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Abstract

Fire use in protected savannas of Africa is a common practice. Fires in these savannas create many environmental benefits, such as reducing grass, brush and trees that can fuel large and severe wildfires and improving wildlife habitat. However, wrong timing of fire can threaten plants, animals and habitats. This study investigated the effects of time of burning on woody plant composition, diversity and density in the Mole National Park, Ghana. A total of twelve 300 m² plots were systematically sampled in a 200 m × 200 m treatment plot established by Park Management each for early burn, late burn and no-burn plots. Twenty-seven different woody species belonging to fourteen families were recorded in all the treatments. Most of the species identified belonged to the families Fabaceae and Combretaceae. *Vitellaria paradoxa* (Shea), *Terminalia avicennioides*, *Combretum adenogonium* and *Combretum molle* were the most common and abundant in all treatments. A TWINSPLAN on sites and species revealed four species groups based on affinity to burning time. A follow-up DCA showed a strong association between burning time and species composition, with the first two axes explaining 65% of variation. The late burn and no-burn treatments recorded the lowest diversity amongst the three treatments. Stem density was highest in no-burn treatment which had lowest species richness and diversity compared to early and late burn treatments. Early burn treatment had the highest diversity and the lowest density of woody species. The study revealed that the different times of prescribed burning influenced vegetation differently. Prescribed early dry season burning could contribute to the management of indigenous woody species in protected fire-prone savannas, because it can promote the diversity of species, as found in the Mole National Park in the Guinea savanna of Ghana.

Keywords

density, diversity, dry season, Guinea savanna, time of burning, woody species

Introduction

Savannas are known to support a large number of plant communities and the species therein (Scholes & Walker 1993; Osborne et al., 2018). However, natural and human disturbances are considered major drivers of species occurrence and diversity in savannas. The frequency and magnitude of disturbances are major factors shaping savannas (Sheuyange et al., 2005; Andersen et al., 2012), and amongst these, natural and anthropogenic fires are important in savanna ecosystem function. However, fire regimes have been increasingly altered by human use of fire for various fire-assisted activities (Sheuyange et al., 2005; Santin & Doerr 2016; Osborne et al. 2018). Thus, fire is recognised as a tool in traditional fire practices in many rural economies, as well

as the management of vegetation in conservation sites around the world (Eriksen 2007; Archibald 2016; Beale et al., 2018).

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African savannas in particular, have been influenced by fire and adapted to it over millennia (Beringer et al., 2007; van Wilgen, 2009). Thus, to a large extent, many species in African savannas have adaptations to survive persistent fires, which include developing fire-resistant bark, roots that grow deep into the ground and growing dormant buds (Nefabus & Gambiza, 2007) as well as development of belowground structures for the storage of carbohydrates (Issifu et al., 2019; Wigely et al., 2019). Some researchers recognise that anthropogenic fires have played a vital ecological role in the occurrence, evolution and conservation of productive and resilient savannas (Archibald et al., 2012; Andela & van der Werf 2014; Andela et al., 2017).

Many rural dwellers in savannas around the world use fire for cultural, social and economic purposes. For instance, in Kenya, other parts of Africa (Nyongesa & Vacik 2018) and Brazil (Mistry, 1998), fire is used to stimulate the growth of fresh forage for animals, for tapping honey and attracting game for hunting. In Ghana, fire is also used to minimise labour costs in land preparation as well as increase agricultural production and productivity (Amoako et al., 2018). In savanna conservation sites and protected areas, including the Serengeti, Tanzania, fire is used to control vegetation so as to keep it open for grazing animals. In the Kruger National Park, South Africa, fire is applied to reduce wildfire risk later in the fire season, which is the same practice in the Mole National Park, Ghana (Beale et al., 2018). Still in South Africa, the management of the Pilanesberg National Park believes that fire diversity supports biodiversity (Beale et al., 2018). Other studies (e.g. Gomes et al., 2020) have also indicated that frequent burning resulted in patch mosaics of vegetation, exhibiting diverse stages of recovery at the landscape scale but could result in changes in vegetation cover, species richness and composition at the regional and subsequently at a global scale. For the reasons mentioned above, Alvarado et al. (2018) asserted that fire suppression in fire prone savannas may not change the area burnt, but rather make fewer and bigger fires with less diversity. Thus, attesting to fire as an indispensable tool for savanna management.

