

ASSESSMENT OF THE STRUCTURAL ATTRIBUTES OF *VITELLARIA PARADOXA* CF. GAERTN. AND *PARKIA BIGLOBOSA* (JACQ.) BENTH. TO DISTURBANCE-RELATED DRIVERS IN MOLE NATIONAL PARK AND ADJACENT COMMUNITIES, IN GHANA'S SAVANNAH REGION

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ABSTRACT

Vitellaria paradoxa and *Parkia biglobosa* are natives of the African Savannah biome and are much valued for their numerous uses. However, they are fast losing their multipurpose role due to increasing environmental disturbances. This study examined the structural response of individuals to disturbances in Mole National Park (MNP) and Park-adjacent communities (PAC - Larabanga and Mognori). Polynomial regression was performed to determine the relationship between the structural attributes (dbh, crown size, density, and plant height). Principal component analysis was used to evaluate the influence of disturbance on the structural attributes. Overall, individual density did not differ substantially for *V. paradoxa* and *P. biglobosa* in the two land-use types. The density per ha of *V. paradoxa* and *P. biglobosa* was slightly higher in MNP than in PAC. Similarly, the dbh of *P. biglobosa* and *V. paradoxa* were larger in MNP compared with PAC. Key drivers like bushfires, animal trampling, bare ground, and erosion jointly explained 58.9% of variations in the structural attributes of the two species. As disturbances continue, it is almost certain that these multipurpose tree species are set to go extinct if they are not protected from further human impact by Park managers and land owners in PAC. Thus, to revert the current state of these MPTS, we proposed that government policymakers should institute the following measures four-point measures highlighted in the conclusion section of this study.

Keywords: Plant structural attributes, disturbances, principal component analysis, polynomial regression, vegetation types, protected areas, park adjacent communities.

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INTRODUCTION

Multipurpose trees such as *Vitellaria paradoxa* and *Parkia biglobosa* are natives of the African Savannah biome (Lompo et al., 2017) and are much valued for their numerous socio-economic and ecological uses (ecosystem services). On the part of socio-economic values, their products such as food and medicine (Ouedraogo, 1995; Sacande and Clethero, 2007; Orwa et al., 2009; Egbewole et al., 2015) and trees used for traditional beekeeping (Nombré et al. 2009; Schweitzer et al. 2014), contribute to income generation for rural communities (Kakaï et al., 2011). Besides being one of the key sources of fuelwood in Ghana, the uses of *Vitellaria paradoxa* (shea tree) nut for shea butter extraction and the seeds of *Parkia biglobosa* (Dawadawa tree) for making dawadawa, has partly supported the livelihood of about 30% of the population (Yaro, 2008).

On the part of their ecological importance, *Parkia biglobosa* plays a critical role in nutrient cycling (Gbadamosi, 2005; Udobi et al., 2010) and is shown to have a high intrazonal genetic diversity within humid forest agro-ecological zones (Amusa et al., 2014). Farmers in Africa preserve these valuable resources by nurturing them in an agroforestry system within the agricultural lands, characterized by scattered trees on fallow and cultivated land. The multiple uses of these species made them acquire protective status in most parts of their ranges (Bonkougou, 2002; Oni, 2006).

The two species are fast losing their multipurpose role due to increasing population pressure (Boffa, 1999) as the natural forest can no longer meet the demand on it for timber, food, and other forms of livelihood (Ismaila and Abibou, 2002). These human-led factors have significantly contributed to their population decline in recent times (AbdulRahaman

et al., 2016). These species' exploitation rates cut across protected and unprotected ecosystems (AbdulRahaman et al., 2016). In the Sudan savannah zone, for instance, the highest density of shea trees (*Vitellaria paradoxa*) in the 1940s, was estimated to be 230 trees ha⁻¹ (Chevalier, 1946). However, the last six decades saw a significant reduction in density to a minimum of 11 trees ha⁻¹ (Nikiema et al., 2001) largely due to profound changes in farmers' practices.

Studies by Kelly et al. (2004) on the impact of farmers' practices on size class distribution and spatial pattern of *Vitellaria paradoxa* in Mali, reported that the species was gradually becoming aggregated with a gradient ranging from cultivated fields to fallow and finally to forest zones. A similar decline in the population of these species has been reported in Biosphere reserves in Benin (Djossa et al., 2008). The intensive cropping system in most Sudanian Savannah regions is not favourable for species recruitment in cultivated lands (Raebild et al., 2012). These disturbances coupled with unsustainable harvesting of the fruits of *Vitellaria paradoxa* and *Parkia biglobosa* by humans and foraging pressure by animals (especially primates and elephants), exploitation for fuelwood, and medicinal use, have contributed significantly to their low regeneration success (Djossa et al., 2008; Raebild et al., 2012; Lompo et al., 2017).

Dogbevi (2009) estimated that 9.4 million *Vitellaria paradoxa* trees were found in both protected and unprotected areas, and covered about 77,670 km² of Ghana's northern land (Hatskevich et al., 2011). Though not scientifically investigated, some indigenous farmers (e.g., Mr. Mohammed Pers. Comm.) and Park managers (e.g., Mr. Ali Mohammed, Pers. Comm.) in protected areas of Northern Ghana, have observed a recent population decline of *Vitellaria paradoxa* and *Parkia biglobosa*. No scientific

studies on the factors that influence the structural dynamics of these two species in Mole National Park (MNP) and Park adjacent communities (PAC). Given the high conservation concern of the Savannah biome in the Northern Region of Ghana, due to the cascading impact of climate change (Owusu, 2017) and environmental disturbances like incidence of bushfire, herbivory, and illegal logging, especially in MNP (Nsor *et al.*, 2018) and PAC (i.e., Larabanga and Mognori), it is envisaged that the population of these species will further reduce, with a consequent effect on the already fragile ecosystem. Thus, understanding how current threats like fire, erosion, animal trampling, tree felling, and the bare ground will impact the structural attributes or characteristics (i.e., diameter at breast height, crown size, and height) is critical in the implementation of the right conservation measures, to protect these multipurpose tree species. This study aimed to assess how the structural characteristics of individuals of *Vitellaria paradoxa* and *Parkia biglobosa* responded to the prevailing environmental disturbances in Mole National Park and Park adjacent communities. We hypothesized that the impact of environmental disturbances will not reflect variations in the structural characteristics among individuals of the two species in MNP – (protected area) and PAC – (unprotected areas).

