Woody species composition, structure and diversity of vegetation patches of a Sudanian savanna in Burkina Faso

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In order to develop conservation guidelines, information on the state of Sudanian forests is urgently needed. Inventories conducted in four types of forest–dense woodland, open woodland, gallery forests and fallow land–have shown in particular that the Fabaceae and Combretaceae families are the most abundant. Young individuals are predominant, and there are numerous rare species. Species with high conservation importance should be reintroduced in order to maintain a viable population.

Photo 1.
Dense woodland.
Photo D. Tiveau.

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RÉSUMÉ

COMPOSITION, STRUCTURE ET DIVERSITÉ DES ESPÈCES LIGNEUSES EN SAVANE SOUDANAISE AU BURKINA FASO

La variabilité climatique croissante et les impacts des activités humaines entraînent une forte dégradation des forêts de la région soudanienne. Afin de développer des orientations de conservation, il est urgent de disposer d'informations sur l'état actuel de ce type de végétation. Nous présentons ici la composition, la structure et la diversité des espèces ligneuses sur des parcelles de quatre types : forêt dense, forêt claire, forêt-galerie et jachère abandonnée. Toutes les espèces ligneuses ont été systématiquement identifiées et mesurées sur un échantillon de quinze parcelles de 0,25 ha. Les densités, dominances, fréquences et valeurs d'importance générique ont été calculées pour caractériser la composition spécifique. Plusieurs paramètres ont été calculés pour déterminer l'hétérogénéité de chaque parcelle. Au total, 89 espèces représentatives de 29 familles et 66 genres ont été enregistrées, avec un nombre décroissant en forêt dense et claire, en forêt-galerie et en jachère. Les familles les plus abondantes sont les fabacées et les combrétacées. La densité des tiges de diamètre (dhp) supérieur ou égal à 5 cm et la surface terrière sont les plus élevées en forêt-galerie. La courbe de répartition par classe de dimension est en forme de J inversé, indiquant une prédominance d'individus jeunes. Les indices de diversité montrent une diversité plus élevée en forêt dense et une similitude généralement faible entre parcelles. La distribution de l'abondance spécifique pour chaque parcelle est logarithmique, attestant d'un grand nombre d'espèces rares. Les espèces de grande importance pour la conservation doivent être réintroduites, afin de maintenir une population de taille viable.

Mots clés : biodiversité, conservation, forêt sèche, espèce menacée, zone boisée.

ABSTRACT

WOODY SPECIES COMPOSITION, STRUCTURE AND DIVERSITY OF VEGETATION PATCHES OF A SUDANIAN SAVANNA IN BURKINA FASO

The woodlands of the Sudanian region are heavily degraded due to increasing climatic variability and anthropogenic impacts, and only relatively small patches are left within the savanna area. In order to develop conservation guidelines, information on the current status of this vegetation type is urgently needed. We describe the species composition, structure and diversity of woody species in four patches of vegetation: dense woodland, open woodland, gallery forest and abandoned fallow. All woody species were systematically identified and measured in fifteen 0.25-ha sample plots. Density, dominance, frequency, and species and family importance values were computed to characterize the species composition. A variety of diversity measures were calculated to examine the heterogeneity of each patch. A total of 89 species representing 29 families and 66 genera were found; of which 67, 60, 35 and 23 species were recorded in the dense woodland, open woodland, fallow, and gallery forest, respectively. Fabaceae and Combretaceae were the most abundant families. The density of stems ≥ 5 cm dbh and the basal area were higher in the gallery forest than in the other patches. The size class distributions of the vegetation produced a reverse J-shaped curve, indicating that the forest is dominated by young individuals. Diversity indices showed that dense woodland was the most diverse, and similarity between patches was generally low. The species abundance patterns for each patch displayed the log series distribution, indicating large numbers of rare species. We identified species with high conservation importance that should be reintroduced to maintain a viable population size.

Keywords: biodiversity, conservation, dry forest, threatened species, woodland.

RESUMEN

COMPOSICIÓN, ESTRUCTURA Y DIVERSIDAD DE LAS ESPECIES LEÑOSAS DE LA SABANA SUDANESA EN BURKINA FASO

La creciente variabilidad climática y el impacto antrópico provocan una fuerte degradación de los bosques de la región sudanesa. Para desarrollar orientaciones de conservación, es urgente contar con informaciones sobre el estado actual de este tipo de vegetación. Presentamos aquí la composición, estructura y diversidad de las especies leñosas en cuatro tipos de parcela: bosque espeso, bosque abierto, bosque de galería y barbecho abandonado. Todas las especies leñosas fueron sistemáticamente identificadas y medidas en una muestra de quince parcelas de 0,25 ha. Se calcularon densidades, dominancias, frecuencias y valores de importancia de género para caracterizar la composición específica. Se calcularon varias medidas para determinar la heterogeneidad de cada parcela. Se registraron un total de 89 especies representativas de 29 familias y 66 géneros, con un número decreciente en bosque espeso y abierto, en bosque de galería y en los barbechos. Las familias más abundantes son las fabáceas y combretáceas. La densidad de tallos de un diámetro ≥ a 5 cm y el área basimétrica son más altas en los bosques de galería. La curva de distribución por clase de dimensión tiene una forma de J invertida, lo que indica un predominio de individuos jóvenes. Los índices de diversidad muestran una diversidad más alta en bosque espeso y una similitud generalmente baja entre parcelas. La distribución de la abundancia específica en cada parcela es logarítmica, indicador de un gran número de especies raras. Las especies de gran importancia para la conservación deben reintroducirse para mantener una población con un tamaño viable.

Palabras clave: biodiversidad, conservación, bosque seco, especie en peligro, zona forestal.

Introduction

African dry forests and woodlands vegetation types are characterized by more or less continuous tree cover (70%), prolonged drought lasting more than three months per year, and by their occurrence within the savanna biome (Menaut *et al.*, 1995). They cover approximately 13 million km^2, 43% of the total area of the continent, and are divided into two distinct regions, in the northern hemisphere (Sudanian region) and the southern hemisphere (Zambezian region). The Sudanian region lies between 6° and 13° N and covers an area of 5.25 million km^2 (Menaut *et al.*, 1995). The dry forests and woodlands of the Sudanian region are tending to disappear due to increasingly severe climate conditions and anthropogenic impacts, leaving only relatively small patches within the savanna area (Menaut *et al.,* 1995).