Fires are known to break the dormancy of some plant species which enhances recruitment and adaptability to fire-prone environments (Auld & Bradstock, 1996). In Kenya, fire is also reported to be effective in the elimination of competing and parasitic species such as *Striga hermonthica*, and improving habitats (Denslow, 2002; Atera et al., 2018). Gomes et al. (2020) observed that in the Brazilian Cerrado, for instance, biennial fires increased the recovery of herbaceous biomass from 40% to 60%, 24 months after fire. Ruthven et al. (2003) on the other hand, observed in Texas that frequent use of fire eliminated less fire-tolerant woody and grass species. Gill (2005) showed that late season fires may be detrimental to some plant species and cause the extinction of other species. Sheunyange et al. (2005) argued that frequent fires reduced shrub species richness, but positively influenced tree species richness in Namibia.

Fires have differential effects on savanna landscapes depending on the fire regime, which is in turn influenced by factors such as climate, soil and plant type (Sheunyange et al., 2005). Fires have shown to have both depressive and stimulatory effects depending on the intensity, frequency, season (including the time of burning: early or late within the season) and type of species (Birnin-Yauri & Aliero, 2010).

Season is a primary predictor of fire ignitions; hence it affects the other attributes of a fire regime (Archibald et al., 2012; Alvarado et al., 2018). However, Amoako & Gambiza (2022) confirm that people are more concerned about the season of fire than frequency and type of fire. Certainly, the time of ignition of fire during the long dry season in most savannas has ecological implications, particularly on plant species over space and time, although, Fontain et al. (2009) and Russels-Smith et al. (2012) have shown that in Australia, the frequency at which the vegetation is burnt determines the species that dominate a plant community, but not the time of burning. William et al. (1998) on the other hand, found that late season fires were devastating, primarily because there was more dry fuel with extreme fire weather. The study further showed that different plant species responded to fire differently as observed in the other parts of Africa (Brookman-Amissah et al., 1980; Bassett et al., 2003; Shackleton & Scholes, 2000).

The different times of fire application within the fire season may favour the growth of different plant species. Similar to some mature plants, some seeds have fire adaptive traits to late season fires that stimulate germination and succession after fire (Gomes et al., 2020), thus, increasing their germination percentage and abundance (Gomes et al., 2020). In contrast, Myers et al. (2004) and Penman et al. (2007) have shown that some seeds are not able to withstand fires and therefore gradually disappear. However, in the Guinea savanna of Ivory Coast, N'dri et al. (2018) found that mid and late season fires did not have significant damaging effect on trees because most trees shed their leaves before the late season, opposing the observations by Williams et al. (1998) in Australia. Whereas the effects of fire on plant communities and species have received extensive attention, the significance of altered species due to the specific attributes of a fire regime are poorly investigated.

In this regard, the role of time within the season and frequency of burning or no-burning and their effect on species composition in terms of frequency and diversity in savanna ecosystem management is very significant. Although fire seems to be an indispensable tool for managing savannas, the influence of fire on plant species density and diversity in the Sudano-Guinean savanna needs to be studied further. There are very few studies conducted on how the time of burning influences species composition in the Guinean savanna (Brookman-Amissah et al., 1980; Bagamsah, 2005). Again, with the changing climate and fire conditions over time and space there's the need to keep track of species in fire prone savannas.

