Woody vegetation structure and composition at four sites along a latitudinal gradient in Western Burkina Faso

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Photograph 1.
An individual of *Anogeissus leiocarpa* at the Belehede site .
Photograph F. Bognounou.

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RÉSUMÉ

STRUCTURE ET COMPOSITION SPÉCIFIQUE DE LA VÉGÉTATION LIGNEUSE DE QUATRE SITES SUR UN GRADIENT LATITUDINAL AU BURKINA FASO OCCIDENTAL

Comprendre la distribution de la végétation ligneuse et les facteurs qui la sous-tendent est une étape cruciale pour la conservation et la gestion des communautés végétales de l'écosystème des savanes boisées. Cet article présente la composition spécifique, la structure et la diversité des essences ligneuses de quatre sites sur un gradient latitudinal dans les secteurs nord-sahélien, sud-sahélien, nord-soudanien et sud-soudanien du Burkina Faso occidental. Toutes les essences ligneuses ont été systématiquement identifiées et mesurées sur 82 placettes de 50 × 20 m^2. La densité, la dominance, la fréquence, les espèces et les valeurs d'importance ont été calculées pour caractériser la composition spécifique. Des mesures de diversité ont été calculées pour analyser l'hétérogénéité de chacun des sites. Au total, 74 espèces représentant 26 familles et 53 genres ont été recensées, parmi lesquelles les familles des Combrétacées, Mimosacées et Caesalpiniacées s'avèrent dominantes. Les caractéristiques structurelles font apparaître des différences significatives ($p < 0,001$) entre sites et espèces. Pour certains sites, les distributions par classe de dimension font apparaître une courbe en J inversé, indiquant une végétation dominée par des arbres juvéniles. La composition spécifique fait apparaître une faible similitude entre sites, indiquant une diversité bêta élevée qui reflète des différences au niveau des conditions du milieu, de la topographie et de distance entre sites. Les différences spécifiques entre sites mettent en lumière l'importance des approches à l'échelle du paysage pour comprendre les distributions, la composition, la structure et la diversité spécifiques, dans une optique de mise en œuvre de mesures de restauration et de conservation favorisant la surface terrière totale et la diversité de ces écosystèmes.

Mots-clés: diversité biologique, richesse spécifique, relation environnementale, paysage fragmenté, conservation, zone soudanienne.

ABSTRACT

WOODY VEGETATION STRUCTURE AND COMPOSITION AT FOUR SITES ALONG A LATITUDINAL GRADIENT IN WESTERN BURKINA FASO

Understanding the distribution patterns of plant species and the underlying factors is crucial to the conservation and management of plant communities in savannah-woodland ecosystems. This article describes the species composition, structure and diversity of woody species at four sites along a latitudinal gradient in the North Sahelian, South Sahelian, North Sudanian and South Sudanian sectors in western Burkina Faso. All woody species were systematically identified and measured in 82 sample plots measuring 50 × 20 m^2. Density, dominance, frequency and species and family importance values were computed to characterize the species composition. A range of diversity measures were calculated to analyze the heterogeneity of each site. A total of 74 species representing 26 families and 53 genera were found. The predominant families were Combretaceae, Mimosaceae and Caesalpiniaceae. Significant differences were found between the structural characteristics ($p < 0.001$) of sites and species. At some sites, the tree size-class distributions formed a reverse J-shaped curve, indicating vegetation dominated by juvenile individuals. Similarity in tree species composition between sites was found to be low, which indicates high beta diversity and reflects differences in habitat conditions, topography and between site distances. These site-specific differences highlight the importance of landscape-scale approaches in understanding species distribution patterns, composition, structure and diversity, as well as in applying restoration and conservation measures geared to total basal area and diversity in these ecosystems.

Keywords: Biodiversity, Species richness, Environmental relation, Fragmented landscape, Conservation, Sudanian zone.

RESUMEN

ESTRUCTURA Y COMPOSICIÓN ESPECÍFICA DE LA VEGETACIÓN LEÑOSA DE CUATRO ESTACIONES DE UN GRADIENTE LATITUDINAL EN BURKINA FASO OCCIDENTAL

La comprensión de la distribución de la vegetación leñosa y los factores subyacentes es una etapa crucial para la conservación y el manejo de las comunidades vegetales en ecosistemas de sabanas arboladas. Este artículo describe la composición específica, la estructura y diversidad de las especies leñosas de cuatro estaciones a lo largo de un gradiente latitudinal en los sectores norte y sur saheliano y norte y sur sudanés de Burkina Faso occidental. Todas las especies leñosas fueron sistemáticamente identificadas y medidas en 82 parcelas de muestreo de 50 × 20 m^2. Se calcularon la densidad, dominancia, frecuencia, especies y valores de importancia para caracterizar la composición específica. Se realizaron mediciones de diversidad para analizar la heterogeneidad en cada una de las estaciones. Se contabilizaron un total de 74 especies que representan 26 familias y 53 géneros. Las familias dominantes eran las combretáceas, mimosáceas y cesalpináceas. Se encontraron diferencias significativas entre las características estructurales ($p < 0,001$) de estaciones y especies. En algunas estaciones, las distribuciones por clase de dimensión configuran una curva en forma de J inversa que indica una vegetación dominada por árboles juveniles. La composición específica pone de manifiesto una baja similitud entre estaciones, lo que indica una alta diversidad beta y refleja las diferencias en las condiciones del medio, la topografía y las distancias entre las estaciones. Las diferencias específicas entre las estaciones evidencian la importancia de los enfoques a escala de paisaje para comprender las distribuciones, composición, estructura y diversidad específicas a la hora de aplicar medidas de restauración y conservación adecuadas para toda el área basal y para la diversidad de estos ecosistemas.

Palabras clave: diversidad biológica, riqueza específica, relación medioambiental, paisaje fragmentado, conservación, zona sudanesa.

Introduction

African dry forests and woodlands cover approximately 43% of the continent across two distinct regions: the northern hemisphere (also known as the Sudanian region) with humid and arid woodlands and the southern hemisphere (also known as the Zambezian region) with miombo woodlands (MENAUT *et al.*, 1995). Sudanian savanna-woodland covers an area of 5.25 million km² stretching from Senegal in the west to the Ethiopian highlands in the east, between latitudes 6° and 13° (MENAUT *et al.*, 1995). In West Africa, savanna-woodlands stretch from Guinea's tropical forest zone to the semi-desert and desert of the Sahara (COLE, 1986).