Vegetation patterns, dynamic processes and species diversity in the Sudanian savannas are often attributed to environmental heterogeneity (Menaut *et al.*, 1995; Bellefontaine *et al.*, 2000). For example, large termite mounds have an important effect on community structure, both in terms of spatial tree distribution, density and diversity (Konaté *et al.*, 1998). The relationship between vegetation changes and edaphic variations has also been noted. Savannas with a high density of trees and shrubs are confined to areas dominated by ferruginous soils while savannas of low tree and shrub density are confined to areas with brown loam soils (Menaut *et al.*, 1995). Grazing and browsing by large herbivores also modify the composition, structure and diversity of savanna vegetation (Richardson-Kageler, 2003). Fire, which is a common event in the savanna, is another factor that modifies savanna vegetation, depending on its severity, time and frequency of occurrence (Menaut *et al.*, 1995; Sawadogo *et al.*, 2002). Fire, grazing, browsing and selective tree cutting are the most important anthropogenic disturbances in the savanna that determine vegetation patterns (Scholes, Walker, 1993; Menaut *et al.,* 1995). Local species richness and diversity of savanna ecosystems are generally maintained by dynamic interaction between local colonization processes from species pools at larger spatial scales and local extinction due to competitive exclusion processes, which in turn are influenced by disturbances.

Degradation of savanna woodlands due to agricultural expansion, overgrazing, fire and wood cutting is a serious environmental concern in Burkina Faso, as in many tropical countries (Fries, Heermans, 1992). Natural forests in the country currently cover approximately 7 million ha and forest plantations cover 67 000 ha, representing 26% of the country's land area (274 200 km^2). The remaining woodlands and dry forests are preserved in State forest reserves established for wood production and biodiversity conservation (Bellefontaine *et al.*, 2000). The Tiogo forest, where the present study was conducted, is one of these State forest reserves in Burkina Faso. It was delimited by the French colonial administration in 1940, and covers 30 000 ha. Phytogeographically, it is situated in the Sudanian regional centre of endemism in the transition from the northern to the southern Sudanian zone (White, 1983; Fontes, Guinko, 1995). The Tiogo forest is not strictly protected against human impacts and is being utilized both legally and illegally by local people living around the reserve. The impact of such exploitation on biological diversity in Tiogo forest is not well documented.

This study is contributing to an on-going study aiming to develop models for sustainable management of savanna woodlands in Burkina Faso (Sawadogo *et al.*, 2005). We describe the species composition,

Photo 2.
Open woodland.
Photo D. Tiveau.

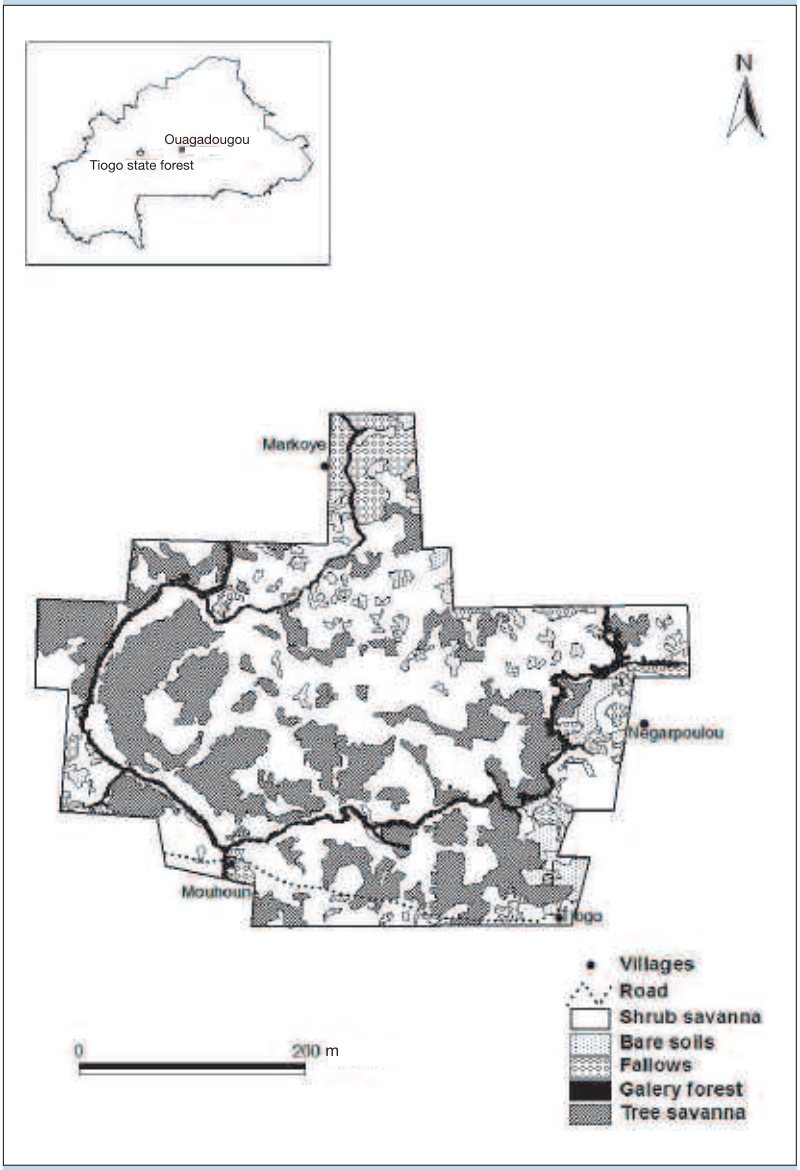

Figure 1.
Vegetation map of Tiogo State forest in the Sudanian savanna of Burkina Faso.
Source: RPTES Project and 7 ACP BK/031 Project.

structure and diversity of woody species in a Sudanian savanna (Tiogo State forest reserve) in relation to patches of different vegetation types: dense woodland, open woodland, gallery forest and abandoned fallow. It is generally believed that habitat heterogeneity (patchiness) increases tree diversity in dry forests, woodlands and savanna (Menaut *et al.*, 1995). Describing the vegetation will help to identify species of high conservation importance in the Sudanian savanna. Despite the great interest in red-list species and considerable efforts to compile information on their distribution and biology (Anonymous, 1999; Iucn, 2004), data on their presence and abundance in savanna woodland are still limited. An assessment of species composition and diversity also provides information to develop guidelines for conservation priorities.

Materials and methods

Study area

The study was conducted in Tiogo State forest, located at 12° 13' N and 2° 42' W at an altitude of 300 m above sea level in Burkina Faso, West Africa. It is located along the only permanent river (the Mouhoun, formerly known as the Black Volta) in the country. The area receives unimodal rainfall lasting for 6 months, from May to October. The mean (± SD) annual rainfall for 1992-2002 was 827 ± 198 mm. The mean daily minimum and maximum temperatures were 16°C and 32°C in January (the coldest month) and 26°C and 40°C in April (the hottest month).