MATERIALS AND METHODS

Study sites

The Mole National Park (MNP) and Park adjacent communities (PAC) - Larabanga and Mognori communities where this study was conducted are located in the Northern Region of Ghana. The MNP is the largest and earliest protected area in Ghana covering an area of 4,577 km². It is situated geographically between latitudes 9° 11' and 10° 10' N and

longitudes 1° 22' and 2° 13' W, with an elevation of 120 to 490 meters above sea level (Figure 1). Rainfall averages between 1100 mm annually and decreases to 1000 mm in the northern parts of the park, with a mean temperature of 28° C which switches to 26° C and 31° C in December and March respectively (MNP, 2011). Relative humidity reaches 90% at night and decreases to about 70% in the afternoons for rainy reasons. In the dry seasons, relative humidity is 50% at night and 20% during the day (MNP, 2011). Vegetation is fairly undisturbed Guinea Savannah dominated by open savannah woodland interspersed with grasses. Dominant savannah woodland species like *Burkea Africana* Hook. *Terminalia macroptera* Guill. & Perr. *Anogeissus leiocarpa* (DC.) Guill. and *Vitellaria paradoxa* C.F. Gaertn. grow on well-drained and deep soils and are often found on a granite outcrop. Plant species numbering 742 which include 148 trees are natives to MNP (Schmitt and Adu-Nsiah, 1993). *V. paradoxa* C.F. Gaertn. and *Parkia biglobosa* (Jacq.) are of management interest within the park due to their high local and commercial values. Other management interests include the protection of wildlife from poaching and the conservation of freshwater aquifers that traverse the length and breadth of the park. However, these plants are common outside the park (MNP, 2011). Mole National Park has 33 fringe communities with an estimated population of about 40,000. Their livelihood depends on peasant crop farming, shea butter extraction, honey production, and livestock rearing (MNP, 2011). Fire is one of the major management tools used to induce early vegetation sprout, especially in the long dry season. This management measure is employed in the form of controlled or prescribed burning among the vegetation types.

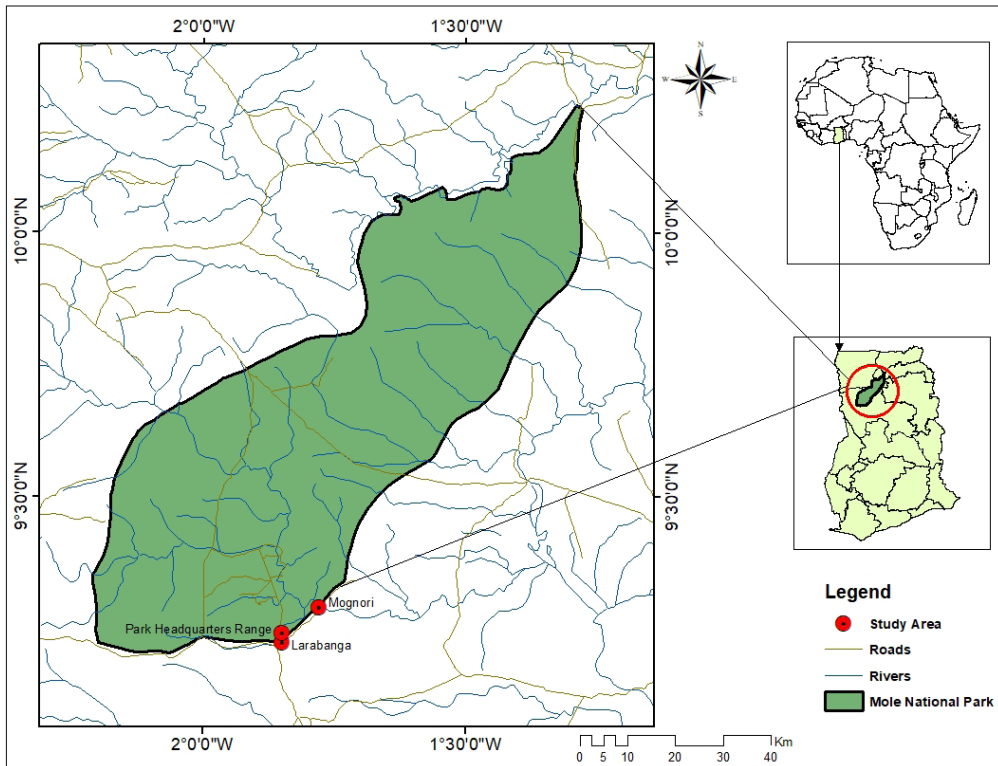


Figure 1: Map of Ghana, showing the selected area of study in Mole National Park (Headquarters Range) and Park adjacent communities (i.e., Larabanga and Mognori)

Plant sampling procedure

Plant data were collected in four different plant vegetation types: Open savannah woodland, Riparian Forest, Shrubland, and Grassland in the MNP and agroforestry lands in park adjacent communities (i.e., Larabanga and Mognori). Each plot in the four vegetation types was classified into condition classes, based on the scope and severity of driver impacts (i.e., farming, grazing intensity, erosion, and fire regimes), by adopting the model approach of Battisti *et al.* (2009), which takes into consideration the relative severity and scope of identified threats. Here, a driver is defined according to the Millennium Ecosystem Assessment (MA), as any natural or human-induced factor that directly (physical and biological) or indirectly

causes a change in an ecosystem (Carpenter *et al.*, 2006; Neuhauser and Pacala, 1999). A direct driver tends to influence ecosystem processes, while an indirect driver operates in a more diffused form, by changing one or more direct drivers (Nelson *et al.*, 2006). Thus, these disturbance-related drivers were considered as possible predictors that may have contributed to influencing the structural attribute dynamics of especially young saplings of *V. paradoxa* and *P. biglobosa*.

These disturbance-related drivers were identified and recorded, following ground validation assessment. A score ranging from 1 to 4 (1 being the lesser impact and 4 being the highest impact) was employed to assess the scope and severity of every threat. More precisely, for 'scope' we referred to

the percentage ratio in each study area (i.e., vegetation type) affected by a specific driver within the last 5 years (where 100% correspond to total site: ha) (Battisti *et al.*, 2009). The scores were assigned as follows: 4: the driver is found throughout (50%) of the study area; 3: the driver is spread in 15–50% of the study area; 2: the driver is scattered (5–15%); and 1: the driver is much localized (< 5%).

For “severity” we referred to the degree to which a disturbance-related driver has an impact on the viability or integrity of plant species across the four vegetation types within the last 5 years. A score of 4 was assigned if the direct driver led to serious damage or loss of the plant species; 3 if induced serious damage; 2 if induced moderate damage; and 1, if little or no damage. Finally, for each driver, we computed their “magnitude” which is the sum of the average values for scope and severity assigned to a specific driver and ranked from the highest to the lowest

value (Salafsky *et al.*, 2003). These drivers are either added either together, multiplied, or averaged, since in arithmetic calculations (addition, multiplication, or average) relative order does not change (Salafsky *et al.*, 2003).