The current mosaic of these savanna-woodland ecosystems is the result of natural and anthropogenic factors, the diversity of woody species being linked to phytogeographical and climatic alterations (FRIES, HEERMANS, 1992). The degradation of savanna-woodlands due to agricultural expansion, overgrazing, fire and wood-cutting is a serious environmental concern. The diversity and distribution of woody plant species richness over space and time vary widely, mainly as a result of anthropogenic disturbance such as deforestation and overgrazing, and variations in biogeography (O'BRIEN, 1993). Because the remaining vegetation is ecologically and socio-economically valuable, sustainable management has become a growing global concern. Therefore, knowledge on species composition at different latitudes is necessary to provide information for developing guidelines for conservation management priorities.

Geographical gradients in the diversity of plant species have long fascinated biogeographers and ecologists (LOMOLINO *et al.*, 2004). Latitudinal gradients of diversity are ultimately dependent on the historical, geographic, biotic, abiotic and stochastic forces (SCHEMSKE, 2002) affecting the geometry, internal structure and location of species ranges in ecological or evolutionary time. Latitude is in fact a surrogate for a number of primary environmental gradients (e.g., temperature and seasonality) that interact and are correlated with each other, making direct tests of hypotheses difficult and controvertible (WILLIG *et al.*, 2003). Different hypotheses have been advanced to explain the influence of latitudinal gradient on species richness (GOUGH, FIELD, 2007). Latitudinal gradient is not ecologically meaningful, but correlates with variation in ecologically meaningful variables such as climate, area and soil. The primary explanatory variables for latitudinal gradient are likely to vary continuously from low to high latitudes, mirroring the particular variation in species richness (GASTON, 2000; GOUGH, FIELD, 2007). Many of the factors put forward to account for diversity are of greatest importance at local scales, having no correlation with latitude and therefore, probably, limited power to explain the overall gradient of species richness. Contemporary climatic variables are typically the strongest single correlates of species richness in empirical studies at this scale. The area also has an important ecological effect on diversity. Diversity tends to increase with area, and diversity gradients can also arise in the absence of environmental gradients due to the random location of species. Plant diversity is expected to mirror the gradient in solar energy from low to the high latitudes. It has been shown that from high to low latitudes, the average species richness increases and a high proportion of species occurs in the tropics (GASTON, 2000).

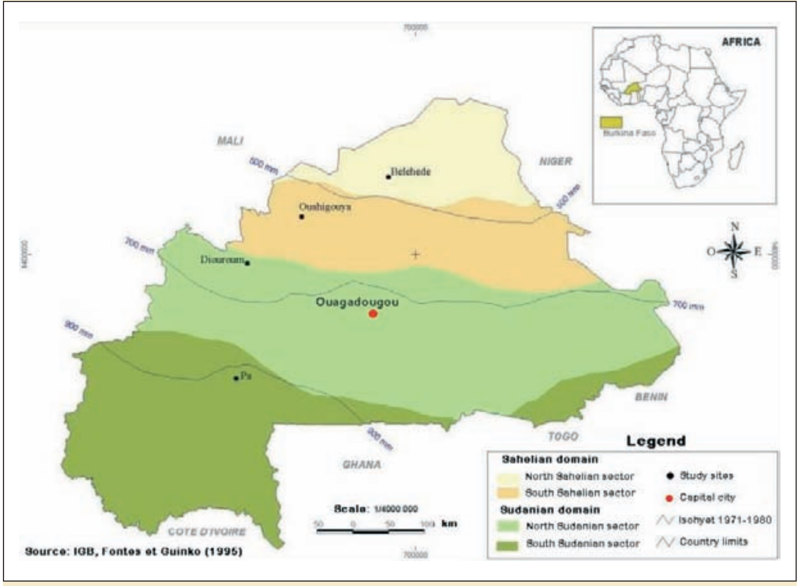

Figure 1.
Phytogeographical map of Burkina Faso with isohyets and location of the study sites.

The objectives of this study are: (i) to describe the species composition, structure and diversity of woody species at four sites along a latitudinal gradient in Western Burkina Faso and (ii) to characterize the dynamics of five Combretaceae species along a latitudinal gradient.

Materials and methods

Study area

The study was carried out at four sites along a latitudinal gradient in Western Burkina Faso, West Africa. The study sites were located at Belehede (14°06' N and 1°12' W), Ouahigouya (13°32' N and 2°22' W), Diouroum (12°58' N and 3°08' W) and Pâ (11°35' N and 3°14' W) (figure 1). The vegetation type at all sites is tree/bush savanna with a grass layer dominated by annual grasses and forb species. Species of the Mimosaceae and Combretaceae families dominate the woody vegetation component. Phytogeographically, the study sites are located in the following sectors defined by Fontes and Guinko (1995):

Belehede is located in the North Sahelian sector. The average mean annual rainfall varies from 400 to 500 mm. The number of rainy days per year varies from 30 to 40 days. The soils most frequently found are solonetz, according to the FAO soil classification system (Driessen *et al.*, 2001). The vegetation is characterized by Saharan and Sahelian woody species (photograph 1). Common woody species are *Grewia tenax*, *Acacia senegal*, *Combretum aculeatum*, *C. micranthum* and *Anogeissus leiocarpa*. The grass layer is dominated by *Aristida* sp., *Cenchrus prieuri* and *Tetrapogon cenchriformis*.

Ouahigouya is located in the South Sahelian sector. The annual rainfall varies from 500 to 600 mm. The number of rainy days per year varies from 40 to 50 days. The soils most frequently found are lithosols. The vegetation is characterized by Saharan, Sahelian and some Sudanian species (photograph 2). Common species are *C. aculeatum*, *C. micranthum*, *C. nigricans*, *Balanites aegyptiaca*, *A. leiocarpa*, *Boscia salicifolia*, *Commiphora africana*, *Grewia flavescens* and *Pterocarpus lucens*. The main grass species were *Aristida hordeacea*, *Cenchrus* sp. and *Chloris lamproparia*.

Photograph 2.
Population of *Combretum micranthum* and *Combretum nigricans* at the Ouahigouya site.
Photograph F. Bognounou.

Diouroum is located in the North Sudanian sector. The annual rainfall varies from 600 to 700 mm. The number of rainy days per year varies from 40 to 70 days. The soils most frequently found are lithosols. The vegetation is characterized by Sudanian and some Sahelian species (photograph 3). Common woody species are *A. seyal*, *C. micranthum*, *C. glutinosum*, *C. nigricans*, *Guiera senegalensis*, *A. leiocarpa* and *Pteleopsis suberosa*. The herbaceous vegetation is dominated by *Andropogon pseudapricus*, *Loudetia togoensis*, *Andropogon gayanus*, *Elionurus elegans* and *Cymbopogon schoenanthus*.