The most frequently encountered soil type is Lixisol, which is mainly deep (› 75 cm) silty clay. These soils are representative of large tracts of the Sudanian zone in Burkina Faso (Pallo, 1998). The vegetation is classified as tree/bush savanna with the understory dominated by annual grasses, *Andropogon pseudapricus* Stapf. and *Loudetia togoensis* (Pilger) C.E. Hubbard and perennial grasses such as *Andropogon gayanus* Kunth. and *Andropogon ascinodis* C. B. Cl. Bush fires occur almost every year throughout the dry season (November to May). Grazing by cattle, sheep and goats is a common phenomenon, which varies spatially and temporally. Livestock is omnipresent in Tiogo forest, mainly during the rainy season (June to October) when the grass is green and the surrounding areas are under cultivation. The livestock carrying capacity of Tiogo forest was 1.4 Tropical Livestock Unit per hectare (Sawadogo, 1996). These patches also support insects, birds, reptiles and mammals, which contribute to important forest ecological functions (pollination and seed dispersal).

Sampling and data analysis

With the aid of aerial photos and criteria defined by Fontès and Guinko (1995), four vegetation patches within the Tiogo forest were identified: dense woodland, open woodland, gallery forest and abandoned fallow (figure 1). The dense woodland (also referred to as dry forest) is characterized by a closed tree canopy with several woody strata, and a scarce and discontinuous grass layer subject to sporadic and sparse fire (photograph 1). The open woodland has an upper stratum of deciduous trees of small to medium size, with their crowns more or less touching above a sparse woody stratum (photograph 2). The ground layer consists of grasses, herbs and suffrutescent plants in sufficient density to allow sufficient annual burning. Gallery forest, defined as narrow patches along the fringes of semi-permanent water courses (Lamprecht, 1989), occurs along the floodplains of the Mouhoun river, and the tree species are mainly evergreen (photograph 3). The fallows are agricultural lands abandoned 15 to 20 years ago, with signs of human-induced disturbances such as felled tree trunks or visible stumps (photograph 4).

The inventory was carried out at the end of the rainy season (September 2002) when species can be easily identified and plots are easily accessible. A total of 15 sample plots of 50 x 50 m were marked in representative areas of the different vegetation patches: five in dense woodland, four in open woodland and three each in gallery forest and fallow, in proportion to their coverage. Each sample plot was further divided into four subplots of 25 x 25 m. Each subplot was then systematically surveyed, and all woody species were marked and identified. The following variables were also recorded: number of stems, height of the largest stem using a graduated pole or clinometer for the tallest trees, and circumference at 0.2 m and at breast height, using a measuring tape. All trees or shrubs encountered were identified to species level and nomenclature follows Arbonnier (2000).

The species composition of the plots was described by the following parameters.

- Relative dominance = (total basal area for a species/total basal area of all species) x 100.
- Relative density = (number of individuals of a species/total number of individuals) x 100.
- Relative frequency = (frequency of a species/sum of all frequencies) x 100.
- Relative diversity = (number of a species in a family/total number of species) x 100.
- The importance value index (IVI) = relative dominance + relative density + relative frequency.
- The family importance value (FIV) = relative dominance + relative density + relative diversity.

The frequency of a species is defined as the number of subplots (25 x 25 m) in which the species occurs. The theoretical range for relative dominance, relative frequency, relative density and relative diversity is 0 – 100%, so that IVI of species and FIV may vary between 0 and 300%. Structural characteristics (stem density, basal area, and diameter and height class distributions) were computed for each plot and averaged per vegetation unit for all individuals with a dbh ≥ 5 cm.

To compare diversity within each vegetation patch precisely, we calculated Margalef's index, Simpson's index, Shannon's measure of evenness, Shannon-Wiener's information index and Fisher's diversity index. These indices are widely employed to measure biological diversity (Magurran, 2004). To evaluate β-diversity (similarity between vegetation patches), Jaccard's similarity index and Horns' modification of Morisita's index were computed. Jaccard's coefficient of similarity was calculated based on presence/absence data of the species while Horn's modification of Morisita's index takes into account species abundance. Both indices potentially vary between 0 and 1, and a value close to 1 indicates greater similarity between patches, and hence low β-diversity (Magurran, 2004). Species abundance patterns (also known as Whittaker plot) were plotted for each vegetation unit.

Table I.
Summary of species composition and structural characteristics of trees ≥ 5 cm dbh for each vegetation patch in a Sudanian savanna of Burkina Faso (mean ± SE).

Vegetation patch	Samples plots (number)	Stem density per hectare	Families (number)	Genera (number)	Species (number)	Average dbh (cm)	Basal area (m^2 ha^{-1})
Gallery forest	3	380 (± 18)	5	5	8	15.0 (± 3.84)	19.5 (± 0.03)
Dense woodland	5	367 (± 10)	18	33	44	11.2 (± 2.87)	11.1 (± 0.14)
Open woodland	4	307 (± 6)	14	23	31	10.2 (± 2.68)	7.3 (± 0.18)
Fallows	3	305 (± 5)	10	15	21	9.5 (± 2.80)	5.8 (± 0.06)

Photo 3.
Gallery forest along the Mouhoun River.
Photo D. Tiveau.

Results

Species composition

A total of 89 species representing 66 genera and 29 families were found in Tiogo forest, of which 67, 60, 35 and 23 species were encountered in dense woodland, open woodland, fallow and gallery forest respectively (appendix). For individuals ≥ 5 cm dbh, the number of species was lower in the gallery forest than in the other patches (table I). The species with the highest importance value in the gallery forest were *Mitragyna inermis, Vitex chrysocarpa, Acacia seyal, Pterocarpus santalinoides* and *Acacia polyacantha*, which together accounted for 94% of the total importance value (table II). *Detarium microcarpum* and *Combretum glutinosum* were among the most abundant species in the dense woodland while *Acacia dudgeoni* and *Combretum nigricans* in the open woodland, and *Piliostigma thonningii* and *Piliostigma reticulatum* in the fallows (table II). *Acacia erythrocalyx, Albizia chevalieri, Boswellia dalzielii,* and *Combretum nigricans* stood out as the rarest species in the gallery forest, dense woodland, open woodland and fallow, respectively. A list of other rare species in each vegetation patch is given in table III.

