

POPULATION STRUCTURE OF THREE WOODY SPECIES IN FOUR ETHNIC DOMAINS OF THE SUB-SAHEL OF BURKINA FASO

T. K. SOP^{1*}, J. OLDELAND¹, U. SCHMIEDEL¹, I. OUEDRAOGO² AND A. THIOMBIANO²

¹Biodiversity, Evolution and Ecology of Plants, Biocentre Klein Flottbek and Botanical Garden, University of Hamburg, Ohnhorststr. 18, 22609 Hamburg, Germany

²Université de Ouagadougou, Unité de Formation et Recherche en Sciences de la Vie et de la Terre, Laboratoire de Biologie et d'Écologie Végétales, 03 BP 7021 Ouagadougou 03, Burkina Faso

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ABSTRACT

In developing countries many people depend on woody resources for their livelihoods. Monitoring human impact on the populations of socio-economically important species is therefore important for the conservation of vulnerable plants.

In order to assess and compare the population structure and regeneration patterns of three multipurpose species, namely *Acacia seyal* Del., *Balanites aegyptiaca* Delile and *Pterocarpus lucens* Lepr. in four ethnic areas of the sub-Sahel of Burkina Faso (Samo, Gourmantché, Fulani and Mossi), we used the size-class distribution method (SCD) (Condit *et al.*, 1998). Diameter at breast height (Dbh) of adult individuals of each species were sampled on 1000 m² (20 m × 50 m) plots in each ethnic domain. Recorded Dbhs were distributed among eight size-classes of 5 cm intervals. For each species, the slope of the regression of the SCD was considered to be an indicator of the population structure. Seedlings and saplings were recorded on five nested 25 m² plots and fell into five height classes of 0.5 m intervals.

The target species had significant ($p < 0.001$) negative SCD slopes with an inverse J-shape distribution in all ethnic areas; indicating stable populations with good regeneration. Kruskal–Wallis test for the SCDs of *A. seyal*, *B. aegyptiaca* and *P. lucens* did not differ significantly among the ethnic areas ($p > 0.1$). This suggests that the dynamics of each of the three species is similar across ethnic domains and the sub-Sahel. Data from *P. lucens* depicted an apparent stable population structure which contrasted with our field observations, perception of local people and previous studies. Copyright © 2010 John Wiley & Sons, Ltd.

KEY WORDS: Burkina Faso; population structure; size-class distribution (SCD); regeneration; species dynamics; sub-Sahel

INTRODUCTION

In developing countries a large proportion of the human population relies heavily on natural resources for their livelihoods. Resulting from this are increasing competing demands for utilisation, development and sustainable management of land resources (Mwavu and Witkowski, 2008).

In the Sahelian area of Burkina Faso, woody plant species are affected by human-caused land degradation. Human activities like overgrazing, overly frequent bush fires, uncontrolled and unsustainable agro-pastoral practices and overexploitation of plant products and firewood over the last decades, played a major role in the decrease in vegetation cover and plant diversity in Burkina Faso (Lykke, 2000; Müller and Wittig, 2002; Wezel, 2004). Many studies have reported the continuous decline of trees and shrubs in

the Sahelian area, several of which are very useful to the local human population: *e.g.* Lykke (1998), Hahn-Hadjali and Thiombiano (1999), Müller and Wittig (2002), Kristensen and Balslev (2003), Lykke *et al.* (2004); Thiombiano (2005); Belem *et al.* (2007), *etc.* This is critical because woody plants play an integral part of livelihood strategies for rural people in the Sahel, providing fruit, fodder, firewood, timber, traditional pharmaceutical products and many other products that are used locally or sold for monetary income (Ræbild *et al.*, 2007). Indeed, plants function—in the Sahelian area in particular—as a reserve that ensures continued survival of people and livestock throughout the long dry season when herbaceous vegetation is lacking and stored crops are depleted (Le Houérou, 1980; Lykke *et al.*, 2004) particularly during periods of food shortage (Wezel and Haigis, 2000; Wezel, 2004). It is therefore important to gather information on vegetation dynamics in general and the dynamics of culturally important plants in particular, as such knowledge is necessary for appropriate land management strategies (Lykke, 2000).

*Correspondence to: Tene Kwetche Sop, Biodiversity, Evolution and Ecology of Plants, Biocentre Klein Flottbek and Botanical Garden, University of Hamburg, Ohnhorststrasse 18, 22609 Hamburg, Germany. E-mail: tenesop@googlemail.com

The human population of Burkina Faso has increased from 3.5 million in 1950 to 14.2 million in 2006 (INSD, 2008) and is estimated at 15.7 million in 2009 (CIA, 2010). The population density at the national level has tripled in 50 years: from 16.2, in 1960, to 51.4 inhabitants km⁻² in 2006 (INSD, 2008). About 80 per cent of the population lives in rural areas (INSD, 2008) and is engaged in subsistence agriculture. As a result, pressure on woody plant resources increases continuously, leading to human-caused land degradation.

A number of ethnobotanical studies (Hahn-Hadjali and Thiombiano, 1999; Lykke *et al.*, 1999; Müller and Wittig, 2002; Kristensen and Balslev, 2003; Kristensen and Lykke, 2003; Lykke *et al.*, 2004; Ouedraogo, 2008), carried out in several ethnic groups in Burkina Faso have shown that cultural practices have different influences on how woody plants are used by local people. This means that traditional use of plants and resource management practices are likely to vary from one group to another, implying that the dynamic of a plant species might differ between ethnic areas within the same phytogeographical domain.

Several ecological studies have considered the population structure and dynamics of multi-use tree species in many parts of Burkina Faso (Thiombiano, 2005; Ouedraogo, 2006; Ouedraogo, 2008; Bognounou *et al.*, 2009). However, none of them has specifically focused on a potential variation in the population structure of multipurpose woody species in different cultural and/or ethnic domains (areas) in the Country.