The assessment of all identified threats was carried out within each nested plot. Six nested plots, 400 m² (20 m x 20 m) were randomly laid in each of the vegetation types, from August to December 2018, bringing the total to 48 plots. The plots were at different scales of 4 m², 25 m², and 400 m². Five of the 5 m x 5 m sub-plots were placed at the corners and in the middle of each plot, while five of the 2 m x 2 m quadrats were placed at the edges of each plot. Trees with a diameter at breast height (*dbh*) of 2 – 5 cm, 5 – 10 cm, and >10 cm, were recorded in the 2 m x 2 m, 5 m x 5 m, and 20 m x 20 m, respectively. Tree height was measured using The Haglof Vertex IV Range Finder 15-105-1009 Transponder (Mall WTC Matahari Serpong UG Fl. U10 Tangsel).

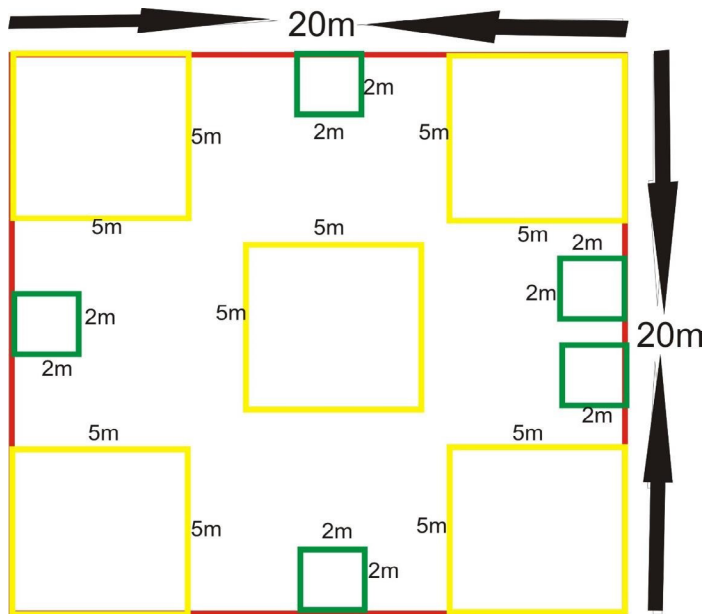


Figure 2: Schematic design of plot layout in different vegetation types for sampling. The alphabets. A, B & C represented 20 m x 20 m, 5 m x 5 m and 2 m x 2 m plot dimensions

Data analysis

A priori test was conducted to determine whether sample plots were normally distributed (i.e., parametric) or otherwise (non-parametric), using the Shapiro-Wilk test. A polynomial regression model (a general linear regression) was performed to determine the relationship between the structural attributes of the two MPTS, namely diameter at breast height (*dbh*) and crown size, *dbh*, density, and plant height. The model fit function $\hat{Y} = b_0 + b_1x_1 + b_2x_k^k + \dots + b_kx_k^k$ was used to fit the k order of the plant data, where \hat{Y} caret is the predicted outcome value for the polynomial model with regression coefficient b_1 to k for each order/degree and Y intercept b_0 . The k predictors raised the power of i , where $i = 1$ to k . (Kleinbaum et al., 1998). Kruskal-Wallis's test was used to test for overall significant differences among individuals of the two species and the six identified threats across the four sites, in the park and Park adjacent communities since our initial test showed that our plots were not normally distributed ($W = 4.5$, $P < 0.05$, Shapiro-Wilk test). Wilcoxon matched pair test was used to determine differences in the abundance of *V. paradoxa* and *P. biglobosa* across the four vegetation types and between the PAC and MNP.

Principal component analysis (an indirect or gradient) (Goodall, 1954) was performed to evaluate the influence of disturbance-related drivers on the variability in structural attributes like *dbh*, crown cover and plant height, and overall individual turn-over. PCA helps to synthesize the environmental dataset and to produce an ordination of quadrats that is based on environmental variables alone (Kent and Coker, 1992). Secondly, whereas all the former variables are highly intercorrelated, the new components are completely uncorrelated and are described as orthogonal and uncorrelated (Kent and

Coker, 1992). A Monte-Carlo permutation test (9999 permutations) was used to test for the significance of the eigenvalues generated by the first three axes in the analyses of the tree structure-driver relationship. All analyses were performed using PAST ver. 3.06 software package (Hammer et al., 2001).

RESULTS

Comparison of density of *Vitellaria paradoxa* and *Parkia biglobosa* across the vegetation types in Mole MNP and PAC

A total of 217 and 179 individuals of *Vitellaria paradoxa* were sampled in the National Park and Park adjacent communities (Larabanga and Mognori), respectively, while nine and five individuals of *Parkia biglobosa* were sampled in the park and Park adjacent communities (Table 1). *V. paradoxa* (from the Savanna woodland, $n = 168$) registered the highest number in the park and adjacent communities (from shrubland vegetation type, $n = 72$).

Overall, the abundance of *V. paradoxa* ($W = 6$, $Z = 0.37$, $P = 0.72$) and *Parkia biglobosa* ($W = 3$, $Z = 1.4$, $P = 0.16$) did not differ significantly between the two land use types. We equally observed from individual land use types, that *V. paradoxa* did not vary substantially across the four vegetation types in Mole National Park ($W = 6$, $Z = 1.60$, $P = 0.11$, *Wilcoxon sign rank test*), and adjacent communities (PAC) ($W = 10$, $Z = 1.83$, $P = 0.068$, *Wilcoxon sign rank test*), likewise *Parkia biglobosa* in MNP ($W = 6$, $Z = 1.6$, $P = 0.10$) and PAC ($W = 3$, $Z = 1.34$, $P = 0.18$).

Comparatively, species density per plot did not differ significantly for *V. paradoxa* ($Hc = 5.5$, $P = 0.14$, *Kruskal-Wallis test*) and *P. biglobosa* ($Hc = 5.848$, $P = 0.12$, *Kruskal-Wallis test*) in the two land-use types (MNP

and PAC) and among the four vegetation types ($P > 0.05$) (Table 2). The number of individuals per hectare of *V. paradoxa* was 0.0000054/ha and 0.0000045/ha in MNP and PAC, respectively. Whereas *P. biglobosa* was found to be 0.0000023/ha and 0.0000013/ha in MNP and PAC. However, from individual

vegetation types, density per plot of *V. paradoxa* was highest in savannah woodland (0.0000042/ha) in MNP and shrubland (0.0000018/ha) in PAC. *P. biglobosa* was found to have the highest density per plot in the riparian zone (0.0000001/ha) in the two land-use types (Table 2).