Fabaceae subfamilies Caesalpinioideae and Mimosoideae were taxonomically diverse and made up the largest groups of taxa in the gallery forest (table IV), although Rubiaceae had the highest FIV owing to the high stem density of its constituent species *Mitragyna inermis* (264 individuals/ha). In the tree and open woodland, Fabaceae-Caesalpinioideae and Combretaceae were the most species-rich families and accounted for 49% and 52% of the total family importance value. In the fallow, Combretaceae was the most species-rich family (5 species) followed by Anacardiaceae (4 species), which had the highest family importance value (76.20%).

Structure

A total of 24 008 individuals were recorded in all vegetation patches, of which 94% were individuals with dbh < 5 cm (considered here as an understory). Excluding the understory, stem density was the highest in the gallery forest, followed by the dense woodland, while the lowest stem density was recorded in the fallow (table I). The average diameter of all individuals ≥ 5 cm dbh and the corresponding total basal area were highest in the gallery forest compared with other vegetation patches. The fallows had the lowest diameter and total basal area (table I).

Table II.
The five most abundant species in each vegetation patch according to decreasing order of the importance value index (IVI).

Forest type	Species	Relative dominance (%)	Relative density (%)	Relative frequency (%)	IVI (%)
Gallery forest	*Mitragyna inermis*	87.13	69.47	57.89	214.50
	Vitex chrysocarpa	3.80	21.75	5.26	30.82
	Acacia seyal	2.85	1.40	10.53	14.78
	Pterocarpus santalinoides	4.79	4.56	5.26	14.61
	Acacia polyacantha	0.79	0.70	5.26	6.75
	Total	99.35	97.89	84.21	281.46
	Remains	0.65	2.11	15.79	18.54
Dense woodland	*Detarium microcarpum*	11.03	19.31	7.06	37.40
	Combretum glutinosum	6.20	13.88	7.65	27.73
	Terminalia avicennioides	12.08	6.29	7.06	25.43
	Lannea acida	8.63	5.64	5.29	19.56
	Tamarindus indica	10.27	4.12	3.53	17.92
	Total	48.21	49.24	30.59	128.04
	Remains	51.79	50.76	69.41	171.96
Open woodland	*Acacia dudgeoni*	11.82	19.28	6.93	38.04
	Combretum nigricans	10.01	12.40	6.93	29.34
	Detarium microcarpum	8.25	12.67	6.93	27.85
	Vitellaria paradoxa	8.54	6.89	4.95	20.38
	Combretum glutinosum	4.79	6.61	7.92	19.32
	Total	43.41	57.85	33.66	134.92
	Remains	56.59	42.15	66.34	165.08
Fallows	*Piliostigma thonningii*	16.05	45.41	11.11	72.58
	Piliostigma reticulatum	6.73	20.96	13.33	41.03
	Vitellaria paradoxa	27.46	2.18	6.67	36.31
	Lannea microcarpa	21.51	6.11	6.67	34.29
	Pseudocedrela Kotschyi	8.15	5.68	6.67	20.49
	Total	79.90	80.35	44.44	204.70
	Remains	20.10	19.65	55.56	95.30

The diameter class distribution of trees in all vegetation patches produced a reverse "J" shaped curve (figure 2). Most individuals, 80% in the fallows, 47.4% in the gallery forest, 70.8% in the open woodland and 65.7% in the dense woodland, were in the 5 – 10 cm dbh class. Four individuals each of *Mitragyna inermis* and *Acacia seyal* in the gallery forest, two individuals of *Tamarindus indica* and one individual of *Sclerocarya birrea* in the dense woodland and one individual of *Anogeissus leiocarpus* in the open woodland reached › 50 cm dbh. In the fallow *Vitellaria paradoxa* was remarkable among the largest dbh class.

The height class distribution of trees produced a negative exponential curve for the fallows, dense woodland and open woodland while the distribution was a skewed bell shaped curve for the gallery forest (figure 3). As a whole, the height of trees ≥ 5 cm dbh ranged from 1.5 to 18.5 m. The tallest emergent tree was a *Pterocarpus erinaceus* (18.5 m, 49 cm dbh) in the open woodland, followed by two *Mitragyna inermis* individuals (16 m tall each, 48 cm and 29 cm dbh) in the gallery forest and one *Anogeissus leiocarpus* specimen (15.5 m and 46 cm dbh) in the dense woodland.

Table III.
The rarest species in each vegetation patch of a Sudanian Savanna of Burkina Faso according to increasing order of the importance value index (IVI).

Forest type	Species	Relative dominance (%)	Relative density (%)	Relative frequency (%)	IVI (%)
Gallery forest	*Acacia erythrocalyx*	0.02	0.35	5.26	5.64
	Piliostigma thonningii	0.13	1.05	5.26	6.45
	Piliostigma reticulatum	0.49	0.70	5.26	6.45
Dense woodland	*Albizia chevalieri*	0.03	0.22	0.59	0.83
	Feretia apodanthera	0.03	0.22	0.59	0.84
	Grewia mollis	0.04	0.22	0.59	0.85
	Gardenia sokotensis	0.06	0.22	0.59	0.86
	Boswellia dalzielii	0.10	0.22	0.59	0.90
	Pteleopsis suberosa	0.16	0.22	0.59	0.96
	Opilia celtidifolia	0.21	0.22	0.59	1.01
Open woodland	*Boswellia dalzielli*	0.08	0.28	0.99	1.34
	Piliostigma reticulatum	0.10	0.28	0.99	1.36
	Bombax costatum	0.11	0.28	0.99	1.38
	Lonchocarpus laxiflorus	0.15	0.28	0.99	1.41
	Tamarindus indica	0.66	0.55	0.99	2.20
	Strychnos spinosa	0.15	0.55	1.98	2.68
	Combretum ghasalense	0.22	0.55	1.98	2.75
Fallows	*Combretum nigricans*	0.06	0.44	2.22	2.72
	Combretum ghasalense	0.13	0.44	2.22	2.79
	Stereopermum kunthianum	0.19	0.44	2.22	2.85
	Terminalia laxiflora	0.24	0.44	2.22	2.90
	Acacia seyal	0.26	0.44	2.22	2.92
	Detarium microcarpum	0.29	0.44	2.22	2.95