Pâ is located in the South Sudanian sector. The annual rainfall varies from 800 to 900 mm. The number of rainy days per year varies from 70 to 90 days. The soils most frequently found are ferralsols. The vegetation is characterized by South Sudanian species (photograph 4). Common woody species are *Acacia sieberiana*, *A. leiocarpa*, *Burkea africana*, *Daniellia oliveri*, *Diospyros mespiliformis*, *C. glutinosum*, *C. nigricans*, *Isoberlinia doka* and *P. suberosa*. The main herbaceous species were *A. gayanus*, *Diheteropogon amplectens*, *Loudetia simplex* and *Vetiveria nigritana*.

Data collection and analysis

The inventory was carried out at the end of the rainy season (November and December 2005) when the plots were easily accessible. The vegetation survey was conducted at the four sites along the latitudinal gradient, following an unbalanced design scheme. A total of 82 quadrats (Belehede 20, Ouahigouya 28, Diouroum 25 and Pâ 18) were laid out in a representative area. The plots were 50 × 20 m^2 in size and about 200 m apart along transect lines laid out through Combretaceae communities. Each sample plot was systematically surveyed and the woody species were recorded and identified. The nomenclature of species followed (Arbonnier, 2002). The following variables were also recorded: number of stems, height of the largest stem and girth at 0.2 m. The relative ecological importance of each woody species and each family at each latitudinal location was described using the following parameters:

- Relative dominance = (total basal area of a species / total basal area of all species) × 100;
- Relative density = (number of individuals of a species / total number of individuals) × 100;

Photograph 3.
Population of *Pteleopsis suberosa* at the Diouroum site.
Photograph F. Bognounou.

- Relative frequency = (frequency of a species / sum of all frequencies) × 100;
- Relative diversity = (number of a species in a family / total number of species) × 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 plots in which the species occurs. The theoretical range of relative dominance, frequency, density, and diversity is 0-100%, and therefore the IVI and FIV may vary from 0 to 300. Structural characteristics (stem density, and girth and height class distributions) were computed for each plot and averaged per site for all individuals. The plants were grouped into seven girth classes of 5 cm interval: Class 1 =]0-5], Class 2 =]5-10], Class 3 =]10-15], Class 4 =]15-20], Class 5 =]20-25], Class 6 =]25-30], Class 7 = girth › 30 cm and into five height classes at 0.5 cm intervals: Class 1 =]0-0.5], Class 2 =]0.5-1], Class 3 =]1-1.5], Class 4 =]1.5-2], Class 5 = height › 2 m.

For a better understanding of plant community structure and composition, diversity indices were computed. These provide more information about community composition than species richness alone (i.e. the number of species present); they also take the relative abundances of different species into account. Biologists use many diversity indices, each of which has strengths and weaknesses (Magurran, 2004). We therefore used a combination of three indices to take advantage of the strengths of each. Specifically, we calculated Shannon's diversity index (H'), Simpson's diversity index (D) and Simpson's Evenness (E).

Shannon's diversity index (H) =

$$-\sum_{i=1}^{S} p_i \ln p_i$$

Simpson's diversity index (D) =

$$\frac{1}{\sum_{i=1}^{S} p_i^2}$$

Simpson's Evenness (E) = D/S

Where S = the total number of species in the community (richness) and p_i = is the relative abundance of the *i*th species in a plot. These indices are widely employed to measure biological diversity (Magurran,

Photograph 4.
Population of *Anogeissus leiocarpa* at the Pâ site.
Photograph F. Bognounou.

Table I.
List of the species encountered at four sites along latitudinal gradient together with their importance value index (IVI).

Species	Belehede	Ouahigouya	Diouroum	Pâ
Acacia ataxacantha	11.11	0.66	0.48	-
Acacia macrostachia	-	1.28	5.71	3.51
Acacia nilotica	8.53	-	-	-
Acacia senegal	27.57	2.78	1.66	1.64
Acacia seyal	14.36	18.96	22.6	-
Adansonia digitata	0.77	0.77	-	-
Annona senegalensis	-	-	0.47	2.59
Anogeissus leiocarpa	36.45	35.9	24.88	60.5
Balanites aegyptiaca	24.94	15.19	2.78	3.35
Bombax costatum	-	-	0.67	-
Boscia salicifolia	5.56	2.95	0.53	0.84
Boscia senegalensis	8.33	-	1.44	-
Cadaba farinosa	-	-	1.72	-
Capparis corymbosa	1.92	-	1.11	-
Cassia sieberiana	-	5.33	3.07	5.23
Combretum aculeatum	34.21	20.96	10.65	-
Combretum fragrans	-	2.38	7.35	-
Combretum glutinosum	4.19	9.45	1.41	8.66
Combretum micranthum	34.68	62.19	28.07	-
Combretum molle	-	-	-	10.47
Combretum nigricans	-	15.89	20.88	50.35
Commiphora africana	10.21	-	1.29	-
Crossopteryx febrifuga	-	-	-	3.97
Dalbergia melanoxylon	7.86	-	1.42	-
Daniellia oliveri	-	-	-	2.47
Detarium microcarpum	-	-	2.12	0.87
Dichrostachys cinerea	1.15	2.77	0.91	1.56
Diospyros mespiliformis	-	3.2	9.64	3.26
Entada africana	-	-	0.54	0.76
Faidherbia albida	-	0.69	-	-
Feretia apodanthera	6.61	3.24	8.3	6.88
Fluggea virosa	-	-	6.35	3.88
Gardenia aqualla	-	-	1.04	1.87
Gardenia erubescens	-	0.82	0.92	0.83
Gardenia sokotensis	-	2.87	4.7	-
Gardenia ternifolia	-	-	1.19	3.36
Grewia bicolor	1.96	1.63	2.96	13.33
Grewia flavescens	14.36	0.97	2.06	-
Grewia tenax	0.54	-	1.24	-
Grewia villosa	3.75	-	-	-
Guiera senegalensis	9.96	42.85	10.18	0.9
Isoberlinia doka	-	-	-	0.82
Holarrhena floribunda	-	0.75	2.67	-
Khaya senegalensis	-	-	-	5.74
Lannea acida	-	-	4.95	6.16
Lannea microcarpa	-	5.23	0.73	1.43

2004). To evaluate β-diversity (similarity between vegetation sites), 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 for the species while Horn's modification of Morisita's index takes species abundance into account. Both indices potentially vary between 0 and 1: a value close to 1 indicates greater similarity between sites and hence low β-diversity (Magurran, 2004).

We also conducted a more in-depth study on five Combretaceae species, i.e. *Anogeissus leiocarpa*, *Combretum aculeatum*, *Combretum micranthum*, *Combretum nigricans* and *Pteleopsis suberosa*, to show the effect of latitudinal locations on their structure. These species are very well represented in the country and are of social and economic importance to local people (Thiombiano, 2005 ; Thiombiano *et al.*, 2006) as fuelwood, medicine and a source of livelihood diversification.