Table 1. Number of individuals of *V. paradoxa* and *P. biglobosa* sampled in each of the four vegetation types in MNP and PAC (Larabanga and Mognori)

Sites	<i>Vitellaria paradoxa</i>			<i>Parkia biglobosa</i>		
	Mole National Park	Park adjacent communities	Total	Mole National Park	Park adjacent communities	Total
Savannah woodland	168	70	238	2	0	2
Riparian zone	1	3	4	4	4	8
Grassland	0	34	34	3	1	4
Shrubland	48	72	120	0	0	0
Mean ± S.E.	54.3 ± 39.5	44.8 ± 16.4		2.3 ± 0.9	1 ± 0.9	
Total	217	179	396	9	5	14

Size-class distribution (SCD) of *V. paradoxa* and *P. biglobosa* across the four vegetation types in MNP and PAC

Generally, the *dbh* classes of *V. paradoxa* and *P. Biglobosa* ranged between 2 – 10⁺ cm in the four vegetation types across the two sites (Table 3). *Vitellaria paradoxa* with a *dbh* class range of 2 - 5 cm recorded the highest number of individuals in the two sites, while *P. biglobosa* was the least among all *dbh* classes in the two sites. The majority of *V. paradoxa* ($n = 86 - 44$) with a *dbh* range of 2 – 10⁺ were found in the Savannah woodland of MNP (Table 2). The riparian zone supported the largest *dbh* for *V. paradoxa*, in MNP (35.01 ± 0.0) and PAC (33.63 ± 8.3), while, the shrubland registered the least *dbh* in the two sites (MNP = 4.34 cm ± S.E. 0.3; PAC = 5.46 cm ± S.E. 0.5) (Figure 3). For *P. biglobosa*,

we observed the largest *dbh* recorded in the grassland type in MNP (84.98 cm ± S.E. 9.4), while the least was registered in the same vegetation type in PAC (3.5 ± 0.0) (Figure 3). The tallest individuals of *V. paradoxa* (10.67 m ± S.E. 3.7) were found in the riparian zone in PAC, while the shortest was registered in the shrubland (1.32 ± S.E. 0.1) in MNP.

The mean height of *P. biglobosa* ranged between 17.33± S.E. 9.4 - 2.0 ± S.E. 0.0 in the grassland community of the MNP and PAC, respectively. Despite these variations in *dbh* and height classes among the vegetation types, *V. paradoxa* (*dbh*: t -test = 0.83, $P = 0.44$; height = t -test = 1.31, $P = 0.24$) and *P. biglobosa* (*dbh*: t -test = 1.78, $P = 0.12$; height: t -test = 1.45; $P = 0.19$) did not vary substantially between MNP and PAC, respectively (Figures 3 & 4).

Table 2. Number of individuals per ha for each vegetation type for *V. paradoxa* and *P. biglobosa* in MNP and PAC

Sites	<i>Vitellaria paradoxa</i>				<i>Parkia biglobosa</i>			
	Mole National Park	Park adjacent communities	Total	Mole National Park	Park adjacent communities	Total		
Savannah woodland	0.0000042	0.00000175	5.59e-5	0.00000005	0.0	5e-7		
Riparian zone	0.000000025	0.000000075	1e-6	0.0000001	0.0000001	2e-6		
Grassland	0	0.00000085	8.5e-6	0.000000075	0.000000025	1e-6		
Shrubland	0.0000012	0.0000018	3e-5	0.0	0.0	0		
Mean ± S.E	0.14 ± 0.09	0.112 ± 0.04		0.006 ± 0.002	0.003 ± 0.002			
Total	0.0000054	0.0000045		0.0000023	0.0000013			

Table 3. Diameter at breast height (dbh) classes of *V. paradoxa* and *P. biglobosa* among the four plant community types in the park and the adjacent communities

dbh	<i>Vitellaria paradoxa</i>							
	Savanna woodland		Riparian zone		Grassland		Shrubland	
	MNP	PAC	MNP	PAC	MNP	PAC	MNP	PAC
2-5	86	13	0	0	0	0	37	58
5.1-9.9	38	9	0	0	0	4	8	4
10+	44	48	1	3	0	30	3	10
<i>Parkia biglobosa</i>								
dbh	Savanna woodland		Riparian zone		Grassland		Shrubland	
	MNP	PAC	MNP	PAC	MNP	PAC	MNP	PAC
2-5	0	0	1	0	0	1	0	0
5.1-9.9	0	0	0	0	0	0	0	0
10+	2	0	3	4	3	0	0	0

Assessment of the structural attributes of vitellaria paradoxa

The crown size of *V. paradoxa* and *P. biglobosa* ranged between 0.3 – 13 m and 0.25 – 22 m, respectively, across the four vegetation types in the two sites. Comparatively, *V. paradoxa* (t -test = 1.47, P = 0.19) and *P. biglobosa* (t -test = 1.96, P = 0.1) did not differ significantly

between the two sites (Figure 5). Generally, the crown size of *P. biglobosa* was found to be the largest in about 90% of the vegetation types (Savannah woodland, riparian, and grassland-dominated communities) compared with *V. paradoxa* (Figure 5).

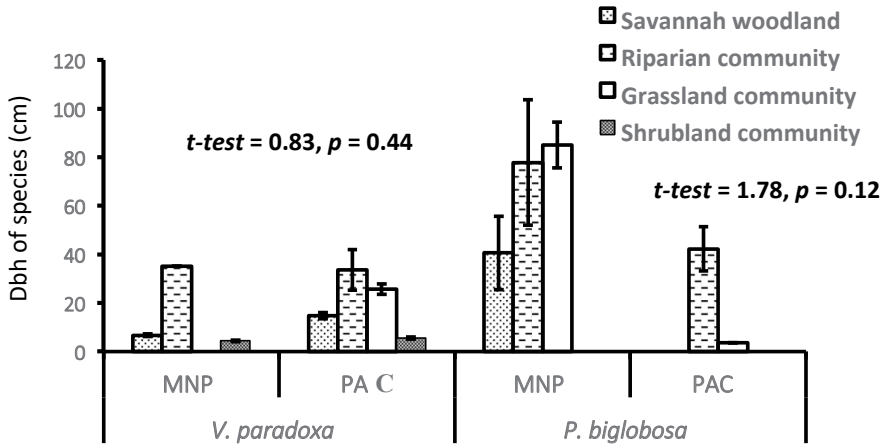


Figure 3: Variations in dbh of *V. paradoxa* and *P. biglobosa* in Mole National Park (MNP) and Park adjacent communities (PAC). Notice that individuals of *P. biglobosa* had the biggest dbh in MNP and PAC