Species diversity

To allow a precise comparison of alpha diversity among vegetation patches, a variety of diversity measures was computed (table V). The total number of individuals (N) as well as the number of species (S) was highest in the tree and open woodland while the gallery forest was the lowest in species richness, although the total number of individuals was relatively higher than in the fallow. In terms of numerical species richness, defined as the number of species per specified number of individuals (S/N), the open woodland and the fallows had the same value (0.09), closely followed by the dense woodland. The gallery forest was the poorest with S/N ratio equal to 0.03. According to Margalef's index of species richness, representing an intermediate mathematical measure between S/N and S, the dense woodland was the most diverse, followed by open woodland, fallows and finally gallery forest. Shannon's measure of evenness did not differ much between the dense woodland and the open woodland, where it was relatively higher than in the fallow and gallery forest. Shannon-Wiener's information index, which combines species richness and evenness into a single value, indicated that the dense woodland was the most diverse (4.34), closely followed by the open woodland (3.89), while the gallery forest was the least diverse (1.33). The reciprocal of Simpson's concentration index ($1/\lambda$), which specifies the inverse of the probability that any two individuals drawn randomly from an infinitely large community belonging to different species would be identical, showed the dense woodland as the most diverse and the gallery forest as the least diverse. Fisher's diversity index, the most stringent and widely recommended measure of diversity, also identified the dense woodland as the most diverse and the gallery forest as the

least diverse. As a whole, most diversity measures showed that the level of diversity decreased in the following order: dense woodland › open woodland › fallow › gallery forest.

When comparing species similarity between vegetation patches, the species composition of the plots in the open woodland and the dense woodland were more similar to each other than the others, as shown by Jaccard's index (table VI). The gallery forest had the least similarity with any of the other vegetation patches. Based on presence-absence data, similarity as high as 35% - 37% was observed between the fallow and open/dense woodlands. When incorporating stem abundance into the estimation of similarity (Morisita's index), the similarity between the fallow and the open/dense woodlands decreased to 19% - 23%, while the similarity between the gallery forest and other patches was still very low. As a whole, the patches were less similar in species composition and abundance, hence high beta diversity.

Species with high conservation priority

Based on the 2004 IUCN Red List of Threatened Species (IUCN, 2004) and conservation status at the national level, we identified species that are of high conservation importance. A total of 28 species were short-listed as endangered and vulnerable in the region (table VII). The abundance of these species in our plots was very low, and nearly half of them were not encountered in our sampling plots. Although categorized as vulnerable species, *Detarium microcarpum,* and *Tamarindus indica* had the highest importance values in the dense and open woodlands, and *Vitellaria paradoxa* in the open woodland and the fallow (table II).

Table IV.
The four most important families (sub-families) in each vegetation patch according toin decreasing order of family importance value (FIV).

	Family/subfamily	Genus	Species	N/ha	FIV
Gallery forest	Rubiaceae	1	1	264	169.11
	Mimosoideae	1	3	9	43.61
	Verbenacea	1	1	83	38.05
	Caesalpinioideae	1	2	7	27.38
Dense woodland	Caesalpinioideae	5	7	93	72.93
	Combretaceae	5	8	85	70.41
	Mimosoideae	3	7	38	34.92
	Anacardiaceae	2	4	23	28.85
Open woodland	Combretaceae	3	6	123	83.30
	Caesalpinioideae	4	5	78	52.03
	Mimosoideae	3	4	78	49.71
	Anacardiaceae	1	3	12	25.84
Fallows	Anacardiaceae	2	4	32	76.20
	Caesalpinioideae	2	3	1	64.03
	Combretaceae	2	5	5	42.23
	Sapotaceae	1	1	7	38.90

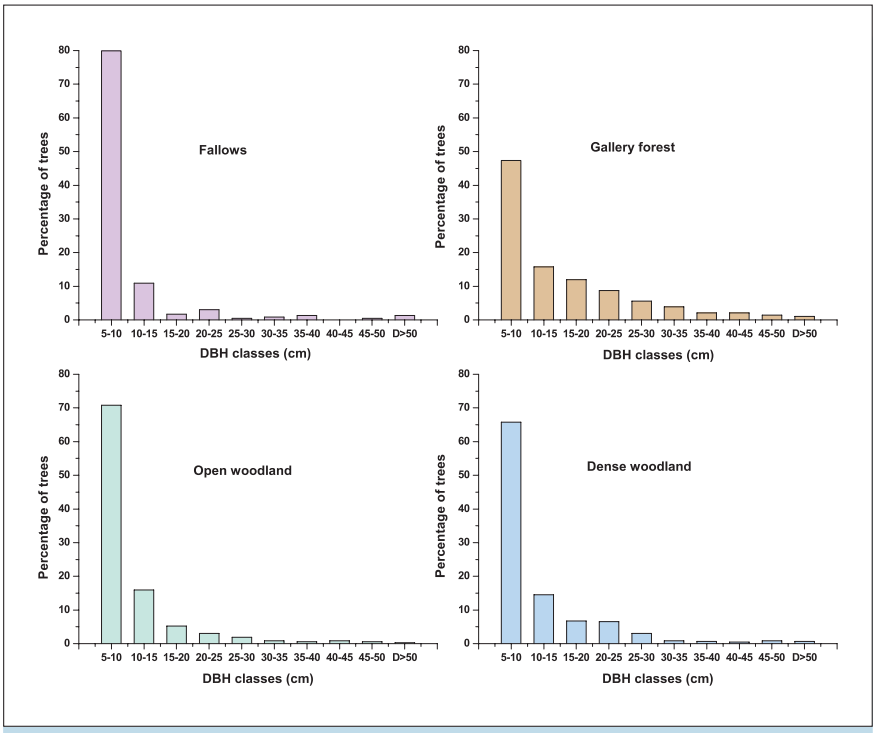

Figure 2.
Diameter class distribution of individuals ≥ 5 cm dbh in four vegetation patches of the Sudanian savanna in Burkina Faso.