For the conservation of vulnerable plants, it is important to have long-term monitoring data on the impact of human exploitation on the populations of the target plant species (Hall and Bawa, 1993). However, such data are often unavailable. In the absence of long-standing demographic data on population trends, standing-tree size distributions have been shown to be a potential and reliable tool for predicting species' responses to disturbance and resultant changes in population structure (Condit *et al.*, 1998; Lykke, 1998; Obiri *et al.*, 2002; Sokpon and Biaou, 2002; Feeley *et al.*, 2007; Tabuti, 2007; Venter and Witkowski, 2010). From a single survey of size-class distributions (SCD)—which can be easily assessed—parameters such as health, viability, regeneration potential and population structures of tree species can be revealed. SCD of trees in a stand is a static representation of population composition at a certain moment in time and can be problematic in estimating rates of change (Sokpon and Biaou, 2002). Regardless, from such data, direct observations can be attained that reveal how plant populations may be affected by extractive activities or other land-uses (Lykke, 1998; Peters, 1999; Dalle *et al.*, 2002; Dalle *et al.*, 2002; Obiri *et al.*, 2002; Feeley *et al.*, 2007; Tabuti, 2007).

The aim of this paper is to report on the study of the population structure and the regeneration patterns of three culturally important woody species (*Acacia seyal* Del., *Balanites aegyptiaca* Delile and *Pterocarpus lucens* Lepr.), in four ethnic domains of the sub-Saharan area of Burkina Faso, using SCD. The results are important for the development and promotion of efficient management practices aiming at a sustainable use and conservation of natural vegetation.

MATERIAL AND METHODS

Study Area

The study was carried out over a broad belt across northern Burkina Faso, starting about 100 km North of the capital Ouagadougou, crossing the Country from West to East and is located between 12°55'–14°05' N and 03°40' W–0°30' E (Figure 1). It encompasses five of the thirteen administrative regions of Burkina Faso, *i.e.* North Region, East region, Centre-Nord region, Boucle du Mouhoun and the Sahel region.

The relief is principally a large peneplain, which gives to the landscape an overall flat view with a mean altitude of *ca* 350 m a.s.l. The most frequent soil types belong to aridisols, tropical ferruginous soils and poorly evolved eroded soils overlying gravels (Bognounou *et al.*, 2010). The climate is of a Sahelian type, characterised by two contrasting seasons: a long dry season from October to May and a rainy period from June to September. Mean annual precipitation ranges from 500 to 600 mm.

The study area included entirely the sub-Saharan phytogeographical sector census of Guinko (1984). Generally, the natural vegetation is sparse and varies from grassy or shrubby steppes to shrubby or woody savannas with more or less impenetrable bushes called **brousses tigrées** (tiger bush) (Guinko, 1984). Small islands of degraded riparian forest were also found along intermittent-flow rivers that are scattered across the study area. However, the dominant vegetation type was agroforestry parklands, indicating that agricultural use of the land is progressively replacing the natural vegetation.

Studied Species

A. seyal, *B. aegyptiaca* and *P. lucens* were selected owing to their wide ecological distribution over the whole study area and their socioeconomic value for the people of the sub-Saharan area of Burkina Faso.

A. seyal (Mimosoideae) is a widespread shrub or tree up to 15 m height that occurs in the Sahelian zone on the base of slopes and in lowlands. It grows on heavy clayey or stony soils and is tolerant of waterlogging (Jøker, 2000; Arbonnier, 2004). It can be found in extensive monospecific stands on