Species richness and population densities were analysed with the generalized linear models using penalized quasi-likelihood with Poisson errors. Sites and species were treated as categorical fixed factors. Generalized linear models with Poisson errors were used in order to account for the non-normal errors and the increasing variances with means that are associated with count data. Penalized quasi-likelihood estimation was used in order to account for over-dispersion (Crawley, 2005). Shannon's diversity index, Simpson's diversity index (H), Simpson's Evenness and species dominance were analysed using linear models, with the same categorical factors. These data fulfilled the assumptions of normality and variance homogeneity. All the statistical analyses and diversity calculations were performed within the R statistical package (R Development Core Team, 2007). The vegan package, developed by the Finnish ecologist Jari Oksanen, was used to calculate diversity indices. The graphs were produced with the gplots package of R.

Table I. (continued)

Species	Belehede	Ouahigouya	Diouroum	Pâ
Lannea velutina	-	-	-	1
Leptadenia hastata	0.58	1.45	-	-
Lonchocarpus laxiflorus	1.08	-	-	-
Maytenus senegalensis	-	0.67	5.13	1.24
Mitragyna inermis	-	-	2.78	-
Ozoroa insignis	-	-	0.85	-
Parkia biglobosa	-	-	-	2.62
Pericopsis laxiflora	-	-	-	3.07
Piliostigma reticulatum	2.68	17.9	17.23	-
Piliostigma thonningii	-	-	-	6.7
Pseudocedrela kotschyii	-	-	0.42	1.9
Pteleopsis suberosa	-	-	20.89	40.4
Pterocarpus erinaceus	-	-	3.33	8.36
Pterocarpus lucens	22.36	5.65	12.37	-
Saba senegalensis	0.71	-	0.9	1.79
Sclerocarya birrea	-	3.5	3.7	-
Securidaca longepedunculata	-	-	0.95	1.93
Senna singueana	-	-	2.59	1.15
Sterculia stigera	-	-	0.67	-
Stereospermum kunthianum	-	1.58	1.86	-
Strychnos spinosa	-	-	-	0.87
Tamarindus indica	-	0.71	2.49	3.91
Terminalia avicennioides	-	-	3.52	1.2
Terminalia macroptera	-	1.16	5.05	8.12
Vitellaria paradoxa	-	3.94	12.68	7.93
Vitex simplicifolia	-	-	-	0.93
Ximenia americana	-	0.65	0.93	0.78
Ziziphus mauritiana	3.56	3.07	3.01	0.87

Results

Species richness and forest stand structure

A total of 74 species, corresponding to 53 genera and 26 families, were found at all four study sites (table I). The generalized linear model using penalized quasi-likelihood with Poisson errors revealed that species richness differed between sites (d.f. = 3, F = 5.95, $P < 0.001$). Among all sites, species richness was highest at Diouroum; the site with the lowest number of species was Belehede (table II). The species with the highest importance value (table III) were *A. leiocarpa* at the Belehede site (IVI = 36.45) and Pâ site (IVI = 60.50); *C. micranthum* stood out as the most abundant species at the Ouahigouya site (IVI = 62.19) and Diouroum (IVI = 28.07). Other species with a high IVI were *C. micranthum*, *C. aculeatum*, *A. Senegal*, *B. aegyptiaca* and *P. lucens*) at Belehede, *G. senegalensis*, *A. leiocarpa*, *C. aculeatum*, *A. seyal*, *P. reticulatum*, and *B. aegyptiaca*) at Ouahigouya, *A. leiocarpa*, *A. seyal*, *P. suberosa*, *C. nigricans*, *P. reticulatum*, *V. paradoxa* and *P. lucens* at Diouroum, and *C. nigricans*, *P. suberosa* and *G. bicolor* at Pâ. The Combretaceae family had the most species, with a higher FIV at all the study sites (table IV). Mimosaceae made up the second largest family at Belehede, Ouahigouya and Diouroum, while at Pâ the Caesalpiniaceae family was the largest. Other important families were Fabaceae and Tiliaceae at Belehede;

Table II.
Summary of species composition and structural characteristics of woody species at four sites along a latitudinal gradient in Western Burkina Faso.

Site	Samples plots	Density ($N.ha^{-1}$) Mean ± S.E	Basal area (m^2ha^{-1})	Family	Genera	Species
Belehede	20	1 022 ± 122	92.88 ± 13.86	13	19	28
Ouahigouya	28	4 424 ± 930	128.85 ± 25.39	18	27	36
Diouroum	25	8 609 ± 1 037	192.75 ± 22.64	23	41	57
Pâ	19	13 447 ± 5 120	252.85 ± 41.36	21	38	46

Table III.
Summary of the importance value index for five Combretaceae species at four sites along a latitudinal gradient in Western Burkina Faso.

Site	Species	Density (N/ha)	Relative density (%)	Relative dominancy (%)	Relative frequency (%)	IVI
Belehede	*Anogeissus leiocarpa*	20	3.35	27.22	5.88	36.45
	Combretum aculeatum	194	19.85	4.56	9.80	34.21
	Combretum micranthum	201	18.60	7.26	8.82	34.68
	Combretum nigricans	0	0	0	0	0
	Pteleopsis suberosa	0	0	0	0	0
	Total	415	41.80	39.03	24.51	105.35
	Remain	607	58.20	60.97	75.49	194.65
Ouahigouya	*Anogeissus leiocarpa*	919	9.68	19.17	7.05	35.90
	Combretum aculeatum	229	12.59	3.24	5.13	20.96
	Combretum micranthum	1 012	28.99	21.02	12.18	62.19
	Combretum nigricans	46	2.18	7.94	5.77	15.89
	Pteleopsis suberosa	0	0	0	0	0
	Total	2 206	53.44	51.37	30.13	134.94
	Remain	2 218	46.56	48.63	69.87	165.06
Diouroum	*Anogeissus leiocarpa*	1 676	11.78	8.89	4.21	24.88
	Combretum aculeatum	380	6.71	2.02	1.92	10.65
	Combretum micranthum	752	13.19	9.90	4.98	28.07
	Combretum nigricans	755	7.63	9.03	4.21	20.88
	Pteleopsis suberosa	1 066	14.48	4.11	2.30	20.89
	Total	4 629	53.79	33.95	17.62	105.36
	Remain	3 980	46.21	66.05	82.38	194.64
Pâ	*Anogeissus leiocarpa*	2 637	25.72	28.21	6.57	60.50
	Combretum aculeatum	0	0	0	0	0
	Combretum micranthum	0	0	0	0	0
	Combretum nigricans	8 312	25.14	19.37	5.84	50.35
	Pteleopsis suberosa	1 680	25.38	10.64	4.38	40.40
	Total	9 992	76.24	58.22	16.79	151.25
	Remain	3 455	23.76	41.78	83.21	148.75

Caesalpiniaceae and Rubiaceae at Ouahigouya; Caesalpiniaceae, Rubiaceae and Anacardiaceae at Diouroum; and Rubiaceae, Fabaceae and Anacardiaceae at the Pâ site.