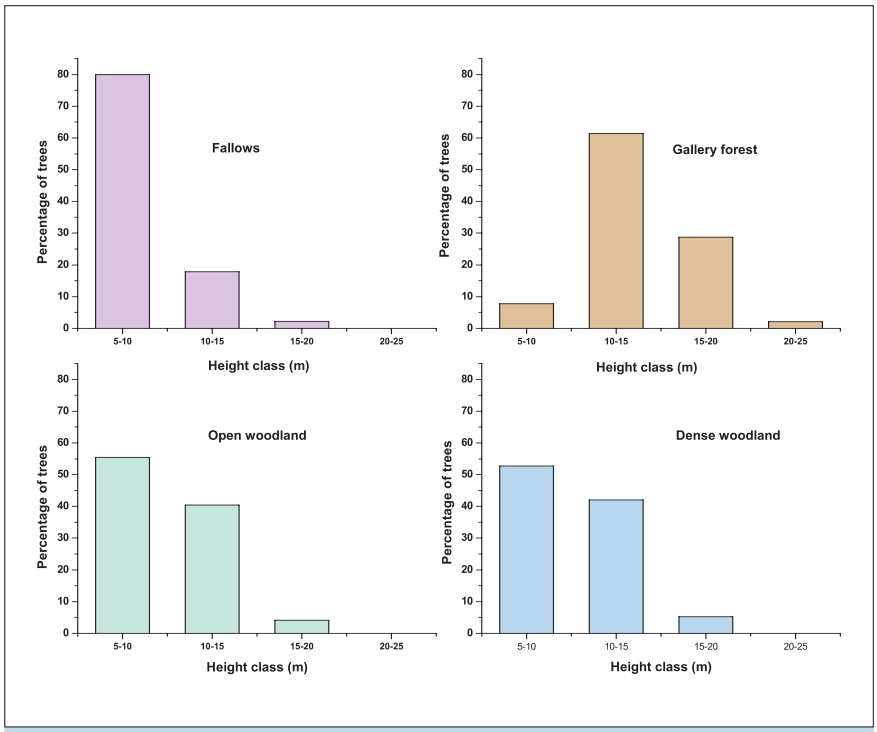

Figure 3.
Height class distribution of individuals ≥ 5 cm dbh in four vegetation patches of the Sudanian savanna in Burkina Faso.

Discussion

The numbers of families, genera and species reported in the present study account for nearly one third of the native woody species found in the country. LEBRUN (1991) reported that the woody flora (trees, small shrubs and climbers) at the country level includes 55 families, 214 genera and 376 species (with 96 exotic species). This relatively high species richness could be attributed to habitat heterogeneity (patchiness), which has been found to increase the tree diversity of woodlands and savannas in Africa (MENAUT *et al.*, 1995). The most common families were Fabaceae/Caesalpinioideae and Combretaceae in dense and open woodland and fallows while Caesalpinioideae and Mimosoideae were most abundant in the gallery forest, a pattern common in most savanna-woodland mosaics in Africa and typical of the northern Sudanian Zone in Burkina Faso (FONTES, GUINKO, 1995; SAWADOGO, 1996). The difference in species composition among patches might be due to micro-site factors. Generally, the growth of trees in semi-arid savanna ecosystems is determined by moisture, soil characteristics, landscape position (SCHOLES, WALKER, 1993) and species-specific growth requirements. For instance, species such as *Mitragyna inermis* and *Cola laurifolia* were found abundantly in the gallery forest, indicating that these species could be well adapted to deep clay soil and better hydromorphic conditions. *Acacia seyal* prefers heavy clay soils (vertisol) whereas *Detarium microcarpum* and *Burkea africana* are most likely to be found on gravel soils. Some species, such as *Vitellaria paradoxa*, do not thrive well in occasionally flooded areas such as gallery forest (HALL *et al.*, 1996). Soil fauna also influences the spatial distribution of trees. For instance, *Tamarindus indica* and *Capparis sepiaria* are often encountered at and around termite mounds, which are common in the dense woodlands of West Africa (KONATÉ *et al.*, 1998).

Table V.
Diversity measures for trees ≥ 5 cm dbh in four vegetation patches of the Sudanian savanna, Burkina Faso.

Diversity measures	Gallery forest	Dense woodland	Open woodland	Fallow
Number of individuals recorded, N	285	461	363	229
Total number of species recorded, S	8	44	31	21
Rate of species increase per individual enumerated, S/N	0.03	0.10	0.09	0.09
Margalef's index of species richness, $D_{Mg} = (S-1)/\ln N$	1.24	7.01	5.09	3.68
Shannon's measure of evenness, $J' = H'/\ln S$	0.64	1.15	1.13	0.91
Shannon-Wiener index, $H' = -\sum p_i \log_2 p_i$	1.33	4.34	3.89	2.76
The reciprocal of Simpson's index, $1/\lambda = \sum n_i (n_i - 1)/ N_i (N_i - 1)$	1.88	12.79	10.66	3.87
Fisher index of diversity $\alpha = N(1-x)/x$ x is the log series parameter	1.53	11.97	8.11	5.63

With regard to stem density, a large number of individuals with dbh ‹ 5 m were found in all patches, indicating the high regeneration potential of trees. Most woody savanna species regenerate by coppicing and root suckering after disturbances such as fire and wood cutting (Sawadogo *et al.*, 2002). Species such as *Entada africana, Detarium microcarpum, Pteleopsis suberosa* regenerate profusely after such disturbances (Ky-Dembele *et al.*, 2007). However, the transition from seedling to sapling or higher size classes often takes a long time due to frequent fire and drought, which induce seedling shoot die-back (Ky-Dembele *et al.*, 2007). Seedling resprouting following disturbance has been observed in 52 woody species of the Sudanian zone in Burkina Faso (Ky-Dembele *et al.*, 2007). Overgrazing also influences biodiversity by favouring unpalatable species, and affects tree size (Moleele, Perkins, 1998). As the gallery forest is partially evergreen throughout the year and close to a water source, it is often frequented by livestock, which in turn reduces species richness by dry season browsing and trampling of young seedlings. This partly explains the low number of species with individuals ≥ 5 cm dbh in the gallery forest. The average diameter and total basal area of trees ≥ 5 cm dbh were the largest in the gallery forest, which could be related to better soil moisture conditions, as moisture is the major factor limiting growth in dry areas. This result agrees with findings from other tropical dry forest ecosystems (e.g. González-Rivas *et al.*, 2006). *Piliostigma reticulatum* and *Piliostigma thonningii*, usually found in fallows with sandy to clay soil, had large numbers of seedlings along the water course, supporting the hypothesis of endozoochorous (Razanamandranto *et al.*, 2004) or hydrochorous seed dispersal in savanna woodlands.