The Northern Region of Ghana contains about 50% of the Guinea savanna of the country and has recorded higher occurrences of fires (40-60%) in the last 30-40 years, than the

other regions (Amanor, 2002; Kugbe et al., 2012). The frequent and uncontrolled fires may influence plant species composition and densities differently in the already sparsely populated parkland (Russels-Smith et al., 2012; Andersen et al., 2012; Fontain et al., 2009). This study, therefore, was conducted to investigate the effects of the time of burning on woody species composition and diversity. The hypothesis tested in this study was that burning regime (i.e., the time of burning in the dry season) influences the frequency, density and diversity of woody species.

Methods

Study area

The study was conducted in the Mole National Park (latitude 9°12' - 10°06' N; longitude 1°25' - 2°17' W with an elevation of 150 m). The Park is 4,577 km² located in the West Gonja District of Northern Region of Ghana in the Guinea savanna. The Guinea savanna is characterised by drought-resistant

woody species mostly belonging to the Fabaceae and Combretaceae. This vegetation constitutes about 60% of the total land area of the Northern savanna zone (Oboubie & Barry, 2005).

The Park's lands were set aside as a wildlife refuge in 1958 and gazetted as a National Park under Wildlife Reserves Regulation (L.I. 710) in 1971 (Schmitt & Adu-Nsiah, 1993). The Park contains a wide variety of plant species such as *Vitellaria Paradoxa*, *Afrormosia laxiflora*, *Combretum adenogonium*, *Isobertia doka*, *Lannea acida*. (Figure 1)

There are variety of ungulates including *Loxodonta africana* (Elephant) *Kobus kob* (Kob), *Kobus ellipsiprymnus* (Waterbuck) *Hippotragus equinus* (Roan), *Cephalophus natalensis* (Duiker), *Alcelaphus buselaphus* (Hartebeest), *Phacochoerus africanus* (Warthog). A variety of bird species are found in the Park. The Park has a total of 33 fringe communities that lie within a five-kilometre radius from the Park with an estimated total population of about 40,000 inhabitants (Abukari & Mwalyosi, 2018). These communities burn to attract game from the Park (Abukari & Mwalyosi, 2018; Yahaya et al., 2021).

The soils are laterite concrete formations of granite, voltaian shale and sandstones (Owusu-Bennoah et al., 1991). They are low in organic matter, with low moisture content as a result of their high drainage characteristics (Mikkelsen & Langohr, 2004; Owusu-Bennoah et al., 1991).

The climate is semi-arid and sub-humid with a unimodal rainfall distribution. The rainy season begins in May and ends in October with a mean annual rainfall ranging from 900 mm to 1,000 mm during the peak between July and September (Oboubie & Barry, 2005). The region experiences a long dry season which lasts November to April with little or no rainfall. Maximum temperatures, typically 40°C, occur towards the end of the dry season (Mid-March to April) and minimum temperatures in December and January, with a mean annual temperature of 27°C. The relative humidity reaches 80% at night in the rainy season, and falls to about

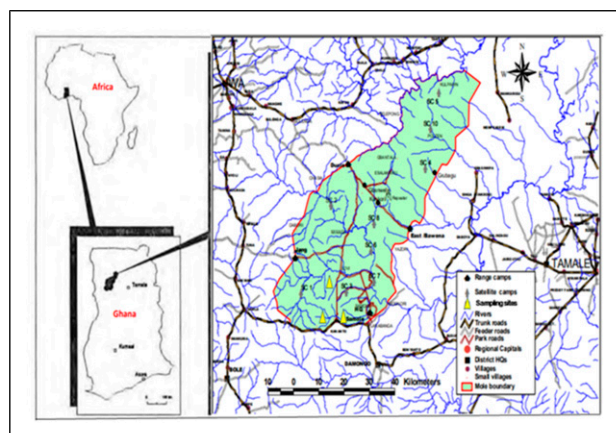


Figure 1. Map of Mole National Park showing study sites (Adapted from Schmitt & Adu-Nsiah, 1993; Yahaya et al., 2021).

