrata	—	—	—	**9.03**	—	**7.83**
Indigofera bracteolata	—	—	—	—	3.77	**5.38**
Indigofera pilosa	—	7.37	—	—	—	—
Loudetia togoensis	—	—	**9.19**	**12.72**	—	3.11
Microchloa indica	—	—	**9.51**	**8.05**	**7.33**	—
Mitracarpus hirtus	—	—	5.08	—	—	—
Panicum laetum	**8.49**	—	—	—	—	—
Pennisetum pedicellatum	—	—	**9.09**	5.17	**8.16**	4.42
Schoenefeldia gracilis	**17.68**	—	—	—	—	—
Setaria pumila	—	—	5.93	—	—	—
Sorghastrum bipennatum	—	—	—	—	3.40	5.43
Spermacoce radiata	5.32	7.03	3.70	—	4.12	—
Spermacoce stachydea	—	—	3.90	3.03	**6.71**	5.40
Sporobolus pyramidalis	—	—	5.44	—	3.29	—
Stylosanthes erecta	—	6.82	—	—	—	—
Tephrosia bracteolata	—	—	—	2.63	—	5.11
Tephrosia pedicellata	—	4.79	5.78	3.06	**7.25**	—
Tripogon minimus	—	—	**8.35**	5.00	4.10	—
Zornia glochidiata	**15.63**	**24.82**	**6.65**	—	—	—

occasional species were *Aristida adscensionis* and *Indigofera stenophylla*. *Trichoneura mollis*, *Sporobolus spicatus*, and *Digitaria fuscescens* are found among rare species. In the protected area of the same climatic zone *Digitaria horizontalis*, *Eragrostis tremula*, and *Cenchrus biflorus* were frequent. Fairly frequent species were represented by *Abutilon pannosum* and *Indigofera stenophylla*. Among occasional species were *Tephrosia lupinifolia*, *Aristida adscensionis*, and *Pandiaka involucrata*.

In the North Sudanian communal area, *Pennisetum pedicellatum*, *Loudetia togoensis*, and *Microchloa indica* belong to the most frequent species. Among fairly frequent species were *Chamaecrista pratensis*, *Spermacoce stachydea*, and *Tripogon minimus*. *Sporobolus pyramidalis* and *Chrysopogon nigritanus* were among occasional species. Among rare species were *Alysicarpus rugosus*, *Ctenium newtonii*, and *Hyperthelia dissoluta*. In the protected area, only *Andropogon pseudapricus* and *Loudetia togoensis* were more frequent. *Andropogon gayanus* and *Hyparrhenia involucrata* were found among fairly frequent species. *Hyperthelia dissoluta*, *Linzia purpurea*, *Chlorophytum blepharophyllum*, and *Chlorophytum orchidastrum* were encountered among occasional species. *Hyparrhenia glabriuscula*, *Sacciolepis ciliocincta*, and *Sphenoclea zeylanica* can be cited as rare species.

In the South Sudanian communal area, *Andropogon pseudapricus*, *Alysicarpus ovalifolius*, *Spermacoce stachydea*, *and Pennisetum pedicellatum* were more frequent. *Tripogon minimus* and *Pennisetum polystachion* were encountered among fairly frequent species. Occasional species were represented by species like *Sporobolus pyramidalis* and *Hyparrhenia rufa*. Among rare species were *Chrysopogon nigritanus*, *Cienfuegosia heteroclada*, and *Caperonia serrata*. In the protected area, most frequent species were *Andropogon gayanus*, *Andropogon pseudapricus, and Chamaecrista pratensis*. Among fairly frequent species were *Monechma ciliatum*, *Indigofera dendroides*, and *Lepidagathis anobrya*. Occasional species

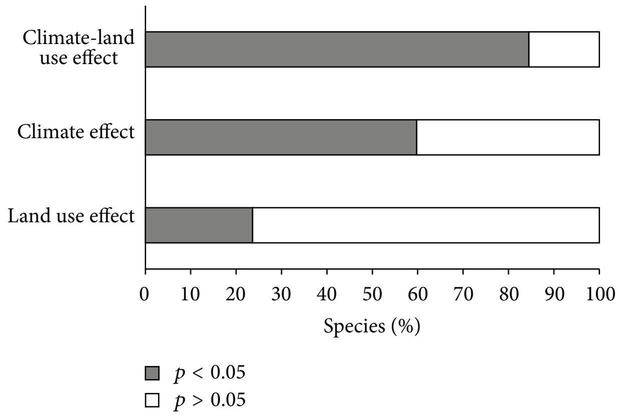

Figure 2: Percentage of herbaceous species according to their responses to land use, climate gradient, and their interaction ($p < 0.05$: significant responses; $p > 0.05$ no significant responses).