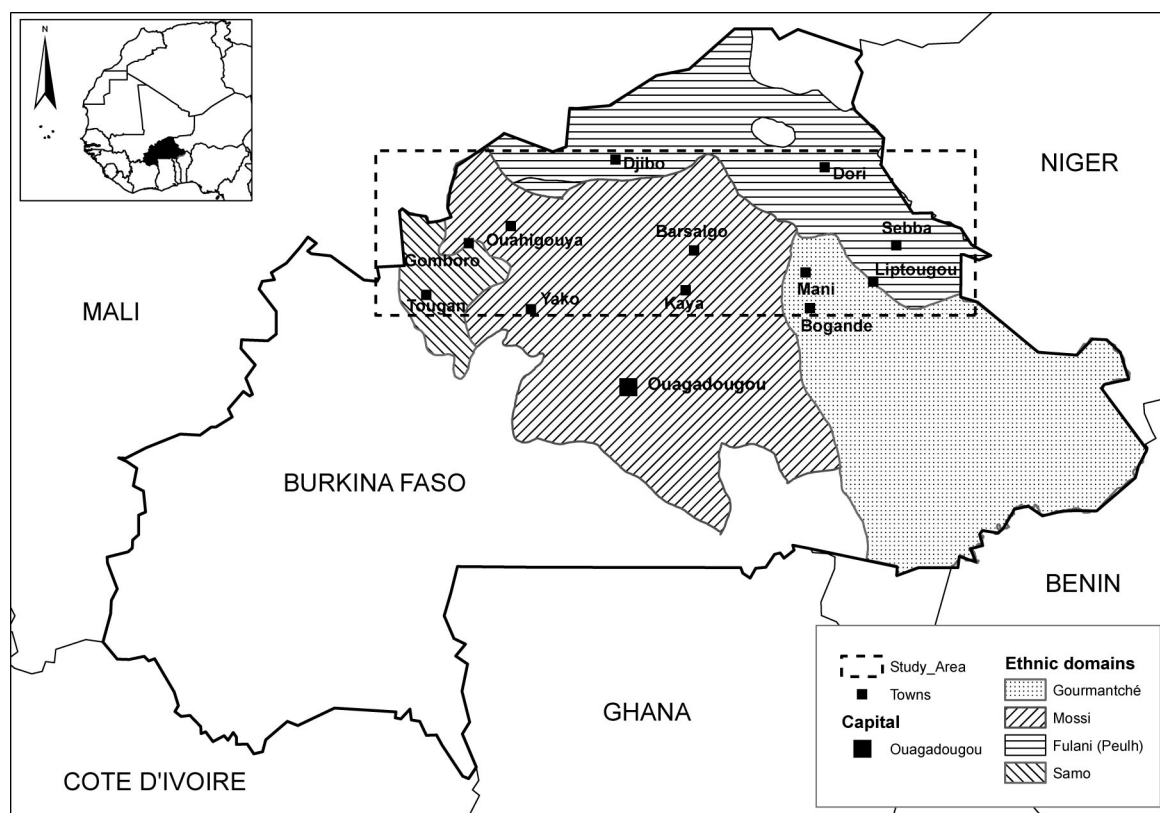


Figure 1. Location of the study area with the main ethnic domains.

alluvial plains, along roads and water channels, near water points and watercourses or as a pure forest over quite large areas. *A. seyal* is an important source of energy and its gum is consumed or sold on Sahelian markets. Its bark, leaves and pods are used as fodder for animals.

B. aegyptiaca (Balanitaceae) is a shrub or small tree of up to 10–12 m height, native to the West African Sahel and other semiarid regions in sub-Saharan Africa with a wide ecological distribution (Hall, 1992). Regarded by White (1983) as one of the chief woody species in the drier part of the Sahel zone in Africa, it grows on all types of soils and can live more than 100 years. The economic importance of *B. aegyptiaca* stems from its role as a source of fruits and fodder at the height of the dry season (Hall, 1992). Its branches are used as firewood and for construction. Arbonnier (2004) pointed out that *B. aegyptiaca* increases in frequency and cover with overgrazing.

P. lucens (Fabaceae) is generally a bushy shrub or a small tree up to 7 m that has an irregular distribution in the study area. It is locally common and mainly found on rocky hills and in 'tiger bush' (thickets), where it can form pure stands on well drained sites, on deep sandy soils, or on stony, gravelly or lateritic soils. *P. lucens* is the main source of fodder for livestock and cattle in the Sahelian area of

Burkina Faso during the dry season. Bark, roots and leaves are used to cure several diseases, while the wood, which is very hard, is used for housing construction, granaries, small carpentry, fuel, leather tanning, etc. (Sacande and Sanon, 2007).

Ethnic Domains and Cultural Settings

Four main ethnic groups (Figure 1) are found in the study area: Mossi, Fulani, Gourmantché and Samo. They represent 53, 8, 7 and 2 per cent, respectively, of the total population of Burkina Faso (TLFQ, 2010). The Fulani are mainly Muslims while the others are mixed Christians and Muslims, or practice African traditional religion. In former times, the Fulani (in French 'Peulh') lived as nomadic pastoralists, with limited agricultural activities. They have now settled in permanent villages where they combine livestock rearing (goats, sheep, cows and donkeys) with extensive agriculture (Kristensen and Balslev, 2003). The Mossi, Gourmantché and Samo have always been farmers although they currently invest more or less equally in pastoralism and agriculture, and for the Samo in particular, bush fires are very used as part of land use (e.g. to clear land before cultivation).

The territory of each ethnic group is defined as the area where the group is largely dominant. Of course, internal

migration exists but it occurs mostly towards the south in the Sudanian zone, and is motivated principally by the search for new and productive agricultural lands. Migration is however limited as it involves only 10 per cent of the total population of Burkina Faso (INSD, 2008). In general, land management in rural areas is guided by the cultural traditions of the native ethnicity, which often have more rights to the land than the immigrants (Ræbild *et al.*, 2007). Human population density is variable among the ethnic areas: 67, 48, 36 and 27 inhabitants km⁻² for the Mossi, Gourmantché, Samo and Fulani ethnic areas, respectively (INSD, 2008).

Field Sampling and Measurement

An inventory of tree population stands was conducted in summer to autumn 2008 and 2009, based on a simple random scheme. In the absence of distribution maps for the species, exploration across the study area was necessary to identify accessible populations. Sampling units were plots of 1000 m² (20 m × 50 m) in size. Depending on the extent of stands of the target species, one to five plots were randomly laid out within the population. The number of sampled units per species and per ethnic area varied, due to the varying abundance of the target species in the four ethnic domains.

Diameter at breast height (Dbh) was recorded from the circumference of the trunk measured at 1.3 m above ground level, using a simple tape. Within the 1000 m² plots all individuals of the target species with a Dbh ≥ 5 cm were sampled. For individuals with multiple stems, the largest stem was measured.

Assessment of Regeneration Structure

Natural regeneration gives information on the regenerative capacity of a population (Shackleton, 1993; Obiri *et al.*, 2002). Regenerative individuals were sampled in five subplots of 25 m² (5 m × 5 m) nested within each sampling unit. Individuals with a circumference <15.7 cm (*i.e.* Dbh < 5 cm) were all recorded as juveniles. Circumferences of saplings and seedlings were not measured. Seedlings and saplings were counted and classified according to five height-classes of 0.5 m intervals: 0–0.5, 0.5–1, 1–1.5, 1.5–2 m and >2 m. According to Steven (1994) (cited in Ouedraogo, 2006), the subdivision of the juveniles into height classes helps to gain insight into potential growth and development problems among seedlings and saplings.

Each plot was geo-referenced with a GPS and the ethnic area in which the plot is sampled was recorded as well.

Data and Statistical Analysis

For each species, we calculated the mean Dbh and the mean population density per ethnic area, as well as for the whole area (*i.e.* all samples from the four ethnic territories). Analysis of variance (ANOVA) was used to compare mean Dbh and densities across the ethnic areas.