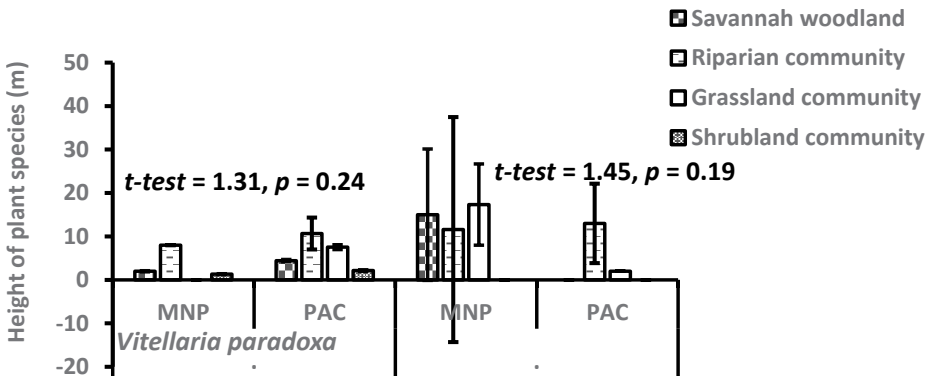


Figure 4: Comparison of the height of *V. paradoxa* and *P. biglobosa* in Mole National Park (MNP) and Park adjacent communities (PAC). Notice that *P. biglobosa* species were the tallest both in MNP and PAC

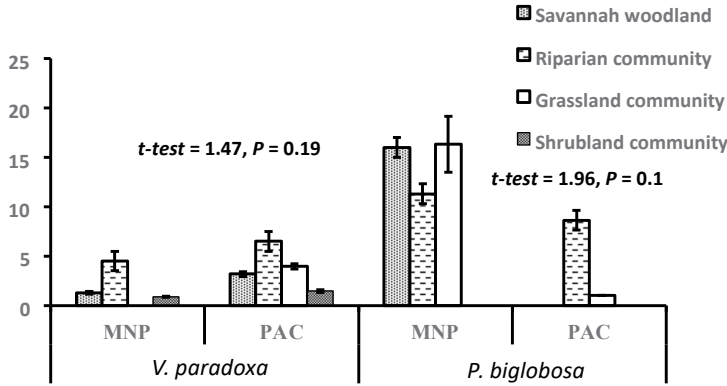
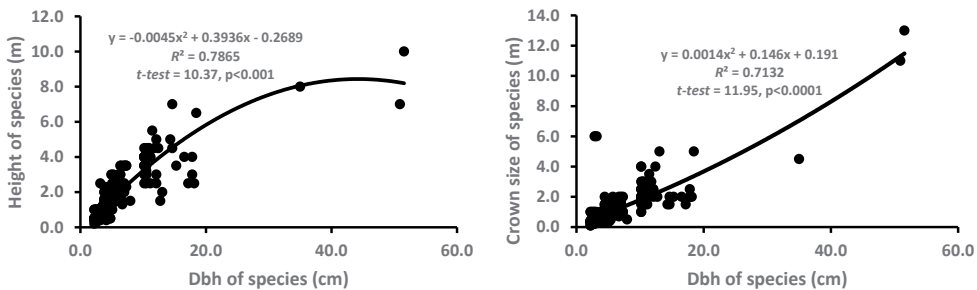


Figure 5: Variations in crown size of *V. paradoxa* and *P. biglobosa* in Mole National Park (MNP) and park adjacent communities (PAC). Notice that *P. biglobosa* had the biggest crown size in MNP and PAC

Relationship between structural attributes *V. paradoxa* and *P. biglobosa* in MNP and Park PAC

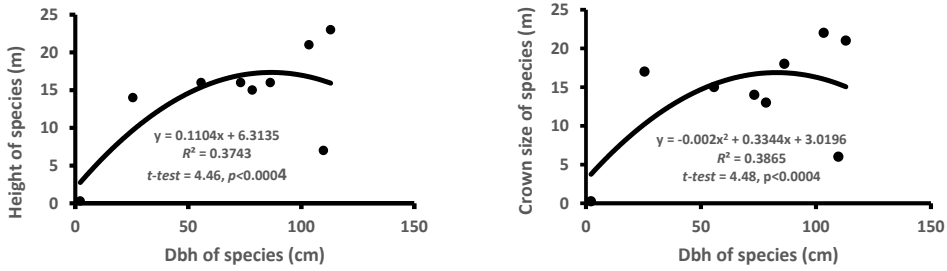
The relationship between *dbh* and plant height ($r^2 = 0.79$; $P = 0.0001$, $t\text{-test} = 10.37$) and *dbh* and crown size ($r^2 = 0.71$, $P = 0.0001$, $t\text{-test} = 11.95$) of *V. paradoxa* was found to be very strong in the four vegetation types in MNP (Figure 6a). For *P. biglobosa*, we observed the relationship between *dbh* and plant height ($r^2 = 0.37$) and *dbh* and crown size ($r^2 = 0.38$) to be marginally weak in the four vegetation types in MNP, although the structural characteristics among individuals appear to vary substantially ($t\text{-test} = 4.46$, P

$= 0.0004$ and $t\text{-test} = 4.48.92$, $P = 0.00004$, respectively) (Figure 6b). However, in PAC, the relationships between *dbh* and plant height ($r^2 = 0.84$) and *dbh* and crown size ($r^2 = 0.88$) showed a strong correlation for individuals of *V. paradoxa* (Figure 7a). This strong relationship is reflected in the significant differences between the *dbh* and plant height ($t\text{-test} = 10.02$, $P = 0.0001$) and *dbh* and crown size ($t\text{-test} = 11.92$, $P = 0.0001$). Similarly, individuals of *P. biglobosa*, also correlated strongly between the *dbh* and plant height ($r^2 = 0.99$, $P = 0.06$, $t\text{-test} = 2.18$,) and *dbh* and crown size ($r^2 = 0.98$, $P = 0.03$, $t\text{-test} = 11.92$) in PAC (Figure 7b).