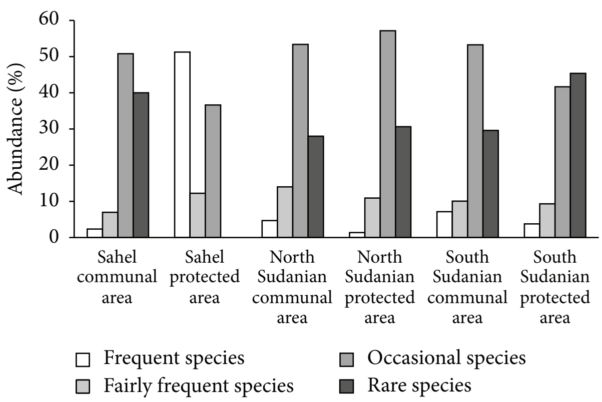

Figure 3: Abundance of herbaceous species according to their frequency classes.

can be represented by *Hyparrhenia smithiana*, *Hyparrhenia glabriuscula*, and *Pennisetum unisetum* and rare species by *Andropogon tectorum* and *Monocymbium ceresiiforme*.

4. Discussion

4.1. Effect of Climatic Gradient and Land Use on Savanna Herbaceous Species Richness. In Savanna ecosystems, herbaceous species richness increases with increasing annual precipitation. Species richness in the Sudanian zone is higher than in the Sahelian zone. These results are in accordance with Bognounou et al. [21] and Schmidt et al. [27], who observed, respectively, increasing of woody and overall species numbers with the increasing of rainfall and the duration of the rainy season. Species richness at landscape scale in West Africa is expected to rise with precipitation towards the South [44], a pattern in accordance with our results found for Burkina Faso [21, 27, 45].

The absence of a significant difference in species richness between the protected and the communal area in the Sudanian zone provides evidence that land use affects species richness of herbaceous vegetation less than climate. Devineau et al. [26] and Shackleton [46] found at the landscape scale, that herbaceous vegetation richness does not differ inside and outside protected areas.

The difference observed for the Sahel between species richness in communal and protected areas might be explained by the fact that this protected area was realized by fencing. Compared to the Sudanian zone of Burkina Faso, in the Sahel zone, the protected area (the Sylvopatoral Reserve and Partial Fauna Reserve of Sahel) was most affected by human pressure. To reduce the impact of human pressure in this protected area in Sahel zone the work was done in fenced area. Consequently, these protection issues probably might explain the observed difference in species richness between protected and communal areas.

The dominance of families of Poaceae, Fabaceae, Cyperaceae, and Malvaceae in all study areas reflects that these families are the most frequent in Savanna herbaceous vegetation in West Africa [1, 45, 47]. The Poaceae family is well represented, as grasses are the largest family of vascular plants in Savannas [45, 48–50].

4.2. Effect of Climate and Land Use on Herbaceous Vegetation Diversity and Composition. Hill's diversity numbers reveal that herbaceous vegetation was more diverse in the Sudanian zone than the Sahelian zone. The significant difference of mean species and abundant species numbers along the climate gradient shows that precipitation increase favors an increase of herbaceous species richness in Savanna ecosystem. The low values found for very abundant species show that the different climate and land use conditions were dominated by a group of species and the relative high evenness value underlines that dominant species have a regular distribution of their individuals [1, 24, 51, 52]. In fact, species diversity is often dominated by species evenness patterns [51].

The similarity in herbaceous species composition and abundance between climate and land use conditions is low. The low similarity in herbaceous species composition and abundance between climate-land use conditions reflects differences in climate conditions and land use regimes. In addition, the low to moderate level of similarity between climate and land use combinations indicates high beta-diversity and accentuates the importance of climate and land use in explaining herbaceous species diversity at larger spatial scale.