The analysis showed significant differences between sites concerning the structural characteristics of the stands. The mean stem density (d.f. = 3, F = 9.30, P ‹ 0.001) and the mean basal area (d.f. = 3, F = 6.45, P ‹ 0.001) increased significantly from Belehede to Pâ (table II). The girth class distribution for all species at each site formed a reverse “J” shaped curve. The dominant class corresponds to individuals with ≤ 5 cm dbh (figure 2) and comprised seedling and/or saplings.

Table IV.
Summary of the importance value index of woody plant families at four sites along a latitudinal gradient in Western Burkina Faso.

Site	Families	No Species	Relative diversity %	Relative dominance %	Relative density %	FIV
Belehede	Combretaceae	5	17.86	41.97	47.13	106.96
	Mimosaceae	5	17.86	24.68	16.47	59.00
	Fabaceae	3	10.71	10.96	7.60	29.27
	Tiliaceae	4	14.29	0.54	9.28	24.11
	Balanitaceae	1	3.57	10.86	9.18	23.61
	Capparaceae	3	10.71	3.28	6.16	20.15
	Burseraceae	1	3.57	5.69	1.09	10.35
	Rubiaceae	1	3.57	0.83	1.86	6.26
	Rhamnaceae	1	3.57	0.35	0.76	4.69
	Caesalpiniaceae	1	3.57	0.41	0.31	4.29
	Bombacaceae	1	3.57	0.24	0.04	3.85
	Apocynaceae	1	3.57	0.19	0.04	3.79
	Asclepiadaceae	1	3.57	0.00	0.09	3.66
Ouahigouya	Combretaceae	8	22.22	64.83	78.52	165.58
	Mimosaceae	6	16.67	10.88	6.65	34.20
	Caesalpiniaceae	3	8.33	7.17	4.59	20.10
	Balanitaceae	1	2.78	7.04	2.38	12.19
	Anacardiaceae	2	5.56	4.55	0.34	10.44
	Rubiaceae	3	8.33	0.24	1.56	10.13
	Tiliaceae	2	5.56	0.05	1.26	6.87
	Fabaceae	1	2.78	1.32	1.13	5.22
	Sapotaceae	1	2.78	0.64	1.38	4.80
	Capparaceae	1	2.78	1.47	0.20	4.44
	Ebenaceae	1	2.78	0.24	1.04	4.06
	Bignoniaceae	1	2.78	0.89	0.05	3.72
	Asclepiadaceae	1	2.78	0.41	0.40	3.58
	Rhamnaceae	1	2.78	0.13	0.38	3.29
	Bombacaceae	1	2.78	0.11	0.02	2.90
	Apocynaceae	1	2.78	0.02	0.09	2.88
	Celastraceae	1	2.78	0.02	0.01	2.81
	Olacaceae	1	2.78	0.00	0.01	2.79
Diouroum	Combretaceae	10	17.54	42.23	59.99	119.77
	Mimosaceae	6	10.53	18.10	4.61	33.24
	Caesalpiniaceae	5	8.77	8.32	8.06	25.15
	Rubiaceae	6	10.53	3.71	6.78	21.03
	Fabaceae	3	5.26	4.70	5.13	15.10
	Anacardiaceae	4	7.02	4.58	0.67	12.26
	Sapotaceae	1	1.75	6.32	3.29	11.37
	Capparaceae	4	7.02	1.37	1.51	9.90
	Ebenaceae	1	1.75	3.56	3.02	8.33
	Tiliaceae	3	5.26	0.25	1.03	6.54

Table IV. (continued)

Site	Families	No Species	Relative diversity %	Relative dominance %	Relative density %	FIV
Diouroum	Apocynaceae	2	3.51	0.95	0.70	5.16
	Euphorbiaceae	1	1.75	0.88	2.41	5.04
	Balanitaceae	1	1.75	2.33	0.07	4.15
	Celastraceae	1	1.75	0.79	1.27	3.82
	Rhamnaceae	1	1.75	0.68	0.79	3.23
	Burseraceae	1	1.75	0.47	0.06	2.28
	Bignoniaceae	1	1.75	0.04	0.28	2.08
	Bombacaceae	1	1.75	0.28	0.01	2.04
	Sterculiaceae	1	1.75	0.24	0.02	2.01
	Polygalaceae	1	1.75	0.24	0.02	2.01
	Olacaceae	1	1.75	0.28	0.01	2.04
	Annonaceae	1	1.75	0.09	0.10	1.94
	Meliaceae	1	1.75	0.00	0.15	1.91
Pâ	Combretaceae	8	17.39	66.55	81.21	165.16
	Caesalpiniaceae	7	15.22	4.64	3.08	22.94
	Rubiaceae	5	10.87	3.36	3.33	17.55
	Fabaceae	3	6.52	8.11	0.67	15.30
	Mimosaceae	4	8.70	3.40	0.86	12.95
	Meliaceae	2	4.35	4.10	2.08	10.53
	Anacardiaceae	3	6.52	2.10	0.64	9.27
	Tiliaceae	1	2.17	3.28	3.48	8.94
	Sapotaceae	1	2.17	2.77	0.78	5.72
	Euphorbiaceae	1	2.17	0.01	1.68	3.87
	Balanitaceae	1	2.17	0.90	0.26	3.33
	Celastraceae	1	2.17	0.01	0.51	2.69
	Polygalaceae	1	2.17	0.39	0.08	2.65
	Annonaceae	1	2.17	0.13	0.27	2.57
	Ebenaceae	1	2.17	0.04	0.30	2.51
	Apocynaceae	1	2.17	0.00	0.33	2.50
	Verbenaceae	1	2.17	0.14	0.06	2.38
	Rhamnaceae	1	2.17	0.02	0.12	2.31
	Loganiaceae	1	2.17	0.05	0.08	2.31
	Capparaceae	1	2.17	0.00	0.11	2.29
	Olacaceae	1	2.17	0.00	0.05	2.23

Species diversity and similarity between sites

The analysis revealed that among the diversity indices, Shannon's measure of evenness (table V; d.f. = 3, F = 10.61, P < 0.001) and Simpson's diversity index (table V; d.f. = 3, F = 8.38, P < 0.001) were significantly different between sites. By contrast, Simpson's Evenness index did not vary significantly between sites (d.f. =3, F = 0.40, P = 0.75). When comparing species similarity between the sites (table VI), similarity was fairly low between the Belehede and Pâ sites (17.5% and 0.4% for Jaccard's index and Morisita's index, respectively). The highest similarity (55% and 59% for Jaccard's index and Morisita's index, respectively) was observed between the Diouroum and Ouahigouya sites.