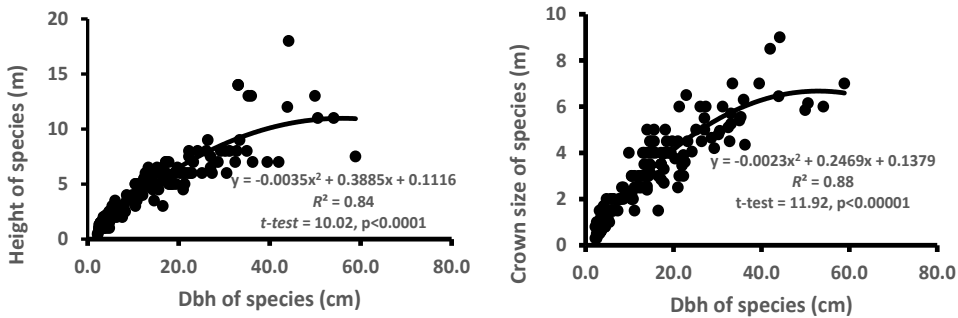
(a)

Assessment of the structural attributes of *vitellaria paradoxa*

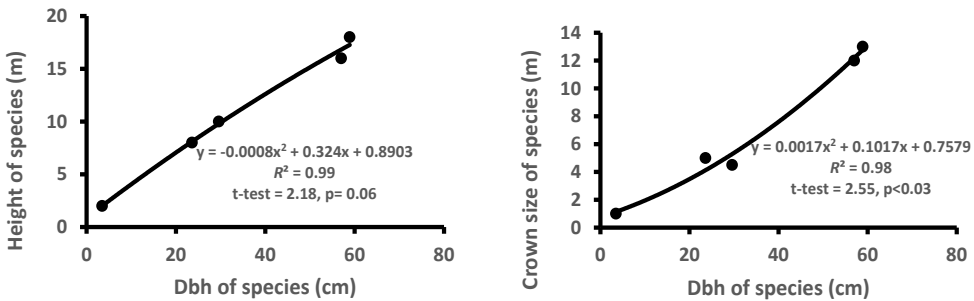


(b)

Figure 6: (a) Relationship between *dbh* and plant height, crown size for *V. paradoxa*, and (b) *P. biglobosa* in MNP



(a)



(b)

Figure 7: (a). Influence of *dbh* and plant height for *V. paradoxa* and (b) *P. biglobosa* in PAC. Notice the strong correlation between the structural attributes of the two species

Relationship between disturbance-related drivers and structural attributes of *V. paradoxa* and *P. biglobosa* among the four vegetation types in MNP and PAC

The principal component analysis (PCA) ordination diagram showed that bare ground ($r = 0.63$, $P = 0.05$), animal trampling ($r = 0.57$, $P = 0.05$) on PC 1 and bushfire ($r = -0.69$, $P = 0.05$) and erosion ($r = 0.52$, $P = 0.05$), on PC 2, were the major drivers that impacted on the structural characteristics of *Vitellaria paradoxa* and *Parkia biglobosa* (Figure 8, Table 4). These disturbance-related drivers substantially differed among the plots in the five plant community types ($H_c = 74.44$, $P = 0.006$, *Kruskal-Wallis's test*). Further Monte-Carlo test, revealed significant differences ($P = 0.05$) in processes that influenced the structural characteristics of individuals. The first two components (PC1 = 34.5% and PC 2 = 24.4%) jointly accounted for 58.9% of the variances in the structural attributes (i.e., *dbh*, crown cover, and plant height) among individuals of the two species (Figure 8, Table 4). Individuals in plots found in the woodland, shrubland, and grassland vegetation types in MNP (e.g., WDI 1, WDI 2, WDI 3, WDI 4, WDI 5, SHI 42, GRI 26, and GRI 29, in the lower right of the ordination diagram), responded positively to the incidence of fire. This was evidenced in their larger *dbh*, crown size, and overall high abundance.

The occurrence of fire, animal trampling (by Elephants, Buffalos, and Kobs), erosion and bare ground in the majority of the plots (~ 72.9%) (as shown in the upper right and lower left of the diagram), were nearly proportional in PAC and MNP, and across the four vegetation types. Nearly 47.8% of individuals (mostly juveniles) were the most affected by these disturbances, as was manifested in their mean *dbh* being < 5 cm ($3.4 \pm$ S.E. 0.06) as well as their abundance. Plots where widespread tree felling occurred, positively correlated with bare ground ($r_s = 0.63$, $P = 0.05$) and bushfire ($r_s = 0.82$, $P = 0.01$) across the two sites (Table 5). Erosion was found to be prevalent in areas of excessive tree-felling activities ($r_s = 0.48$, $P = 0.05$) (Table 5).

Individuals of *V. paradoxa* as shown in the upper left of the ordination diagram (RPO 19, RPO 20, RPO 22, RPO 23, and GRI 25), were generally less impacted by erosion, bushfire, animal trampling, and tree felling. These plots were mainly from the riparian zone in PAC and constituted approximately 10.4% of the total sample plots. The presence of larger *dbh* (35.01 cm \pm S.E. 0.01) and the mean height of $10.67 \pm$ S.E. 3.7 among individuals of *Vitellaria paradoxa* in this PAC, was indicative of the lesser impact of the disturbances. Only individuals from two plots in the shrubland vegetation type (SHO 46 and SHO 47) and one plot from the grassland vegetation type (GRO 24), were negatively impacted by erosion (Figure 8). Notwithstanding the eroded portions in these plots, we observed fewer than 11 individuals with larger *dbh*, (10 cm).

Assessment of the structural attributes of vitellaria paradoxa

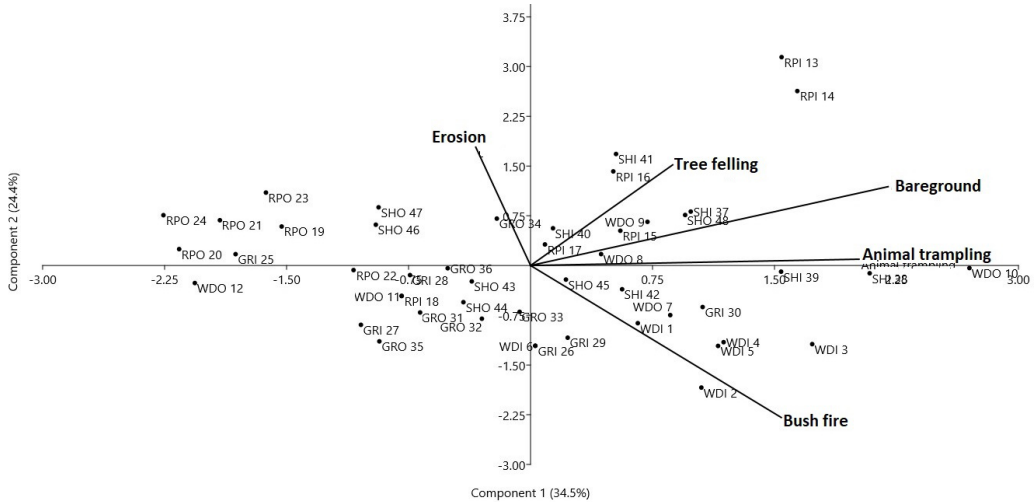


Figure 8: Principal component analysis (PCA) diagram, showing the influence of disturbance-related drivers on plant structural attributes, in 48 plots from Park adjacent communities and Mole National Park.