The difference in herbaceous vegetation composition is related to the dual effect of climate and land use conditions. Climate conditions explain the difference in species composition between different climate zones [21, 27]. Land use causes differences in species composition within a climate zone. Indeed, human disturbances influence composition and distribution of plant species [5]. Patterns of species richness and cover are determined by multiple environmental factors (climate change and human activities) [53]. Generally, local species richness and diversity of Savanna ecosystems are maintained by dynamic interactions between local colonization from species pools at larger spatial scales and local extinction due to competitive exclusion [11]. Thus the herbaceous vegetation of West African Savannas is dominated by a pool of species which vary according to the climatic

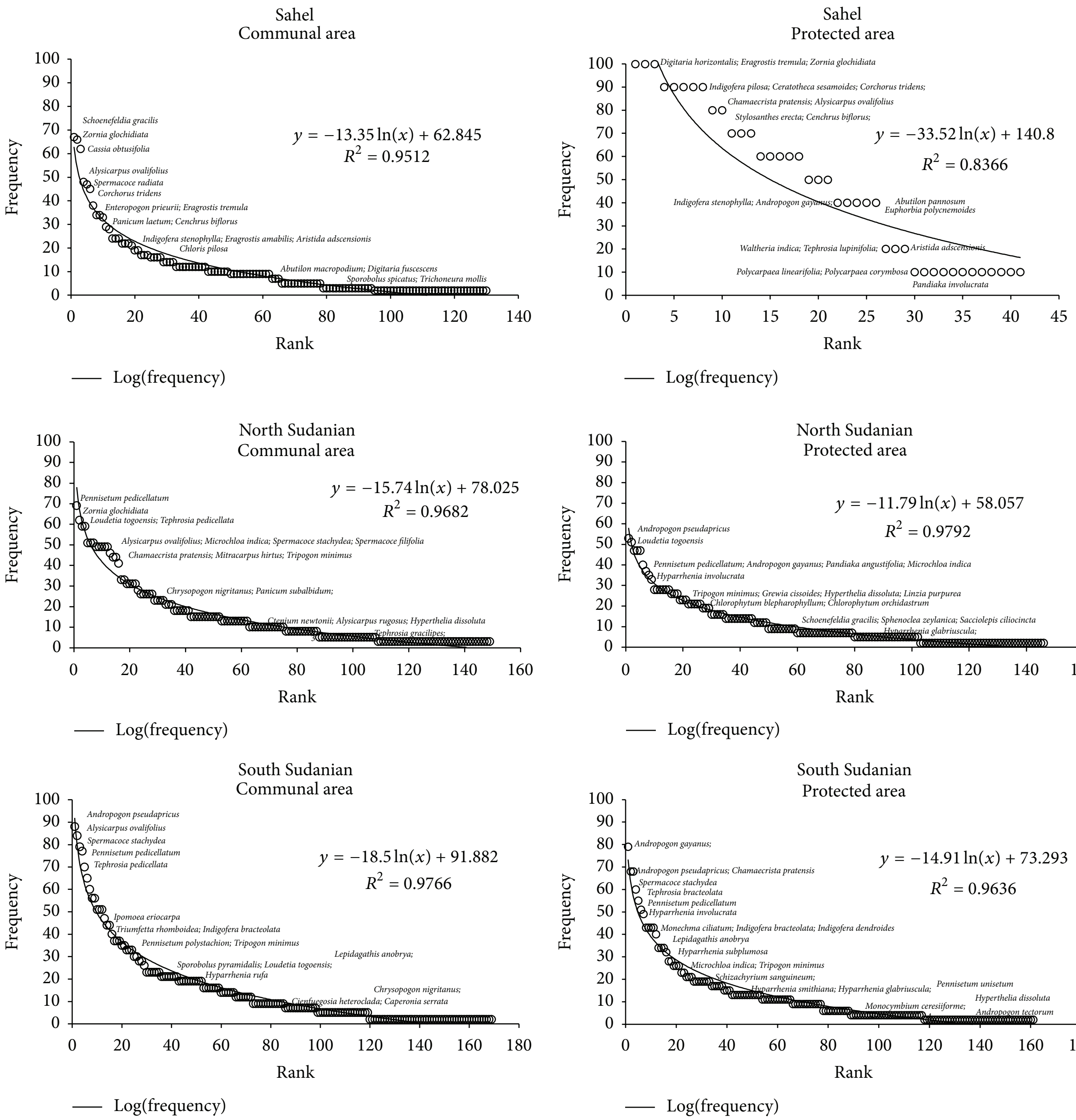

Figure 4: Rank-frequency diagram.