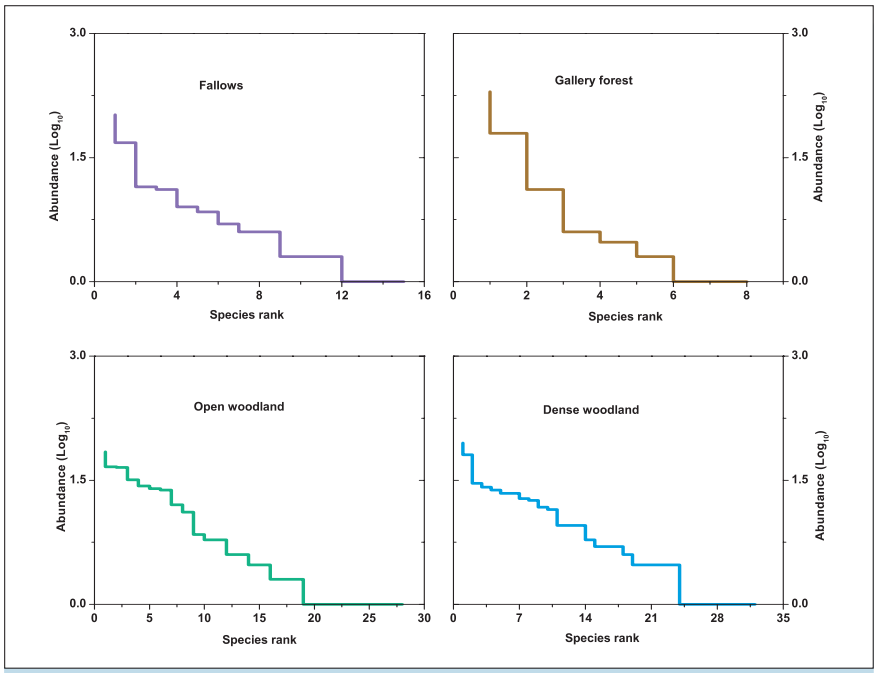

Figure 4.
Species abundance plots for individuals ≥ 5 cm dbh in four vegetation patches of the Sudanian savanna in Burkina Faso.

Table VI.
Similarity in species composition (individuals with ≥ 5 cm dbh) between vegetation patches in Sudanian Savanna.

Index		Dense woodland	Open woodland	Fallow
Jaccard´s	Gallery forest	0.106	0.054	0.115
	Dense woodland		0.563	0.354
	Open woodland			0.368
Morisita's	Gallery forest	0.002	0.003	0.000
	Dense woodland		0.590	0.189
	Open woodland			0.233

Most indices showed that dense/open woodlands are more diverse than gallery forest and fallows. According to Simpson's dominance index, the dense woodland and the open woodland samples were the most diverse in comparison with the fallows and gallery forest. This is most likely related to relatively large numbers of abundant species found in these patches. The Shannon-Wiener index is usually found to fall between 1.5 and 3.5 and is rarely above 5.0 (Magurran, 2004). The values found in this inventory fall within the expected range. Fisher's index showed that the dense woodland, the open woodland and the fallow, in decreasing order of magnitude, were more diverse than the gallery forest. This implies that the majority of the species in the gallery forest have irregular and clumped spatial distribution and are thus characterized by low alpha diversity.

Table VII.
Species listed in IUCN or national red list species data base together with their relative abundances in our sampling plots.

Species	Status	Relative abundance (%)
Afzelia africana	Endangered*	0.65
Khaya senegalensis	Endangered*	Nd
Dalbergia melanoxylon	Endangered*	Nd
Daniellia oliveri	Vulnerable	Nd
Diospyros mespiliformis	Vulnerable	0.55
Entada africana	Vulnerable	0.83
Fagara zanthoxyloides	Vulnerable	Nd
Nauclea latifolia	Vulnerable	Nd
Rauvolfia vomitoria	Vulnerable	Nd
Securidaca longepedunculata	Vulnerable	0.23
Trichilia roka	Vulnerable	Nd
Vitex doniana	Vulnerable	Nd
Ximenia americana	Vulnerable	2.48
Acacia erythrocalyx	Vulnerable	Nd
Annona senegalensis	Vulnerable	0.42
Gossypium anomalum	Vulnerable	Nd
Guibourtia copallifera	Vulnerable	Nd
Hibiscus gourmania	Vulnerable	Nd
Landolphia heudelotii	Vulnerable	Nd
Adansonia digitata	Vulnerable	1.48
Vitellaria paradoxa	Vulnerable	4.76
Detarium microcarpum	Vulnerable	10.8
Lannea microcarpa	Vulnerable	6.11
Sclerocarya birrea	Vulnerable	1.75
Saba senegalensis	Vulnerable	0.12
Spondias monbin	Vulnerable	Nd
Parkia biglobosa	Vulnerable	0.20
Tamarindus indica	Vulnerable	2.34

* 2004 IUCN Red List of Threatened Species;
Nd = species not encountered in our sample plots.

The similarity in species composition and abundance between the different vegetation patches was generally low, except the dense and open woodlands that had 56% and 59% similarity in species composition and abundance, respectively. Interestingly, species composition similarity between the fallows and the dense and open woodlands was as high as 37%, and abundance similarity as high as 23% . This agrees with the idea that abandoned fallows are important landscape elements for forest ecosystem restoration and serve as biodiversity refuges in fragmented landscapes (Lamb *et al.*, 1997). In addition, the low level of similarity between patches, and hence the high beta diversity, accentuates the importance of patches in maintaining high species diversity at larger spatial (landscape) scales in ecosystems.

To conclude, this study reveals that the Tiogo dry forest has a large number of woody species and high diversity, which in turn is related to habitat heterogeneity (patchiness). However, the majority of the species are represented by few individuals, including 14 red-listed species that were missing in our plots. The reintroduction of rare and threatened species is therefore highly desirable to save them from local extinction and to maintain a viable population size. It should be noted that local species richness and diversity in savanna ecosystems are generally maintained by dynamic interaction between local colonization processes from species pools at larger spatial scales and local extinction due to competitive exclusion processes. Measures to support the regeneration of woody species (e.g. protection from or reducing the frequency and/or intensity of disturbance) should also be taken to increase the

Photo 4.
Abandoned fallows.
Photo D. Tiveau.

abundance of rare and threatened species. However, successful restoration requires involvement from many disciplines and stakeholders, from ecologists to local communities, and from decision makers to ordinary people. Finally, we recommend further study at regional level to update the current conservation status of the species catalogued in IUCN or national red list species data bases.

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Appendix.
List of all woody species recorded in four vegetation patches in the Sudanian savanna of Burkina Faso (* species with dbh < 5 cm; + species with dbh ≥ 5 cm).