The arrows represent each of the disturbance-related drivers plotted to point in the direction of maximum change of explanatory variables on a longitudinal gradient of the two sites. Axes 1 = 34.5% and Axes 2 = 24.4% jointly explained the 58.9% influence of drivers on individuals’ structural attributes and overall

abundance. Plots were coded according to the vegetation type where individuals were sampled. WDI1 – WDO12, represent plots from woodland vegetation plots; RP13 – RPO 24 = riparian vegetation plots; GRI 25 – GRO 36 = grassland vegetation plots and SHI 37 – SHO 48 = shrubland vegetation plots

Table 4. Summary of PCA axis length for plant species, showing the levels of correlation between individuals in the respective plots and environmental disturbances. Asterisk (*) = significant environmental disturbances, following the Monte-Carlo permutation test at 9999 iteration, $p < 0.05$

	PC 1	PC 2	PC 3
Eigenvalues	1.402	0.992	0.731
% Variance explained (58.9)	34.5	24.4	17.9
Number of sites =	3		
Number of individuals (response variables) =	410		
Number of environmental variables =	5		
<i>Correlation</i>			
Bare ground	0.630*	0.341	-0.66*
Bushfire	0.442	-0.694*	-0.064
Tree felling	0.251	0.435	0.521*
Animal trampling	0.579*	0.027	0.524*
Erosion	-0.097	0.511*	-0.113

Table 5. Summary of Spearman rank (r_s) correlation matrix between the drivers in the Mole National Park and park adjacent communities. Significance of R values: * $p < 0.05$; ** $p = 0.01$

	Bare ground	Bushfire	Tree felling	Animal trampling	Erosion
Bare ground			0.269	0.630*	0.042
Bushfire				0.82**	0.126
Tree felling					0.248
Animal trampling					0.612*
Soil erosion					0.481*

DISCUSSION

Comparison of density of *Vitellaria paradoxa* and *Parkia biglobosa* across the vegetation types in MNP and PAC

The decline in species density has been linked to habitat loss and fragmentation (Oliviera, 2001), the prevalence of alien invasive species (Hobbs and Yates, 2003), and biotic conditions (Farmilo *et al.*, 2013). In this study, variations in the number of individuals per hectare of *Vitellaria paradoxa* and *Parkia biglobosa* were attributed to different land use and vegetation types. The marginally high species density in Mole National Park (a managed protected area), was due to a relatively lesser driver impact than in park-adjacent communities (unprotected areas), where the impact of disturbance was more severe and widespread. These species were mostly found in fragmented patches of farmlands and open grazing lands in the park-adjacent communities. Thus, the low density per hectare of *V. paradoxa* and *P. biglobosa* suggests that increasing human-led activities such as excessive felling of the species for domestic use, land clearing for farming purposes, and uncontrolled fires, could further isolate them into much smaller fragmented patches, making them less resilient in the process and consequently

extinct their genetic diversity. Species that occur in small isolated populations as a result of land fragmentation, are more susceptible to inbreeding depression, leading to decreased genetic diversity and reduced ability to adapt to changes in environmental conditions (Frankham and Ralls, 1998; Benítez-Malvido and Martínez-Ramos, 2003; Frankham, 2005). Hobbs and Yates (2003) also contend that the abundance of native species is at risk of local extinction, due to their vulnerability to landscape disturbances in isolated habitat fragments.

Variations in the number of individuals per hectare based on vegetation type were probably due to habitat-specific resilience or resistance to disturbance-related drivers like annual fires in the different land-use types. Resilience describes the ability of a system to endure disturbances and consists of two factors, the resistance to a disturbance and the recovery to a pre-disturbance state after the disturbance occurred (Hodgson *et al.*, 2015). Hartung *et al.* (2021) suggested that the resilience of a habitat to disturbances is due to their adaptation to increasing recurrent disturbances like fires. Besides the habitat resilience, an abundance of individuals per ha of *V. paradoxa* in MNP, and *P. biglobosa* in the shrubland vegetation in MNP and PAC, may be linked to the development of certain adaptive traits over time to withstand the

frequent occurrence of disturbances like fire and animal trampling. These species of savanna-origin are characterized by coarse thick bark and asperous leaves (Cunningham, 2001; Wilson & Witkowski, 2003), which probably make them withstand fire regimes mostly in the dry season. Thus, the ability of these two woody species to tolerate severe impacts of disturbances is in line with the statement of Grime (1979) about stress-tolerant species. The author pointed out that many stress-tolerant species are adapted to survive in conditions in which productivity is chronically or seasonally limited. Keeley (2011) concluded that plant traits such as resprouting, serotiny and germination by heat and smoke, are some of the adaptive strategies that plants use to survive in fire-prone environments.

Relationship between disturbance-related drivers and the structural attributes of *V. paradoxa* and *P. biglobosa* among the four vegetation types in MNP and PAC

Several studies have linked the decline of plant species populations to habitat loss and fragmentation (caused by fire and herbivory) (Oliviera, 2001; Fahrig, 2003), edge effects (Farmilo *et al.*, 2013), and prevalence of alien invasive species (Hobbs and Yates, 2003). The over exploitation of *V. paradoxa* C.F. Gaertn. and *P. biglobosa* (Jacq.) Benth. that led to their rapid decline, especially in sub-Saharan countries, was attributed to an increase in human population growth, increasing land fragmentation, and high demand for fuelwood, especially charcoal (Okiror *et al.*, 2011; Udo *et al.*, 2016). In this study, we found the incidence of fire, animal trampling, bare ground, and erosion, as the key drivers that affected the abundance, density, and structural attributes (i.e., *dbh*, crown size, and plant height) of *V. paradoxa* and *P. biglobosa* in park adjacent communities (PAC) than

in Mole National Park (MNP). While the influence of disturbances on some stand parameters differed, disturbances on others like stand density were almost similar in PAC and MNP. This suggests that the scope and severity of disturbances like fire were similar in the two land use types. The indiscriminate use of fire for hunting, land preparation, honey extraction, and charcoal production by the rural folks in PAC, often sweeps into the park, and in the process affects the density of these woody species. Additionally, the use of prescribed burning to induce early sprouting in the park occasionally burns out of control, with the consequent effect on species density per unit area.