zones and land use conditions. In the Sahel, *Schoenefeldia gracilis*, *Zornia glochidiata, Panicum laetum*, *and Cassia obtusifolia* (communal area) and *Digitaria horizontalis* and *Zornia glochidiata* (protected area) are the most dominant herbaceous species. According to Kadeba et al. [52], in the Sahel, *Schoenefeldia gracilis* is a dominant species of glacis and *Cassia obtusifolia* and *Panicum laetum* are dominant species in lowlands and *Digitaria horizontalis* and *Zornia glochidiata* on sand hills. The predominance of grass species such as *Microchloa indica*, *Loudetia togoensis*, *Pennisetum pedicellatum*, *Tripogon minimus*, and *Andropogon pseudapricus* in the communal areas of the Sudanian zone could be explained by grazing pressure which favors installation of annual or small size herbaceous species [50]. Protection allows establishment and occurrence of taller robust species such as *Hyparrhenia involucrata*, *Andropogon gayanus*, *Andropogon pseudapricus*, and *Hyparrhenia subplumosa*.

4.3. Effect of Climate and Land Use on Savanna Herbaceous Species Frequency of Distribution. The frequency of herbaceous species is more influenced by the interaction between climatic conditions and land use regimes than their separate effects. In fact, the distribution of herbaceous species is principally affected by climate, which determines geographical affinity [27], and land use, which affects the spatial heterogeneity of vegetation and influences ecosystem processes [1, 54]. This results in the fact that a species which is the most frequent under a given climate and land use condition becomes rare under other climate and land use conditions.

Overall, most of the listed species are classified as occasional or rare. The low percentage of frequent species and the high rate of occasional and rare species implies on the one hand a great heterogeneity among herbaceous plant communities of each climate and land use condition and on the other hand the vulnerability of these rare herbaceous species. These results are in concordance with the studies of Sambaré [42] who revealed that in Savanna plant communities the percentage of rare and occasional species is high. Indeed, the presence of several types of habitats (dry, bowal, fresh, and wet) within the different climate and land use conditions could favor the maintenance of distinct herbaceous vegetation communities. Some species could be exacting and therefore remain confined to particular environmental conditions. This is the case of *Trichoneura mollis*, *Sporobolus spicatus*, *Abutilon macropodium*, and *Digitaria fuscescens*, which are rare species only found in the communal Sahelian area. These species have not been found up to now in Burkina Faso; their presence is certainly linked to the transhumant pastoralism grazing. Indeed, their occurrence has been reported in Niger and other Sahelian countries [55]. *Linzia purpurea*, *Pennisetum unisetum*, *Andropogon tectorum*, and *Monocymbium ceresiiforme* are rare species encountered exclusively in protected areas of the Sudanian zone [56]. In fact, *Pennisetum unisetum* is a perennial grass species consumed during food storage period and it develops on alluvial soils. *Monocymbium ceresiiforme* (perennial grass) found on poor acid soils with fine gravel has magic and religious use for hunting protection and against evil spell. *Andropogon tectorum* (perennial grass) prefers ferruginous fresh soils under shade of woodland Savannas or riparian forests [55]. *Linzia purpurea* is forb which develops in woodland Savanna on detritus [56]. The specificity of these species for particular soils conditions makes them rare. Their absence in communal areas is certainly due to habitats destruction in these areas.

5. Conclusion

This study shows that specific richness of herbaceous vegetation increases significantly with precipitation, and is, thus, mainly determined by climate, whereas the effect of land use is less important. Herbaceous vegetation diversity described by mean richness and the numbers of abundant species reveals that the Sudanian zone and the communal areas were, respectively, more diverse than the Sahelian zone and the protected areas. The number of very important species demonstrated that only few species are dominant and the evenness pattern showed that these dominant herbaceous species exhibit a regular distribution of their individuals within herbaceous communities. The composition of Savanna herbaceous species is dependent on climate and land use conditions. Land use affects more the composition of herbaceous vegetation than its richness. The occurrence of herbaceous species in Savanna ecosystem is more controlled by the interaction between climate and land use than by their separate effects. Occasional and rare species constitute the most important part of Savanna herbaceous vegetation diversity, characteristic of heterogeneity of ecosystems and vulnerability of herbaceous species.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

The authors thank the DFG (German Research Foundation, BE 4143/2-1, and HA 6789/1-1) and the Ministry of Secondary and Higher Education of Burkina Faso for financial support.