Species	Family	Gallery forest	Dense woodland	Open woodland	Fallows
Acacia dudgeoni Craib. ex Hall.	Mimosoideae		+	+	
Acacia macrostachya Reichenb. ex DC.	Mimosoideae		+	+	*
Acacia erythrocalyx (L.) Willd	Mimosoideae	+	+	*	
Acacia polyacantha (Hoechst. ex A. Rich.) Brenan	Mimosoideae	+			
Acacia seyal Del.	Mimosoideae	+	+	*	+
Adansonia digitata L.	Bombacaceae		*	*	
Afzelia africana Smith ex Pers.	Caesalpinioideae		+	*	
Albizia chevalieri Harms	Mimosoideae		+	*	
Albizia malacophylla (A. Rich.) Walp.	Mimosoideae		*	*	
Allophylus africanus P. Beauv.	Sapindaceae		*		
Annona senegalensis Pers.	Annonaceae		*	*	*
Anogeissus leiocarpus (DC.) Guill. & Perr.	Combretaceae		+	+	*
Azadirachta indica A. Juss.	Meliaceae		*		
Baissea multiflora A. DC.	Apocynaceae		*	*	
Balanites aegyptiaca (L.) Del.	Balanitaceae		+	+	+
Bombax costatum Pellegr. & Vuillet	Bombacaceae		+	+	
Boswellia dalzielii Hutch.	Burseraceae		+	+	
Bridelia ferruginea Benth.	Euphorbiaceae				*
Burkea africana Hook. f.	Caesalpinioideae		+	+	
Cadaba farinosa Forssk.	Capparaceae		*		*
Capparis sepiaria L.	Capparaceae	*	*	*	*
Capparis tomentosa Lam.	Capparaceae		*		
Cassia sieberiana DC.	Caesalpinioideae	*	*	*	
Cola laurifolia Mast.	Sterculiaceae	*			
Combretum collinum Fresen.	Combretaceae			*	
Combretum fragrans F. Hoffm.	Combretaceae		+	+	+
Combretum glutinosum Perr. ex DC.	Combretaceae		+	*	+
Combretum micranthum G. Don	Combretaceae		+	+	*
Combretum nigricans Lepr. ex Guill. & Perr.	Combretaceae		+	+	+
Crataeva adansonii DC.	Capparaceae		*		
Crossopteryx febrifuga (Afzl. ex G. Don) Benth.	Rubiaceae		+	+	
Detarium microcarpum Guill. & Perr.	Caesalpinioideae	*	+	+	+
Dichrostachys cinerea (L.) Wight. & Arn.	Mimosoideae		*	*	+
Diospyros mespiliformis Hochst. ex A. Rich.	Ebenaceae	*		+	
Entada africana Guill. & Perr.	Mimosoideae		+	+	+
Feretia apodanthera Del.	Rubiaceae		+	*	*
Ficus glumosa Del.	Moraceae		+		
Flueggea virosa (Roxb. ex Wild.) Voigt	Euphorbiaceae		*	*	
Gardenia erubescens Stapf & Hutch.	Rubiaceae	*			
Gardenia sokotensis Hutch.	Rubiaceae		+	*	
Gardenia ternifolia Schumach. & Thonn.	Rubiaceae		+	*	
Grewia bicolor Juss.	Tiliaceae		+	+	+
Grewia flavescens Juss.	Tiliaceae		*	*	
Grewia venusta Fresen.	Tiliaceae		+	+	*

Appendix (continued)

Species	Family	Gallery forest	Dense woodland	Open woodland	Fallows
Guiera senegalensis J.F. Gmel.	Combretaceae	*	+	*	
Holarrhena floribunda (G. Don) Dur. & Schinz	Apocynaceae			*	*
Isoberlinia doka Craib & Stapf	Caesalpinioideae		+		
Lannea acida A. Rich.	Anacardiaceae		+	+	+
Lannea microcarpa Engl. & K. Krause	Anacardiaceae		+	+	+
Lannea velutina A. Rich.	Anacardiaceae		+	+	+
Loeseneriella africana (Willd.) Wilczek	Hippocrateaceae	*			
Lonchocarpus laxiflorus Guill. & Perr.	Papilionoideae		*	+	
Maerua angolensis DC.	Capparaceae	*	*	*	*
Maytenus senegalensis (Lam.) Exell	Celastraceae		+	*	*
Mimosa pigra L.	Mimosoideae		*		
Mitragyna inermis (Willd.) Kuntze	Rubiaceae	+			
Moghania faginea (Guill. & Perr.) Kuntze	Papilionoideae	*			
Opilia celtidifolia (Guill. & Perr). Endl. ex Walp.	Opiliaceae		+	*	
Paullinia pinnata L.	Sapindaceae	*			
Pericopsis laxiflora (Benth.) van Meeuwen	Papilionoideae			*	
Phyllanthus reticulatus Poir.	Euphorbiaceae	*			
Piliostigma reticulatum (DC.) Hochst.	Caesalpinioideae	+	+	+	+
Piliostigma thonningii (Schumach.) Milne-Redh.	Caesalpinioideae	+	+	+	+
Prosopis africana (Guill. & Perr.) Taub.	Mimosoideae		+	+	
Pseudocedrala kotschyi (Schweinf.) Harms	Meliaceae		*		+
Psorospermum senegalense Spach	Clusiaceae		+		
Pteleopsis suberosa Engl. & Diels	Combretaceae		+		
Pterocarpus erinaceus Poir.	Papilionoideae		+	+	
Pterocarpus santalinoides L'Hér. ex DC.	Papilionoideae	+			
Rytigynia senegalensis Blume	Rubiaceae	*			
Saba senegalensis (A. DC.) Pichon	Apocynaceae		*	*	
Sclerocarya birrea (A. Rich.) Hochst.	Anacardiaceae		+	*	+
Securidaca longepedunculata Fres.	Polygalaceae			*	
Senna singueana (Del.) Lock	Caesalpinioideae		*		*
Sterculia setigera Del.	Sterculiaceae		+	*	
Stereospermum kunthianum Cham.	Bignoniaceae		+	*	+
Strychnos spinosa Lam.	Loganiaceae			+	
Syzygium guineense (Willd.) DC.	Myrtaceae	*			
Tamarindus indica L.	Caesalpinioideae		+	+	
Terminalia avicennioides Guill. & Perr.	Combretaceae		+	+	+
Terminalia laxiflora Engl.	Combretaceae			*	+
Terminalia macroptera Guill. & Perr.	Combretaceae		*		
Vitellaria paradoxa Gaertn. f.	Sapotaceae		+	+	+
Vitex chrysocarpa Planch. ex Benth.	Verbenaceae	+			
Vitex simplicifolia Oliv.	Verbenaceae			*	
Xeroderris stuhlmannii (Taub.) Mendonça & E.P. Sousa	Papilionoideae		*		
Ximenia americana L.	Olacaceae		+	+	*
Ziziphus mauritiana Lam.	Rhamnaceae	*	*		
Ziziphus mucronata Willd.	Rhamnaceae		*		+

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