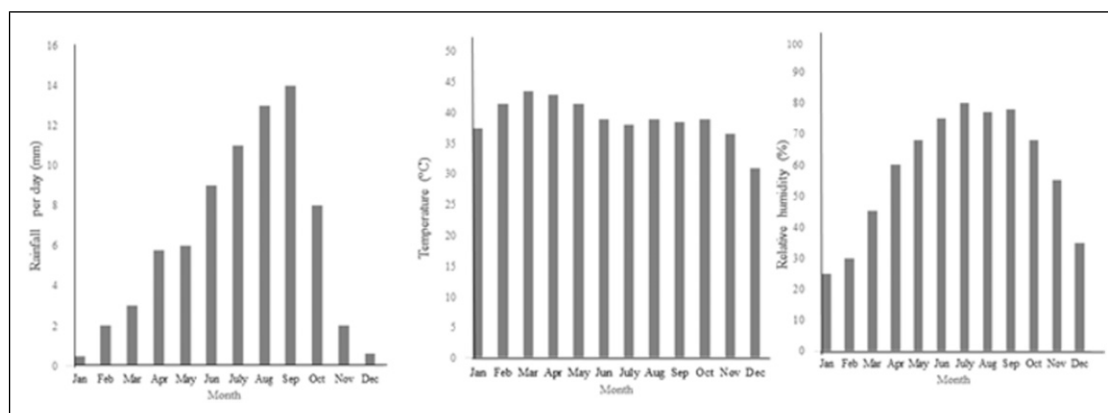


Figure 2. Average monthly values of rainfall, temperature and humidity of study area in the last 20 years. Source of data: <https://www.worlddata.info/africa/ghana/climate-northern.php>

70% in the afternoons dropping to 50% and 20% in the dry season at night and afternoon respectively (Figure 2).

The Harmattan winds, which occur during December to early February, have a considerable effect on the temperatures in the region, which may vary between 14°C at night and 40°C during the day (Siaw, 2001). These dry conditions and the strong Harmattan winds facilitate vegetation burning. Early dry season burn is usually done between November and January whereas late season burning begins in February to March ending. Prescribed burning has been practised in the Park before the demarcation of the area for conservation. Burning early in the dry season is to keep the animals from straying into the fringe communities to be poached and farms to reduce human-wildlife conflict. Indeed, the area of Mole National Park was part of the Game Clearance Area for tsetse

control which was established in the early 1950's and covered the whole northern part of Ghana (Schmitt & Adu-Nsiah, 1993; Adam et al., 2013). Thus, an early burning policy was introduced to also control tsetse infestation in the area (Schmitt & Adu-Nsiah, 1993). The Park has experienced indiscriminate burning and challenges of poaching from the fringe communities. Co-managing the buffer zones with these communities under a programme known as the Community Resource Management Area (CREMA) has not been very successful (Yahaya et al., 2021).

Data collection

Information on vegetation burning, obtained from the Faculty of Renewable Natural Resources, University for Development Studies and the Management of the Mole National Park, indicated that small portions in the Mole National Park are demarcated for early burning, late burning or no-burning for research purposes. The treatment blocks were demarcated in 1994 in areas that were already subjected to prescribed early and late burning and an area demarcated behind the Park information centre for no-burning i.e., one block per treatment. This is made possible because the treatments are bounded by roads, which serve as fire breaks, otherwise most parts of the park are burnt annually. Burning is prescribed in the park for both late and early dry seasons, to prevent the vegetation from transitioning into thickets or closed woodland which may not be favourable for the variety of animals that are in the park. Also, fire is used to stimulate grass growth for the animals to prevent them straying into the fringe communities (Sackey & Hale, 2008a).