Size-Class Distribution

Analysis of SCD followed the method proposed by Condit *et al.* (1998) and Lykke (1998). Data on Dbh were assembled in eight diameter size classes of 5 cm intervals (5–10, 10–15, *etc.*). All individuals with a Dbh larger than 40 cm were grouped into a single class. SCDs were plotted in a graph to allow visual comparison.

Population Structure

Population structure for each species in each ethnic area was inferred by analysing the slope of a linear regression of SCD parameters. Therefore, we calculated ordinary least-squares regression (OLS) with the SCD midpoint (*mi*) treated as the independent variable, and the average number of individuals in each SCD (*N_i*) as the dependant variable. In order to obtain straight line plots (Obiri *et al.*, 2002), *N_i* was transformed by ln(*N_i* + 1) since some size classes had zero individuals. The regression was finally performed between ln(*N_i* + 1) and ln(*mi*). The slopes obtained from the regression were used as an indicator of population structure for each species (Condit *et al.*, 1998; Lykke, 1998; Obiri *et al.*, 2002; Tabuti, 2007). Interpretation of the shape of the population structure of each species follows Shackleton (1993), Everard *et al.* (1995) and Obiri *et al.* (2002): negative slopes indicate good rejuvenation and recruitment, since larger size-classes have proportionally fewer individuals. A flat distribution with a slope of zero indicates equal numbers of individuals in small and large size classes. Positive slopes characterise poor recruitment with more individuals in the larger than in the smaller size-classes. The steepness of the slope was used to describe regeneration trend for each species. Steep negative slopes indicate better recruitment than shallow slopes (Lykke, 1998; Obiri *et al.*, 2002; Mwavu and Witkowski, 2009).

In order to determine the stability of populations in each ethnic area, we calculated the quotient between successive diameter size-classes. Interpretation followed Botha *et al.* (2004) and Mwavu and Witkowski (2009): constant quotients between successive size-classes indicate a stable population, while variable quotient values represent an unstable population.

Finally, we computed the Permutation Index (PI) (Wiegand *et al.*, 2000; Shackleton *et al.*, 2005; Venter and Witkowski, 2010) of each species in all ethnic areas as well as for the total study area. PI examines the degree of deviation from the monotonic decline expected in an undisturbed population and is based on the principle that the SCD of an 'ideal' or undisturbed population should decline monotonically. PI is the sum of the absolute distances between the expected and real location (rank) of all size classes, hence ignoring the relative frequency of different size classes (for details see Wiegand *et al.*, 2000). PI is

higher in a discontinuous SCD than in a continuous, monotonically declining population (Botha *et al.*, 2004). A monotonically declining population shows a PI equal to zero while a population with a discontinuous SCD (a disturbed population) will have a $PI > 0$ (Venter and Witkowski, 2010).

Assessing a Potential Difference between Ethnic Areas

We compared the SCD of each of the four species in each ethnic domain using the non-parametric Kruskal–Wallis test (Quinn and Keough, 2002) combined with *post hoc* Mann–Whitney pairwise comparisons. The significance level was set *a priori* to 0.05 per cent. These tests were chosen due to uneven sampling and because the SCD frequencies were not normally distributed. Testing of multiple hypotheses at the same time can lead to an increase of Type-I errors, *i.e.* when a correct H_0 is mistakenly rejected. Therefore, *p*-values were adjusted at the 5 per cent level using a Bonferroni correction, allowing more realistic *p*-values (Quinn and Keough, 2002).

All analyses were performed with the statistical software package R (R Development Core Team, 2008) except for the Kruskal Wallis and the *post hoc* test, which were done using the software PAST (Hammer *et al.*, 2008).

Analysis of Regeneration Data

For each species, total seedling density (*i.e.* at the study area level) and density within each ethnic area were computed. Juvenile densities were compared using the Kruskal–Wallis test.

As stated earlier, all juveniles were split into five height classes (0–0.5, 0.5–1, 1–1.5, 1.5–2 m and >2 m). We extended the method of Condit *et al.* (1998) for the juvenile population. Regeneration structure was investigated by computing the slope of regression of the height class for each species across ethnic areas. Height-class midpoint was the

independent variable and the frequency of each class was the dependant variable. Interpretation of height-class distribution and regeneration patterns were also inspired from Shackleton (1993) and Everard *et al.* (1995); *i.e.* negative slopes were considered to be stable juvenile populations and positive slopes, disturbed and unstable recruitment. In addition, the stability of height-class distributions for each species across ethnic areas was assessed by the mean of PI and the quotient between successive height classes.

RESULTS AND DISCUSSION

Population Parameters

For each species in all ethnic areas, the number of plots sampled, number of individual trees recorded, mean Dbh and mean density ha^{-1} are summarised in Table I. Mean Dbh for the three species showed a high standard deviation (SD) within all ethnic areas, indicating the heterogeneity in the demographic patterns of the assessed tree populations. For all species, mean Dbh and mean density per ethnic area did not vary significantly.

Density of *A. seyal* ranged from 431 ind. ha^{-1} in the Gourmantché area to 560 ind. ha^{-1} in the Fulani area but did not differ significantly ($p = 0.11$) among ethnic domains.

B. aegyptiaca had a density that varied from 291 in the Gourmantché territory to 456 ind. ha^{-1} in the Samo territory, and the latter differed significantly from the other ethnic domains ($p < 0.01$). Mean density for the total population of *B. aegyptiaca* within the whole study area was 331 ind. ha^{-1} , far greater than the 190 ind. ha^{-1} reported by Menaut (1983) (in Hall, 1992) near Dori, in the Fulani domain.