Table V.
Woody species diversity at four sites along a latitudinal gradient of Western Burkina Faso.

Indice	Belehede	Ouahigouya	Diouroum	Pâ
Species richness (S)	28	36	57	46
Shannon’s diversity index (H)	1.66 ± 0.07	1.08 ± 0.10	1.47 ± 0.13	0.83 ± 0.13
Simpson’s diversity index (D)	3.99 ± 0.29	2.55 ± 0.20	4.03 ± 0.52	1.97 ± 0.25
Evenness (E)	0.41 ± 0.03	0.45 ± 0.03	0.42 ± 0.04	0.38 ± 0.07

Table VI.
Similarity in species composition between vegetation at four sites along a latitudinal gradient in Western Burkina Faso.

Index	Ouahigouya	Diouroum	Pâ
Jaccard			
Belehede	0.422	0.371	0.175
Ouahigouya		0.550	0.344
Diouroum			0.537
Morista			
Belehede	0.373	0.329	0.004
Ouahigouya		0.590	0.024
Diouroum			0.085

Dominant Combretaceae species

Five species, *A. leiocarpa*, *C. aculeatum*, *C. micranthum*, *C. nigricans* and *P. suberosa* were common in nearly all inventory plots, thus making analysis at individual species level possible. Analysis revealed that for these species, there were significant differences between sites (d.f. = 3, F = 21.40, $P < 0.001$) and between species (d.f. = 4, F = 9.79, $P < 0.001$) for density (figure 3). There was also a significant interaction effect of sites and species (d.f. = 12, F = 5.02, $P < 0.001$) on their density. The shape of the girth class distribution varied between species and sites (figure 4). *A. leiocarpa* formed a reverse “J” shaped curve for the plots in Ouahigouya and Pâ. A similar pattern was found at Diouroum, with slight deviation in the first class]0-5], while individuals with dbh > 30 cm were more abundant at Belehede. *C. aculeatum* formed a reverse “J” shaped curve in most sites except Pâ, where no individual was recorded. A similar pattern found for *C. micranthum*, *C. nigricans* and *P. suberosa*, formed a somewhat reversed “J” shaped curve only for the Diouroum and Pâ sites.

The height class distribution varied between species and sites (figure 5). For *A. leiocarpa*, individuals ≥ 2 m in height were more abundant at Belehede, Ouahigouya and Pâ, while at Diouroum individuals ranging from 0.5 to 1 m in height were more numerous. For *C. aculeatum*, the height class distribution displayed a somewhat negative exponential trend for Belehede and Diouroum. At Ouahigouya, the pattern was almost similar, with a slight deviation for individuals of class]0.5-1]. Individuals of class]0-0.5] were abundant at Belehede and Ouahigouya for *C. micranthum* and at Ouahigouya and Diouroum for *C. nigricans*. *P. suberosa* displayed a somewhat negative exponential trend at Pâ while no individual was recorded at the Belehede and Ouahigouya sites.

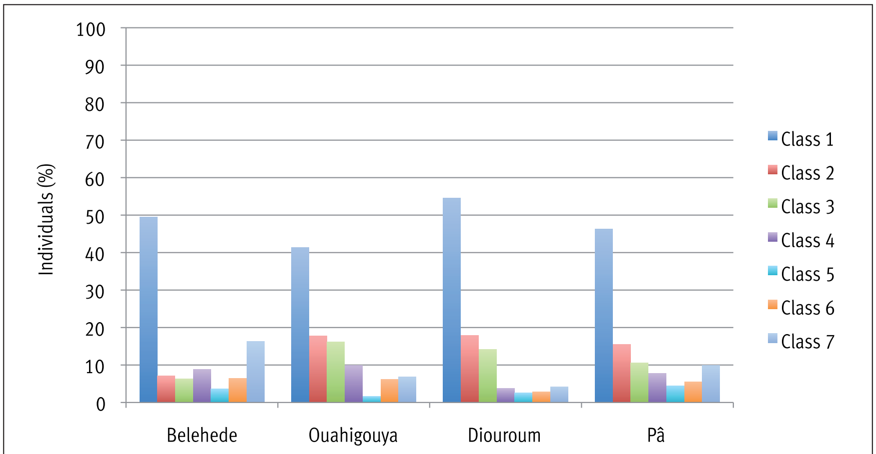

Figure 2.
Height distribution of tree species at four sites along a latitudinal gradient in Western Burkina Faso.

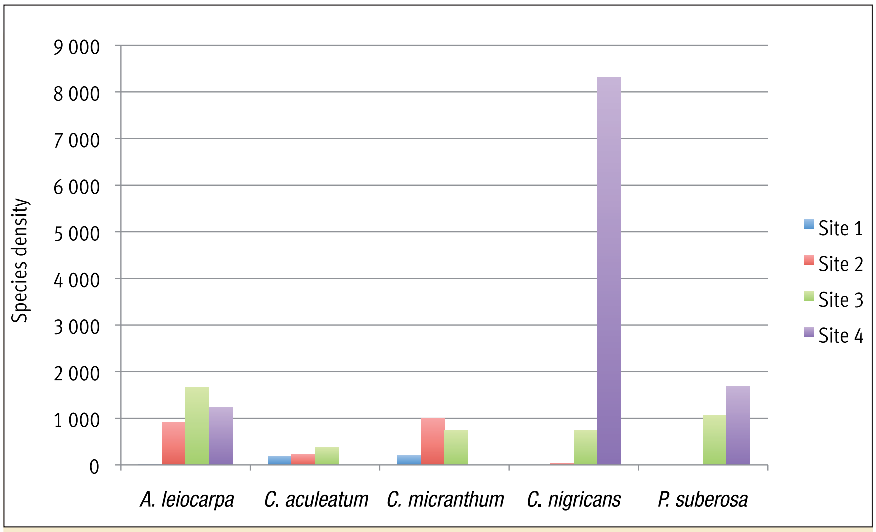

Figure 3.
Density (mean ± SE) of five Combretaceae species at four sites along a latitudinal gradient (1 = Belehede, 2 = Ouahigouya, 3 = Diouroum, 4 = Pâ) in Western Burkina Faso.