Sampling was carried out in blocks exposed to annual early burning (EB), late burning (LB) - and no-burning (NB). Each treatment block measures 200 m × 200 m. Four 300 m²

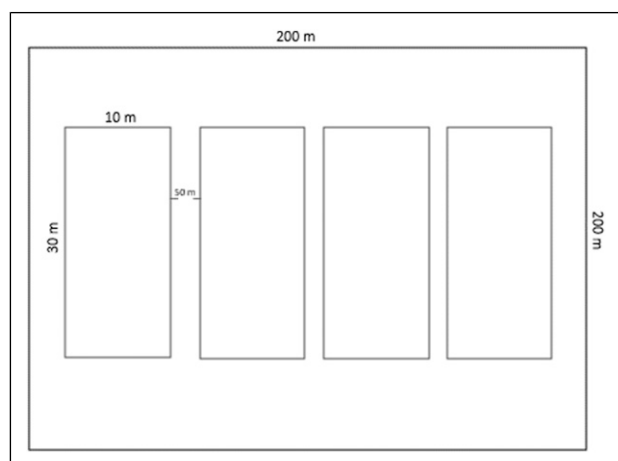


Figure 3. Plot layout and sampling of prescribed burning plots in Mole National Park, Ghana.

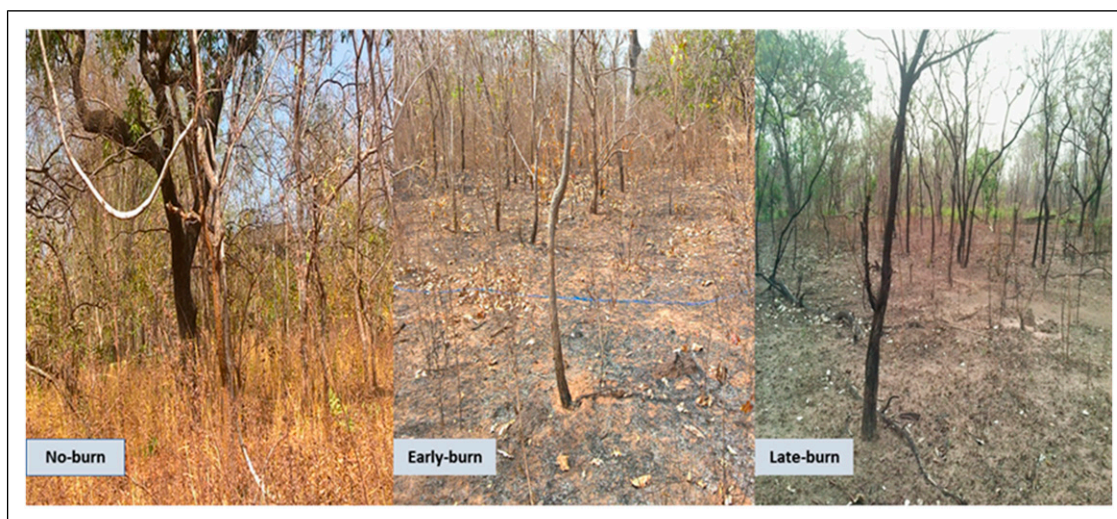


Figure 4. Prescribed burning plots during the dry/fire season showing no-burn, early and late burn treatments in Mole National Park (Photos taken by Esther Ekuamoako).

Table 1. List of woody species identified, their families, densities (mean \pm standard deviation) and relative frequencies in three prescribed burning treatments (N = 4 for each treatment) in Mole National Park.