P. lucens appeared with a density varying from 108.85 in the Gourmantché territory to 170 ind. ha^{-1} in the Mossi

Table I. Summary of structural characteristics of the populations of *A. seyal*, *B. aegyptiaca* and *P. lucens* in Gourmantché, Fulani, Mossi and Samo ethnic areas. Mean \pm SD

Species	Ethnic areas	No. plots	Frequency	Mean Dbh (cm)	SD (mean Dbh)	Tree density/ha	SD (mean density)
<i>A. seyal</i>	Fulani	13	728	12.2	6.12	560.00	262.0
	Gourm.	21	906	10.28	5.23	431.43	146.0
	Mossi	28	1299	9.06	4.25	463.93	220.0
	Samo	21	1171	9.74	4.86	557.62	213.1
	ALL	83	4104	10.08	5.13	494.45	212.7
<i>B. aegyptiaca</i>	Fulani	20	598	15.54	9.16	299.00	95.6
	Gourm.	22	641	16.67	9.15	291.36	155.8
	Mossi	21	620	15.61	9.15	295.24	140.2
	Samo	18	821	14.63	8.06	456.11	210.0
	ALL	81	2680	15.01	8.85	330.86	165.4
<i>P. lucens</i>	Fulani	13	213	17.34	8.34	163.85	68.0
	Gourm.	26	283	14.73	7.25	108.85	59.2
	Mossi	33	527	15.1	10.04	170.00	79.5
	Samo	29	444	14.21	7.41	153.10	64.5
	ALL	101	1467	15.09	8.59	145.2	66.4

region. Population density of this species in the Gourmantché domain was significantly lower than in the other domains ($p < 0.01$).

Size Class-class Distributions Characteristics in Ethnic Areas

The results of the OLS regression analysis of the SCD are given in Table II. The histograms of the SCDs are shown in Figure 2. *A. seyal*, *B. aegyptiaca* and *P. lucens*, as well as their total population at the study area level, had significant negative SCD slopes in the four ethnic territories ($p < 0.001$, except for *P. lucens* in the Fulani area where $p < 0.01$). For all species, SCD histograms in the four ethnic domains and across the study area showed more individuals in the smaller than in the larger size-classes (Figure 2). PI confirmed this trend for *A. seyal* and *B. aegyptiaca* (PI = 0) while *P. lucens* showed a slight deviation from normal distribution with a PI that varied from 0 in the Fulani area to 4 in the Gourmantché territory.

The Kruskal–Wallis test for the SCD slopes of the targeted species across the four ethnic areas did not reveal significant differences (test statistic H was lower than six and $p > 0.1$). This suggests that the SCD of each of the three species is similar across the whole study area, regardless of the ethnic territory.

Mean quotients of successive size-classes for *B. aegyptiaca* were relatively constant in all ethnic areas (0.71, 0.71, 0.67 and 0.62 for the Fulani, Gourmantché, Mossi and Samo domains, respectively), revealing evenly distributed populations for this species. However, the mean quotient index showed a slight fluctuation between successive size-classes of *A. seyal*. The SD of the quotient index for *P. lucens* in all ethnic areas was very high, indicating population instability.

Population Structure and Species dynamics

The overall negative SCD slopes, as well as the size-class profiles are indicative of a reverse J-shape curve for the

studied species in all ethnic territories. The SCD plots clearly reveal that these species have more individuals in the smaller Dbh classes with a gradual decrease in the middle and larger diameter classes (Figure 2). Theoretically, such a trend indicates healthy or expanding populations that are naturally replacing themselves through good recruitment (Geldenhuys, 1992; Obiri and Lawes, 2000; Sokpon and Biao, 2002; Tabuti, 2007). The PI for the targeted species across ethnic domains more or less reflected the SCD slopes, except for *P. lucens* with a slight deviation from indications of a stable population. The quotients of successive classes reveal slight population instability for *A. seyal* and an irregular SCD for *P. lucens*.

The reverse J-shape and healthy populations of *B. aegyptiaca* across the study area and within each ethnic area are consistent with other studies. Indeed, *B. aegyptiaca* has been pointed out—in several parts of Africa—by numerous authors to have an ‘aggressive colonising behaviour’ that ensure stable populations for this species, despite the anthropogenic and climatic driven changes affecting African vegetation (Hall, 1992). On the other hand, the coppicing and resprouting abilities of this endemic Sahelian species makes it possible for *B. aegyptiaca* to sustain its persistence, even in the absence of seed regeneration. This is obviously an advantage over many other species in the unpredictable environment of the Sahel. In an extensive review study on the ecological status of *B. aegyptiaca* across Africa, Hall (1992) reported stable populations throughout its range, with the exception of concerns over population status of the species in northern Ethiopia.

The stability of the population structure of *A. seyal*, in all ethnic areas, might relate to its ecological distribution, being generally confined to alluvial plains and river banks where additional soil moisture is found, even during the dry season.

Table II. OLS slopes for the three species in each ethnic area. ‘All’ indicates the entire study area. PI and mean Quotients of successive classes are given

Species	Ethnic group	Slope	SE slope	R^2	p -value	PI	Mean quotient \pm SD
<i>A. seyal</i>	Fulani	-2.50	0.808	0.94	<0.001	0	0.46 \pm 0.14
	Gourmantché	-2.71	0.686	0.97	<0.001	0	0.27 \pm 0.11
	Mossi	-3.15	0.846	0.97	<0.001	0	0.43 \pm 0.28
	Samo	-3.09	0.846	0.97	<0.001	0	0.34 \pm 0.08
	All	-3.57	0.959	0.96	<0.001	0	0.37 \pm 0.09
<i>B. aegyptiaca</i>	Fulani	-1.62	0.517	0.94	<0.001	0	0.71 \pm 0.18
	Gourmantché	-1.58	0.786	0.87	<0.001	0	0.71 \pm 0.20
	Mossi	-1.56	0.511	0.93	<0.001	0	0.67 \pm 0.09
	Samo	-2.03	0.717	0.93	<0.001	0	0.62 \pm 0.12
	All	-1.97	0.785	0.91	<0.001	0	0.67 \pm 0.13
<i>P. lucens</i>	Fulani	-1.17	0.858	0.75	<0.01	0	0.75 \pm 0.27
	Gourmantché	-1.60	0.789	0.87	<0.001	4	0.59 \pm 0.17
	Mossi	-1.57	0.511	0.94	<0.001	2	0.68 \pm 0.22
	Samo	-1.83	0.741	0.90	<0.001	2	0.62 \pm 0.21
	All	-1.92	0.799	0.91	<0.001	0	0.65 \pm 0.14