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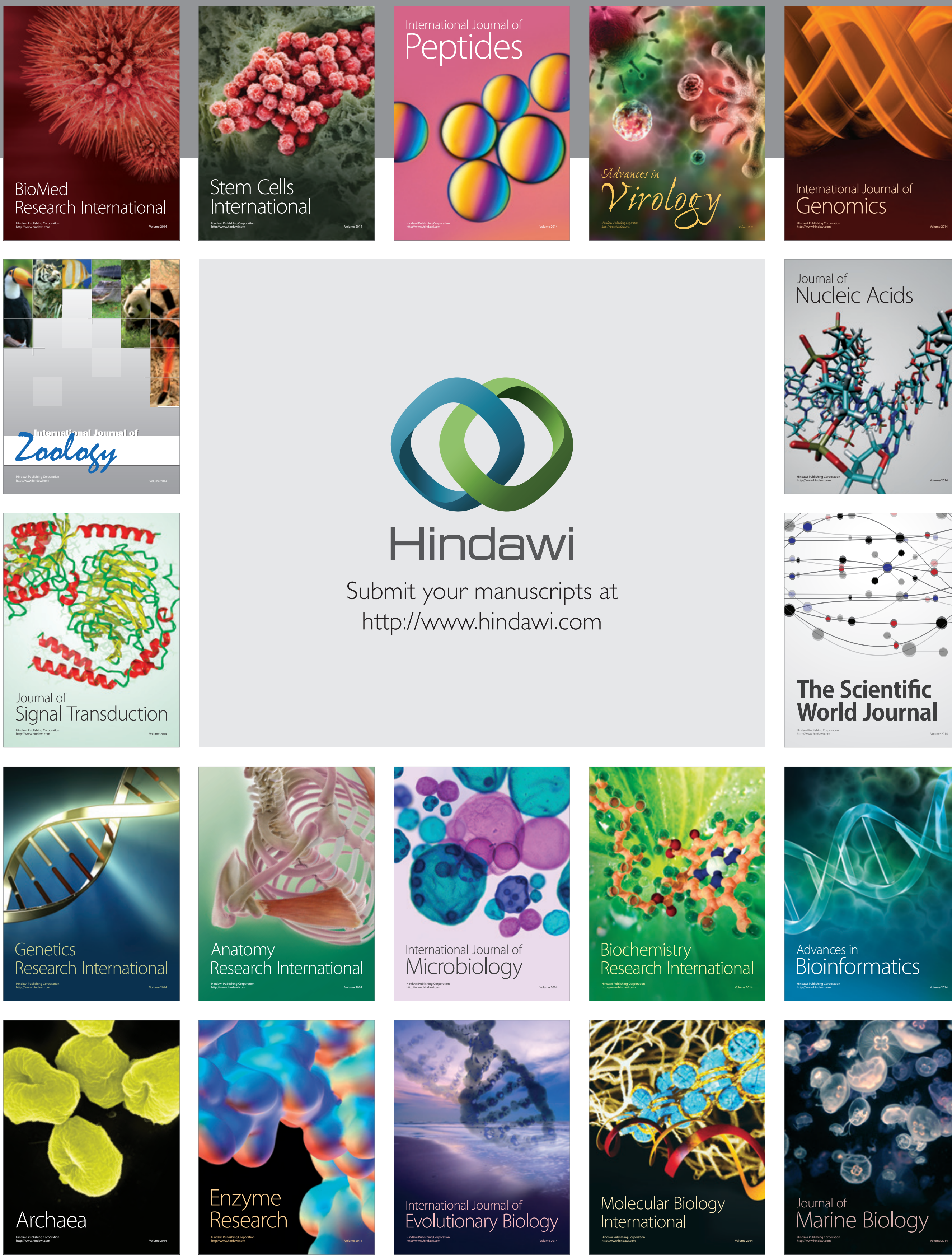
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