Species	Family	Early burning		Late burning		No-burn	
		Density/ha	Frequency (%)	Density/ha	Frequency (%)	Density/ha	Frequency (%)
<i>Afrormosia laxiflora</i> Benth. ex Baker	Fabaceae	67 \pm 133	4.4	116.7 \pm 191.5	4.5	141.7 \pm 139.8	3.0
<i>Anacardium occidentale</i> L.	Anacardiaceae	0.0 \pm 0.0	0.0	50 \pm 79.3	2.0	0.0 \pm 0.0	0.00
<i>Anogeissus leiocarpa</i> (DC.) Guill. & Perr.	Combretaceae	0.0 \pm 0.0	0.0	16.7 \pm 19.5	0.6	650 \pm 795.6	13.0
<i>Burkea africana</i> Hook.	Fabaceae	42 \pm 50	2.7	0.0 \pm 0.0	0.0	8.3 \pm 16.7	0.2
<i>Cochlospermum angolense</i> Welw. ex Oliv.	Cochlospermaceae	0.0 \pm 0.0	0.0	66.7 \pm 92.3	2.6	0.0 \pm 0.0	0.0
<i>Combretum adenogonium</i> Steud. Ex A.Rich	Combretaceae	283 \pm 175	18.6	341.7 \pm 152.4	13.2	108.3 \pm 74.0	2.2
<i>Combretum molle</i> R. Br. ex G. Don	Combretaceae	167 \pm 191	11.0	75 \pm 128.7	3.0	58.3 \pm 95.7	1.2
<i>Combretum nigricans</i> Lepr. ex Guill. & Perr	Combretaceae	\pm 0.5	0.5	0.0 \pm 0.0	0.0	\pm 1.0	0.3
<i>Crossopteryx febrifuga</i> (Afzel. ex G.Don) Benth.	Rubiaceae	25 \pm 50	1.6	0.0 \pm 0.0	0.0	16.7 \pm 33.3	0.3
<i>Daniellia oliveri</i> (Rolfe) Hutch. & Dalziel	Fabaceae	0.0 \pm 0.0	0.0	41.7 \pm 50	1.6	0.0 \pm 0.0	0.0
<i>Diospyros mespiliformis</i> Hochst. ex A. DC.	Ebenaceae	8.0 \pm 17	0.5	0 \pm 0.0	0.0	25.0 \pm 32.0	0.5
<i>Detarium Microcarpum</i> Guill. & Perr.	Fabaceae	25 \pm 32	1.6	0 \pm 0.0	0.0	0.0 \pm 0.0	0.0
<i>Dracaena marginata</i> Lem.	Asparagaceae	0.0 \pm 0.0	0.0	0 \pm 0.0	0.0	8.3 \pm 16.7	0.2
<i>Ficus glumosa</i> Delile	Moraceae	0.0 \pm 0.0	0.0	50 \pm 63.8	1.9	0.0 \pm 0.0	0.0
<i>Hymenocardia acida</i> Tul.	Phyllanthaceae	25 \pm 32	1.6	83.3 \pm 126.2	3.2	8.3 \pm 16.7	0.3
<i>Isobrerlinia doka</i> Craib & Stapf	Fabaceae	100 \pm 77	6.0	0 \pm 0.0	0.0	0.0 \pm 0.0	0.0
<i>Lannea acida</i> A. Rich	Anacardiaceae	8.3 \pm 16.7	0.5	0 \pm 0.0	0.0	8.3 \pm 16.7	0.3
<i>Maytenus senegalensis</i> (Lam.) Exell	Celastraceae	66.7 \pm 81.6	4.4	0 \pm 0.0	0.0	25.0 \pm 50	0.5
<i>Nauclea latifolia</i> Sm.	Rubiaceae	33.3 \pm 27.2	2.2	100 \pm 158.7	3.9	8.3 \pm 16.7	0.3
<i>Piliostigma thonningii</i> (Schumach.) Milne-Redh.	Fabaceae	8.3 \pm 16.7	0.5	16.7 \pm 19.2	0.6	17.4 \pm 32.8	1
<i>Pseudocedrela kotschy</i> (Schweinf.) Harms	Meliaceae	0.0 \pm 0.0	0.0	8.3 \pm 16.7	0.3	141.7 \pm 177.2	3.0
<i>Pteleopsis suberosa</i> Engl. & Diels	Combretaceae	66.7 \pm 133.3	4.0	0.0 \pm 0.0	0.0	0.0 \pm 0.0	0.0
<i>Pterocarpus erinaceus</i> Poir.	Fabaceae	16.7 \pm 33.3	1.0	33.3 \pm 27.2	1.3	0.0 \pm 0.0	0.0
<i>Terminalia avicennioides</i> Guill. & Perr	Combretaceae	425 \pm 152.4	30.0	1400 \pm 1233	54.2	741.7 \pm 360.4	15.0
<i>Trichilia rubescens</i> Oliv.	Meliaceae	16.7 \pm 19.2	1.0	58.3 \pm 42.0	2.3	0.0 \pm 0.0	0.0
<i>Vitellaria paradoxa</i> C.F. Gaertn.	Sapotaceae	100 \pm 81.6	6.0	125 \pm 74.0	4.8	2825 \pm 817.1	58.0
<i>Ximenia americana</i> L.	Olacaceae	16.7 \pm 19.2	1.0	0.0 \pm 0.0	0.0	16.7 \pm 19.2	0.3