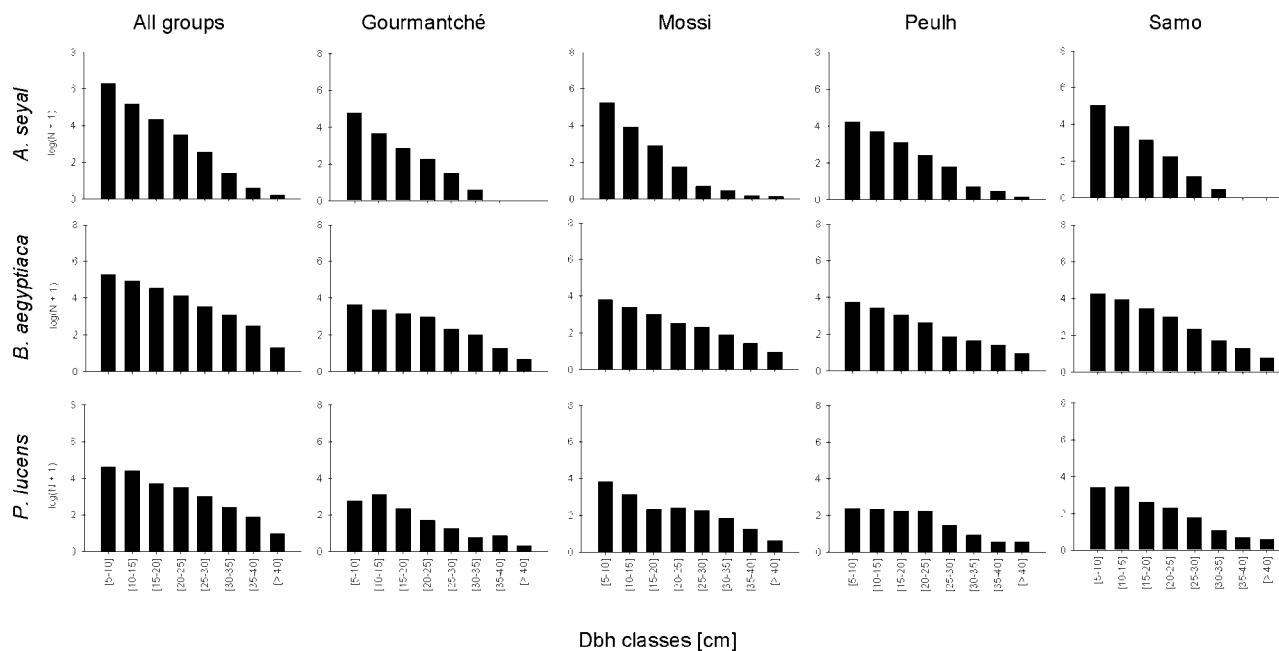


Figure 2. SCD plots of *A. seyal*, *B. aegyptiaca* and *P. lucens* in the Gourmantché, Fulani, Mossi and Samo ethnic areas. The y-axis represents $\ln(\text{individuals ha}^{-1} + 1)$ while the x-axis is diameter at breast height size-classes in 5 cm intervals from 5 to 40 cm.

The stable and healthy population structures of *A. seyal* and *B. aegyptiaca*, despite anthropogenic pressure, is an uncommon pattern for particularly valuable woody species in the Sahel in general. This could be explained, to a certain extent, by a potential change in resource management strategies by the people of the Sahel. Indeed, we observed during the field survey that few adult individuals in the stands of *A. seyal* and *B. aegyptiaca* were cut down completely, but instead were pruned, coppiced or pollarded, allowing resprouting and multi-stemmed regrowth.

The reverse J-shape distribution of *P. lucens* is questionable, since this species is currently considered to be seriously threatened in northern Burkina Faso (Sacande and Sanon, 2007) and has, for the past 30 years, been regarded to be in decline across the entire sahelo-sudanian region (Couteron *et al.*, 1992). Interviews with local populations of the four ethnic areas in 2007, 2008 and 2009 mentioned this plant as drastically declining in the four studied ethnic territories (Sop, unpublished data). In the context of continuous human and livestock population increase, and the subsequent augmentation in land use demands as well as the pressure exerted on this highly useful fodder plant, a recent reversal in population dynamics is highly unlikely. Furthermore, the apparent overall stable structure of the stands of *P. lucens*, showing more individuals in the lowest diameter classes, was unfortunately not supported by a consequent recruitment as expected for species with a reverse J-shape distribution (see Figure 3). Couteron (1992) reported that, in Sudano-Sahelian ecosystems, the population structures of *P.*

lucens were habitat-dependent with the hydric balance being the main driving factor. Sites with a weak hydric balance such as upland and open shrubby-savannas had high mortality of *P. lucens* while dense savannas and depressions with a more favourable hydric balance presented healthier individuals. Ouedraogo (2006) noted that the population structure of *P. lucens* in the Sahel of Burkina Faso varies from a reverse J-shape distribution in the tiger bush to an unstable distribution in the steppes where there is a trend towards the aging of populations. Our field observations showed that *P. lucens* has a versatile morphology depending on both substrate and vegetation type: on hills and coarse soils, *P. lucens* had predominantly a pruned phenotype with small and multi-stem adult individuals, generally of poor vitality. However, in depressions, near watercourses and on well drained sites and on deep sandy soils, thriving individuals were generally single-stems, taller with predominantly larger stem diameters.