The fewer individuals of *Parkia biglobosa* with larger *dbh*, crown size, and height attributes in the grassland and woodland vegetation types of MNP, maybe because of fire susceptibility of the lower diameter class of the woody plants do not allow them to grow to become large trees. The effect of fire on plant performance and functioning has been widely documented (e.g., Resco de Dios, 2020). According to Resco de Dios (2020) one of such plant performance and functioning is their survival, mostly driven by (1) the degree of leaf and bud combustion in non-resprouters experiencing aboveground fires, and (2) fire-induced plant death including the degree of cambium charring, percent losses of hydraulic conductance, or root consumption.

The predominance of juveniles in the PAC was probably due to the felling of mature trees for charcoal and fuelwood production. Additionally, the use of fire for land preparation at the onset of the wet season, and by pastoralists to stimulate early vegetation growth (especially grasses and herbaceous species) for livestock in the dry season, also contributed to the predominance of juveniles in PAC. These disturbance-related drivers tended to create suitable growth conditions

for the regeneration or recruitment of young saplings in the disturbed environment, a phenomenon that is common in the Northern savannah ecosystem of Ghana, where this study was conducted. Recruitment of individuals with small diameters following disturbances such as farming activities has been reported in Pendjari Biosphere Reserve in Benin (Vodouhe *et al.*, 2011). Similarly, Ribeiro *et al.* (2019) revealed that most plant species have over time adapted to fire regimes, and their growth and reproductive attributes are linked to the local fire cycle.

Vitellaria paradoxa and *Parkia biglobosa* are the most preferred fuelwood species for charcoal production among people of Northern Ghana extraction, because of their abundance distribution and probably high-quality fuel, largely used by both rural dwellers and settler communities in urban centres of Ghana. Apart from the community's reliance on these species for fuel energy, the impoverished farmlands in most parts of the PAC and other parts of the savannah region of Northern Ghana, have compelled many households to rely on these species as a source of income generation (i.e., sale of charcoal and fuelwood) for their livelihood. This ultimately leads to excessive exploitation of the two species. Foussemi *et al.* (2012) reported that with the increasing demand for wood fuel and charcoal in the cities and the need for rural inhabitants to improve their income, rural people disregard the laws and even invade protected areas to fell trees. There are reported incidences of the arrest of indigenes from PAC in an attempt to harvest the fruits and branches of *V. paradoxa* and *P. biglobosa* in MNP by park managers. The exploitation of these species is not only limited to Ghana's northern savannah ecosystems, because studies in some communities in Nigeria, revealed that *V. paradoxa* (Shea tree) and *P. biglobosa* (Dawadawa tree) are known to be the preferred source of domestic fuelwood,

besides exploitation for fuelwood use (Oladele, 2002; Abdul-Rahaman *et al.*, 2016). Raebild *et al.* (2012) and Lompo *et al.* (2017) concluded that the continuous unsustainable exploitation of *P. biglobosa* for medicinal use has also contributed to the low regeneration in the Sudanian savannah regions of Sub-Saharan Africa.

Animal trampling activities (particularly elephants) were found to cause severe damage to both the mature and juveniles of the two species in the park. This was probably due to an increase in foraging pressure on the nutritious fruits, seeds, and leaves of the species. The attraction of wildlife (i.e., elephants, antelopes, baboons, monkeys, and chimpanzees) to the MPTS, as a result of their nutritious pulp, seeds, and leaves, has been reported in most savannah regions (Hopkins, 1983; Shao, 2002). Djossa *et al.* (2008) and Raebild *et al.* (2012) also observed the unsustainable harvesting of the fruits of *V. paradoxa* and *P. biglobosa* by humans and foraging pressure by wildlife (especially primates), which tends to affect natural regeneration; a phenomenon common in arid or semi-arid environments.

The overall impact of disturbances on the structural attributes and low abundance of *V. paradoxa* and *P. biglobosa* especially in PAC (i.e., Larabanga and Mognori) suggests their current vulnerability to habitat perturbation and their high conservation concern. This is confirmed by the International Union for the Conservation of Nature (IUCN) *Redlist* of Threatened Species, which classified *V. paradoxa* as vulnerable or threatened, while *P. biglobosa* is classified as near threatened (Abdul-Rahaman *et al.*, 2016). The IUCN listed overexploitation for timber, firewood, and charcoal production, habitat encroachment due to agricultural expansion as well as increasing population growth, as the major threats to these multipurpose trees (Abdul-Rahaman *et al.*, 2016).

CONCLUSION

From our study, it was evident that disturbance-related drivers like the incidence of fire, animal trampling, bare ground, and erosion, in MNP and PAC, were the key factors that negatively impacted the structural attributes of these two multipurpose tree species (*V. paradoxa* and *P. biglobosa*). The impacts were much more severe in the PAC than in the MNP. Besides the impact of the identified disturbance-related drivers, these species were unsustainably exploited by the inhabitants in the PAC. Given the current scope and severity of disturbances and the cascading impacts of climate change, it is almost certain that these multipurpose tree species (MPTS) are set to go extinct if they are not protected from further human impact. Thus, to revert the current state of these MPTS, we proposed that government policymakers should institute the following measures: 1. farmers be encouraged to plant *Vitellaria paradoxa* and *Parkia biglobosa* in their farmlands, as part of agroforestry practice in PAC; 2. bushfire occurrence in PAC must be banned outright, and persons caught in this act, must serve custodial sentences to be determined by policymakers; 3. utilization of these species for charcoal production and fuelwood should be banned outright; 4. establishment of woodlots for fast-growing trees (e.g., *Acacia siamea* and *Leucaena leucocephala*), that have no adverse allelopathic effect on other indigenous species and also improve soil fertility in PAC. These tree species can be used for fuelwood, charcoal production, and the construction of livestock fences; 5. park managers in MNP should construct more watering points or water holes, to help sparsely distribute ungulates and reduce the impact they exert on these species that are found close to the few watering holes; 6. the use of fire as a management tool in the park must be carefully administered so that fires do not burn in other areas not demarcated

for controlled or prescribed burning. This can be done by burning in blocks protected by fire belts and active fire control based on the prevailing factors of fire behaviour such as air temperature, relative humidity, wind speed and direction as well as topography and fuel characteristics.

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Conflict of Interest

The authors declare no conflict of interest exists.

AUTHOR CONTRIBUTIONS

CAN, EA, and **VA**, conceived the idea and designed the methodology; **VA, NOP,** and **OAA** carried out field data collection and data processing; **CAN** and **VA** analyzed the data; **CAN, NOP,** and **EA** led the writing of the manuscript. **CAN, EA, NOP,** and **OAA** undertook a preliminary review of the manuscript. All authors contributed to the final draft and gave their approval for submission.

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