Discussion

The overall species richness reported in this study accounts for nearly one third of native woody species found in the country. Fontes and Guinko (1995) have reported that the woody flora of the country comprises 188 species. A latitudinal variation was found in species richness with an increase from high to low latitudes. This is in agreement with earlier studies that indicate a gradual increase in species richness from north to south in most parts of the country (Schmidt *et al.*, 2005; Stevens, 1989; Clarke, Gaston 2006; Gaston, 2007). This gradient corresponds to an increase in precipitation. Aubréville (1962) has stressed that the even distribution of precipitation throughout the year is a strong ecological factor shaping plant species and community patterns. The differences in species composition between sites 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; Menaut *et al.*, 1995; Bellefontaine *et al.*, 2000; Wiens, Donoghue, 2004; Hillebrand, 2004) and species-specific growth requirements. Another factor influencing site variations in species richness is anthropogenic disturbance (agriculture, livestock, fire, wood cutting), which is frequent in this type of vegetation (Bellefontaine *et al.*, 2000). The most common families were Combretaceae, Mimosaceae, Fabaceae, Caesalpiniaceae and Rubiaceae, a pattern found in most savanna-woodland mosaics in Africa and typical of the northern Sudanian Zone in Burkina Faso (Fontes, Guinko, 1995 ; Savadogo *et al.*, 2007).

Concerning the total density and basal area of the woody populations, a gradual increase was found from high to the low latitudes. This result is in agreement with findings reported by Fontes and Guinko (1995). The reverse “J” shape of the cumulative diameter class distribution of all woody plants in some latitudes is an indication of good regeneration status (Zegeye *et al.*, 2006). A large number of individuals with a girth ≤ 5 cm in diameter were found at all sites. The proportion of seedlings and saplings could therefore suffice to maintain a stable tree population. However, the transition from seedlings to saplings or to a higher size class often takes a long time due to biotic and abiotic factors, and this could explain the low number of species with a girth ≥ 5 cm in diameter. The irregular recruitment of seedlings could be explained by variations in precipitation, drought, massive losses of seeds and young seedlings (seed aging, failure of seeds to germinate, predators, pathogens, seed and seedling mortality), the seed germination medium and anthropogenic disturbances (Kozlowski, 2002).

According to Shannon’s and Simpson’s diversity indices, woody plant populations at the Belehede and Diouroum sites were more diverse than in the Ouahigouya and Pâ sites. This is most likely related to the relatively large numbers of abundant species found in the inventory plots at these sites. Shannon’s diversity 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 are in the expected range. Simpson’s index describes the evenness of the distribution of individuals among species at the four sites as low. This is due to the difference in the importance value index (IVI) of the species on the different sites. The similarity in species composition and abundance between the different latitudes was generally low, except at Diouroum and Ouahigouya which had 55% and 59% similarity in species composition and abundance, respectively. The low similarity in tree species composition between sites reflects differences in habitat conditions and topography. In addition, the low to moderate level of similarity between the sites indicates high beta diversity and accentuates the importance of the latitudinal gradient in explaining species diversity at larger spatial scales in these ecosystems.

There were site and species differences in density for the five Combretaceae species investigated. This differential response of individual species could be related to differences in their biology and ecology, complex interactions of biotic and abiotic factors as well as seedling resilience to

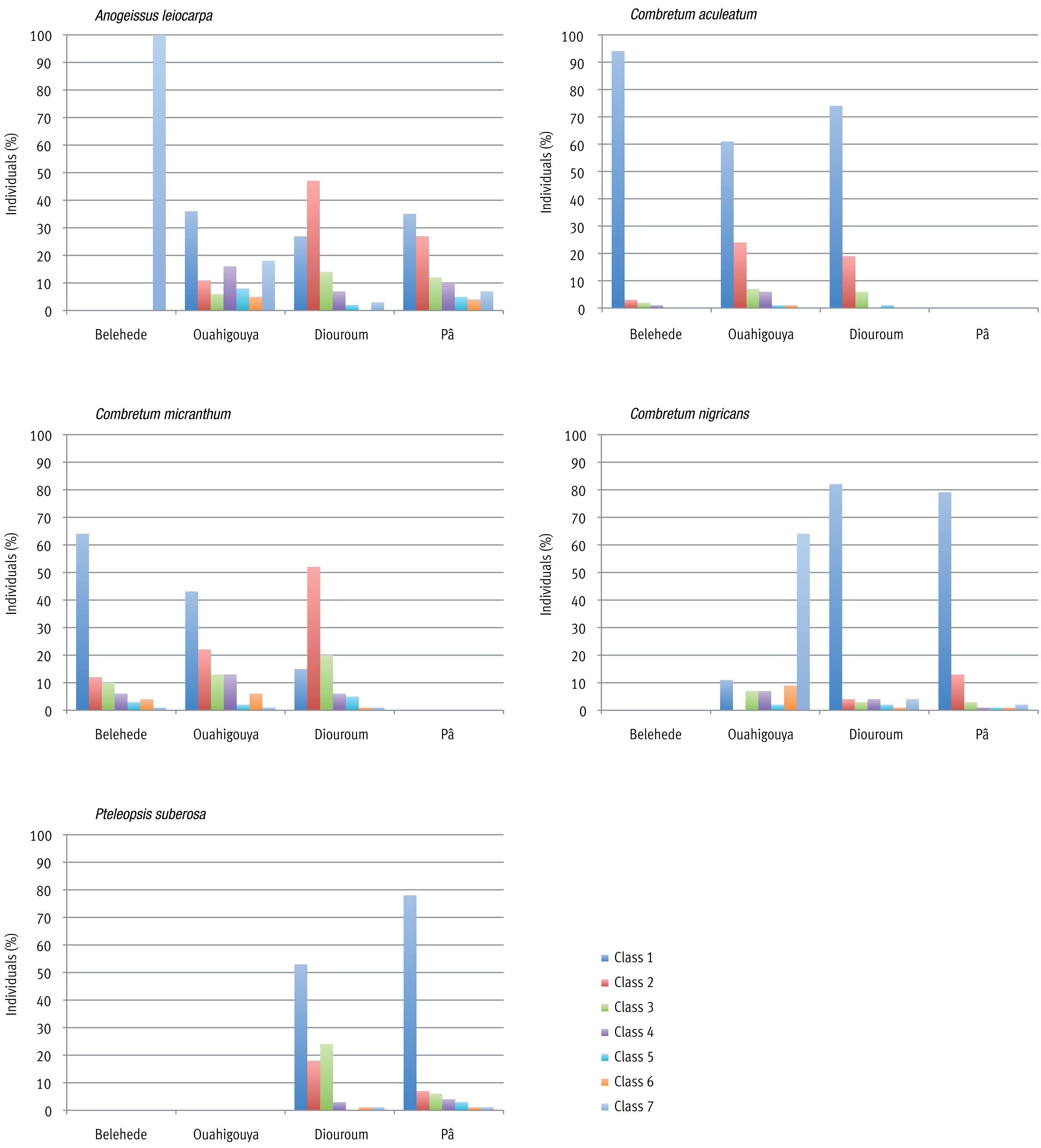

Figure 4.
Girth class distribution of five Combretaceae species at four sites along a latitudinal gradient in Western Burkina Faso.