Since the observed negative slope for *P. lucens* does not corroborate previous findings, we recommend further investigation to assess, notably, a potential effect of habitat variability on the population structure of *P. lucens*.

Seedlings' Population Structure and Regeneration Patterns

It is widely acknowledged that species with a reverse J-shaped SCD distribution are those having stable population structure, naturally replacing senesced individuals with

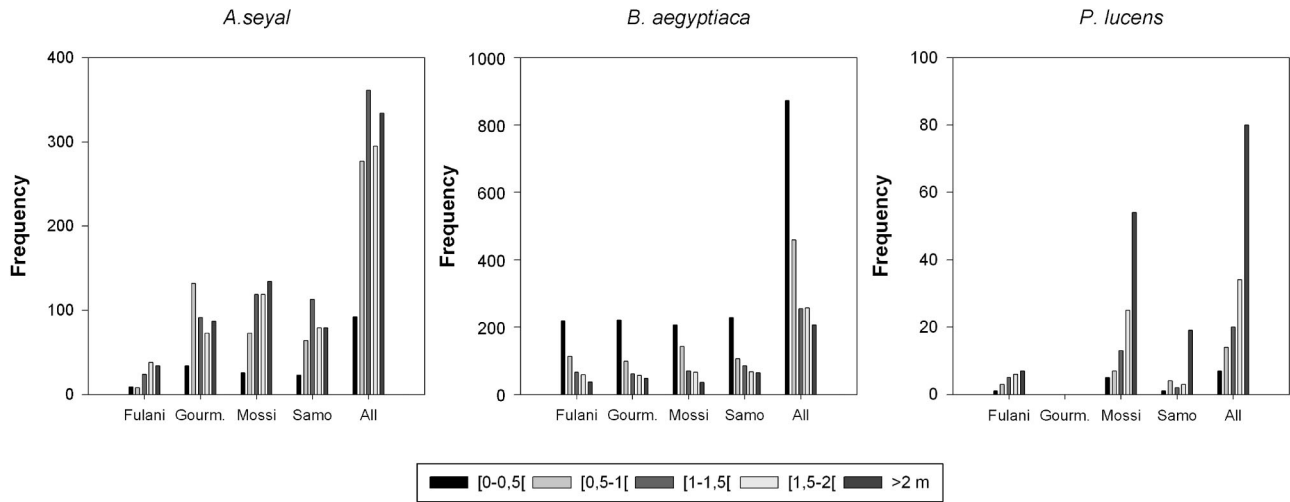


Figure 3. Height-class distribution of the regenerative individuals of *A. seyal*, *B. aegyptiaca* and *P. lucens* in Gourmantché, Fulani, Mossi and Samo ethnic areas.

seedlings and saplings (Condit *et al.*, 1998; Lykke, 1998; Obiri *et al.*, 2002; Tabuti, 2007; Mwavu and Witkowski, 2009). This appears to be the case for *A. seyal* and *B. aegyptiaca*, but not for *P. lucens*, *A. seyal* and *B. aegyptiaca* had, in all ethnic territories, a high number of young individuals as normally expected for species with a reverse J-shape SCD distribution. Conversely, *P. lucens* appeared to have poor regeneration, contradicting the apparently stable population structure displayed by the SCD analysis in all ethnic areas. Juvenile (seedlings/saplings) density and height-class distribution of the three species did not vary significantly with respect to ethnic territory (Table III).

In all ethnic areas, regenerative populations of *B. aegyptiaca* showed significant negative height-class distribution slopes (ranging from -0.59 in the Samo area to -0.78 to the Fulani area). The overall PI was zero or close to zero, indicating a good recruitment with a stable regeneration pattern. Height-class plots show a perfect reverse J-shaped profile showing more juveniles in the smallest classes (Figure 3).

Good regeneration was observed for *A. seyal*, with a relatively high seedling density varying from 695 ind. ha^{-1} in the Fulani area to $1588 \text{ ind. ha}^{-1}$ in the Gourmantché area. However, the positive height-class slopes (0.007 – 0.72) and the relatively high PI (8–12) in each the ethnic areas and

Table III. Summary of regeneration patterns of each species per ethnic area and in the entire study area: mean seedling density, slope of height-class regression and PI

Species	Ethnic areas	No. Subplots	Mean seedling density/Ha	SD	Height -class slopes				PI	Mean quotient \pm SD
					Slopes	SE	R^2	p		
<i>A. seyal</i>	Fulani	65	695.38	781.4	0.72	0.25	0.73	0.05	12	0.5 ± 0.1
	Gourm.	105	1588.57	1890	0.358	0.2	0.38	0.26	8	0.3 ± 0.1
	Mossi	140	1345.71	1127	0.007	0.13	0.96	0.000	12	0.4 ± 0.3
	Samo	105	1363.81	1084.1	0.6	0.15	0.76	0.13	12	0.3 ± 0.1
	ALL	415	1309.88	1320.8	0.58	0.12	0.82	0.07	12	0.4 ± 0.1
<i>B. aegyptiaca</i>	Fulani	100	2080	1264.6	-0.78	0.07	0.96	0.000	2	0.7 ± 0.3
	Gourm.	110	2444.45	1101.4	-0.7	0.03	0.98	0.000	0	0.7 ± 0.3
	Mossi	105	1885.71	1626.9	-0.74	0.11	0.89	0.001	2	0.7 ± 0.3
	Samo	90	1843.81	2537.4	-0.59	0.02	0.98	0.000	4	0.8 ± 0.4
	ALL	405	2049	1698.3	-0.66	0.05	0.97	0.00	0	0.7 ± 0.2
<i>P. lucens</i>	Fulani	65	135.4	207.5	0.9	0.04	0.98	0.16	12	1.6 ± 1.0
	Gourm.	130	0	0	0	0	0	0	0	1.6 ± 1.5
	Mossi	165	252.1	755	1	0.21	0.82	0.99	12	1.6 ± 0.8
	Samo	145	80	193.6	0.94	0.37	0.56	0.91	12	1.6 ± 0.9
	ALL	505	122.8	456.1	0.98	0.16	0.87	0.95	12	1.6 ± 1.0

across the study area, suggests a hampering of seedling establishment and growth of this species.