plots were systematically laid 50 m apart within each of the 200 m \times 200 m treatment blocks. The four samples/plots are pseudoreplicates as all sample plots were located in a single block for each fire treatment (Figure 3 and 4). Thus, a total of 12 plots were sampled in all three treatments (Figure 3).

The early season burns are usually carried out in between November and December, depending on the time the rains

end and the late dry season burning is carried out towards the end of February, up to the end of March. Sampling of woody species was conducted to examine the impact of EB, LB and NB regimes on tree composition, diversity and densities.

In each quadrat, the number of woody individuals with diameter at breast height \geq 10 cm was recorded and each identified to the species level. The identification of species was

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13 Iso dok	--2-24-4--	0010
24 Xim ame	--222-----2--	0010
6 Com mol	--4423424--	0011
14 Lan aci	--2-2-----	0011
15 May sen	--4-44-----	0011
19 Pte sub	-----4-----	0011
2 Ano lei	-4-42--2-2-	0100
18 Pse kot	44-----2-	0100
1 Afr lax	4-444-3-4-	0101
5 Com ade	442-44444444	0101
21 Ter avi	444444444444	0101
23 Vit par	444443442-44	0101
12 Hym aci	2-----23-34-	011
16 Nau lat	-22--233-4-	011
20 Pte eri	-----3-22--3	011
22 Tri rub	-----2-3324-	011
4 Coc ang	-----43	1
8 Dan oli	-----34	1
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Data analysis

A Detrended Correspondence Analysis (DCA) was then performed using the “vegan” package in R (Oksanen, 2017) to compare similarity and elucidate patterns of association of species with the different sites (burning regimes) (Ayoub-Hannaa et al., 2013). This was done for the 24 species retained in the TWINSpan. Function *envfit* in “vegan” was used to assess significance of the prescribed burning regimes on species composition using permutations test (with number of permutations at default 999) (Oksanen, 2017). This tested the null hypothesis of no significant relationship between burning regimes and species composition. Loadings (site scores) on DCA1 and DCA2 were tested for differences among burning regimes in separate linear models using “lme4” package in R (R Core Team, 2017).

Stem density (per ha) was compared among the three burning regimes by fitting a linear model in “lme4” which was followed by Tukey contrasts in “emmeans” package. Prior to this analysis, data on stem density was