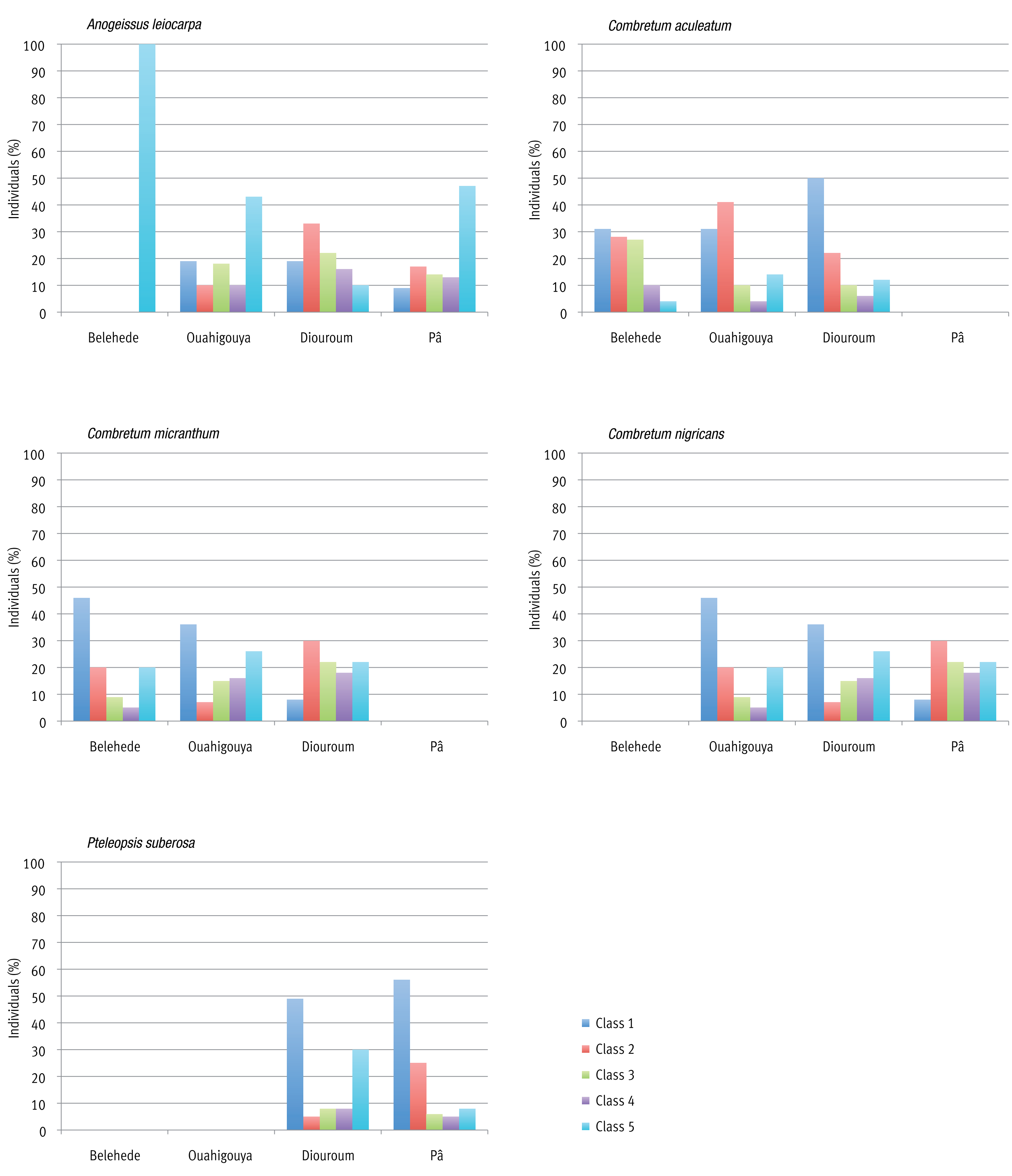

Figure 5.
Height class distribution of five Combretaceae species at four sites along a latitudinal gradient in Western Burkina Faso.

disturbances (Scholes, Walker, 1993), which make seedling populations unpredictable along a latitudinal gradient. For instance, few *A. leiocarpa*, *C. nigricans* and *P. suberosa* individuals, or none, were found in Belehede, indicating that these species are not currently regenerating *in situ* and are therefore not in demographic equilibrium within these sites. This situation may result from seedling susceptibility to climatic and soil conditions or to the absence of suitable regeneration conditions at these sites. It could also be due to the fact that the germination percentage is usually low for these species, as reported in previous studies (Dayamba *et al.*, 2008), primarily due to a large proportion of infertile ovules which could be explained by lack of pollination or inbreeding (Sakande, Sanogo, 2007). Also, towards the north, soil erosion is common and could carry seed stock away through wind deflation or run-off, or deep burying of seed stock through wind deposition or sedimentation.

This situation calls for consideration of these species in restoration programs. *A. leiocarpa* and *C. nigricans* regenerate mainly by seeds and *P. suberosa* by root suckering (Karim, 2001; Thiombiano, 2005; Ky-Dembele *et al.*, 2007). These well established features in the propagation mechanisms of these species could be used to favour seedling establishment and growth with due care for site preparation. In contrast to the population structure of these species at specific sites, the reverse "J" shape of the cumulative diameter class distribution at certain latitudinal locations is an indication of good regeneration status (Zegeye *et al.*, 2006). However the steeper part at the left end of these curves shows an under-representation of saplings and adult individuals and indicates that the success of seedling conversion to saplings and adult trees is relatively low. This situation is presumably due to slow seedling growth or marked mortality owing to biotic or abiotic pressures locally.

CONCLUSION

This study aimed to explore the species composition, structure and diversity of woody species at four sites along a latitudinal gradient in Western Burkina Faso. The results indicate that woody vegetation attributes decrease with increasing latitude from south to north, which could be explained by north-south latitudinal variation in the length and intensity of the dry season, and site-specific biotic and abiotic factors. At all four sites, the number of juvenile individuals was disproportionately higher compared to adult individuals, which could lead to higher recruitment of adults if measures are taken to boost the regeneration of woody species, e.g. protection from or reduced frequency and/or intensity of disturbance, and site preparation to favour seedling establishment and growth. The species which are declining in some areas deserve special attention and need to be conserved to maintain diversity. Low similarity in tree species composition between sites was found, which indicates high beta diversity and reflects differences in habitat conditions, topography and between sites distances. This study also revealed latitudinal and species differences in density and structural characteristics for the main Combretaceae species. This calls for an expansion of conservation and restoration measures to help regenerate these species to their original state at selected sites, due to their high socio-economical importance.

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