P. lucens had low seedling density (ranging from 0 in the Gourmantché area to 252 juveniles ha⁻¹ in the Mossi domain). Height-class distributions for this species showed J-shaped profiles and high PI values (12) in all ethnic territories, indicating an overall irregular recruitment. With so few seedlings and saplings, it is unlikely that the region-wide population of this species is in equilibrium. This reinforces our reservations about the reverse J-shape profile of adult *P. lucens* populations. Our results are nevertheless consistent with Couteron *et al.* (1992), who reported inhibited regeneration of *P. lucens* in northern Burkina Faso as a consequence of browsing pressure that prevents seedling establishment. Indeed, *P. lucens* is one of the most favoured palatable woody species in the Sahelian area of Burkina Faso, especially in the dry season. Germination inhibition due to the hard pericarp of the pods has also been mentioned as a cause of low seedling recruitment (Couteron *et al.*, 1992; Ouedraogo, 2006).

Indeed, the interest of analysing regeneration patterns using height class data is to highlight any inhibition of growth and survival facing the juveniles. The first class (0–0.5 m) represents the establishment phase of the regeneration and indicates the extent of recruitment, while the last class (>2 m) bridges the seedlings/saplings stage and the first diameter size class of young trees. Seedlings and individuals of the first height-class are especially vulnerable to various environmental and anthropogenic perturbations (Bognounou *et al.*, 2009).

B. aegyptiaca showed excellent regeneration capacity as attested by the greater frequency of seedlings in the 0–0.5 m height class in all ethnic areas and at the level of the whole study area (Figure 3). This is consistent with Ganaba (1994) (cited in Ouedraogo, 2006) who listed *B. aegyptiaca* among species that regenerate well in the Sahelian area of Burkina Faso. This is likely due to its highly efficient seed dispersal mechanism (Weber and Montes, 2009), as well as to post-coppicing regrowth, and a prolific production of abundant root suckers, which can develop at considerable distances from the mother tree (Hall, 1992; Bellefontaine, 2005). Vegetative regeneration capacity has an advantage over sexual regeneration for many species in harsh environments (Bognounou *et al.*, 2010) and is undoubtedly important in sustaining regular recruitment and stable populations for *B. aegyptiaca* in the Sahel. Furthermore, young individuals of *B. aegyptiaca* are reputed to grow very slowly (Ndoye *et al.*, 2003) and are heavily browsed by small ruminants, causing many juveniles to remain in the lowest height class for long periods of time.

Contrary to *B. aegyptiaca*, *A. seyal* showed unstable height class distribution profiles (despite a good recruitment) in all areas, characterised by low seedling density in the first

class. This might be an indication of the extreme vulnerability of the seedlings of *A. seyal* to prevailing perturbations. Indeed, stands of *A. seyal* were generally found near water points where sheep, goats and cattle graze, drink and rest. Mortality of young seedlings in the size class 0–0.5 m results from herbivory, trampling and other mechanical damage by the browsers (Tene Sop, personal observation). It is also important to note that seedlings of *A. seyal* are not resilient to browsing, unlike those of *B. aegyptiaca*. The latter have the ability to resprout after browsing, while the former cannot. *A. seyal* is reputed to regenerate well and to be a fast growing species (Argaw *et al.*, 1999). This important trait might also have contributed to the lower number of seedlings in the first class, in that individuals would rapidly grow beyond the seedling stage. The higher number of young individuals in the greater height-classes suggests that as soon as the seedlings exceed the first class they are better able to withstand the existing environmental and anthropogenic constraints.

CONCLUSION

The results of the present study indicate that the targeted multipurpose species had typical reverse J-shape SCDs in all ethnic territories and throughout the study area. Such a trend theoretically characterises species with stable population structures and good recruitment potential. However, analysis of the patterns of regenerative individuals showed contradicting regeneration patterns among the three species. Indeed, *Balanites* had a regular and stable regeneration while *A. seyal* showed a good but slightly disturbed regeneration pattern. *P. lucens* had a very poor and disturbed regeneration that brought into doubt the reverse J-shape depicted by the population structure of this species.

Although *A. seyal* and *B. aegyptiaca* proved to have overall stable and equilibrated populations, the situation might, however, rapidly change as a consequence of increasing human and livestock pressure in the open-access rangeland of the Sahel. Deservedly, Obiri *et al.* (2002) warned that uncontrolled use of even the most abundant and resilient resources can result in severe resource depletion and possibly irreversible degradation. We therefore recommend that sensitisation campaigns be used to encourage the peoples of the Sahelian area to use efficient and sustainable resource management practices.

Finally, this study has shown that each of the studied species had a similar pattern in all ethnic domains as no significant differences were found for SCD, or population and seedling densities. This suggests that plant species dynamics in the study area are unlikely to be governed by ethnic or cultural settings but rather by regional patterns including anthropogenic causes, unrelated to specific ethnic

practices, as well as climate and soil factors of the Sub-Saharan sector of Burkina Faso.

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