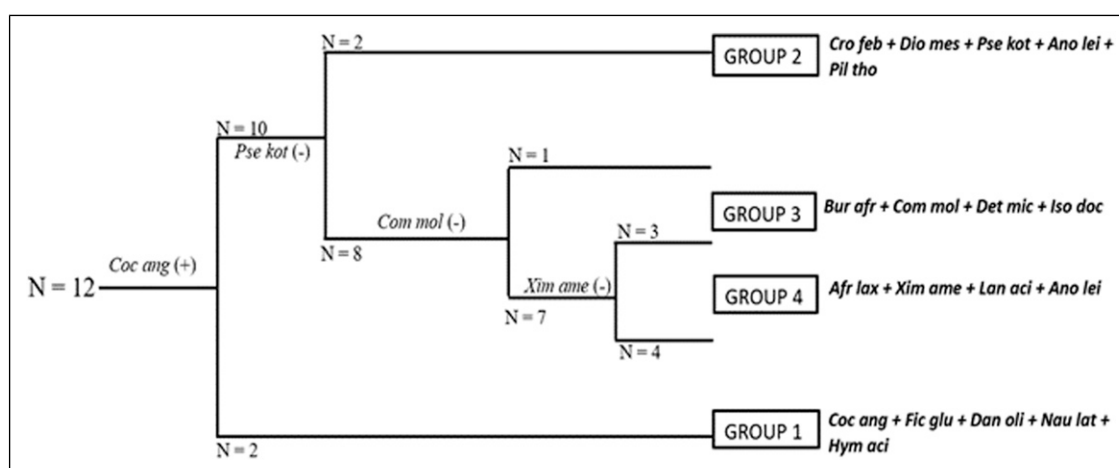


Figure 5. TWINSPLAN dendrogram of 12 burning regime plots and 24 woody species. Species at the splitting points are indicator species. Species to the right and next to the groups are the dominant species in each group. Species are abbreviated to the first three letters of both genus and species. Full species names are found in [Table 4](#).

Ln-transformed to stabilize residual variances and improve normality.

Species richness was determined for each burning treatment by a simple count of the total number of different tree species across plots belonging to the same treatment.

Shannon-Wiener diversity index was calculated for the three burning treatments (eqn 1):

$$H' = - \sum [(p_i \times \ln(p_i))] \quad (1)$$

where p_i is the proportion of individuals found in species i . $p_i = n_i/N$, where n_i is the number of individuals in species i and N is the total number of individuals in each treatment.

Shannon Evenness (J) was calculated for the three burning treatments (eqn 2):

$$J = H' / \ln(S) \quad (2)$$

Where H' is Shannon-Wiener diversity and S is the total number of species in a sample. Species evenness ranges from 0 to 1, with 0 signifying no evenness and 1, a complete evenness.

The Simpson index (D) which measures the dominance of a multispecies community, was computed and then used to estimate Gini-Simpson diversity (eqn 3):

$$D = \frac{\sum \Delta(-1)}{N(N-1)} \quad (3)$$

Where N is the total number of individuals in the community (treatment) and n_i is the number of individuals in the i -th species.

Gini-Simpson index was then computed as $1 - D$. This index returns scores between 0 and 1, with a high score indicating high diversity and a low score

Table 3. DCA scores of sites under three prescribed burning regimes.

Site	Burning regime	DCA1	DCA2	DCA3	DCA4
1	Early burn	1.0076	-0.2053	-0.4394	-0.4647
2	Early burn	1.4727	-0.1286	-0.2914	-0.4729
3	Early burn	1.1683	0.2537	-0.5143	-0.0891
4	Early burn	0.4287	0.0954	-0.0293	0.4609
5	Late burn	0.7498	0.3354	0.3176	0.5848
6	Late burn	0.7823	0.4380	0.5905	0.5472
7	Late burn	0.7198	-0.3015	-0.3732	-0.3666
8	Late burn	0.8472	0.0959	0.3684	-0.0578
9	No burn	-0.8632	-0.7675	0.2224	-0.1515
10	No burn	-0.7576	0.0491	-0.0335	-0.3232
11	No burn	-0.7018	0.3767	-0.1220	-0.1454
12	No burn	-0.5415	-0.3348	0.1810	0.1287

Table 4. DCA scores of species under three prescribed burning regimes.

	Species	Species Code	DCA1	DCA2	DCA3	DCA4
1	<i>Afromosia laxiflora</i>	<i>Afrolax</i>	-0.07039	-0.19126	-0.03979	0.87361
2	<i>Anogeissus leiocarpa</i>	<i>Anoglei</i>	-1.20978	2.21907	-1.01015	-1.05811
3	<i>Burkea africana</i>	<i>Burkafr</i>	1.58299	-0.08014	0.43301	0.55867
4	<i>Cochlospermum angolense</i>	<i>Cochang</i>	1.87091	1.19936	1.70556	2.53683
5	<i>Combretum adenogonium</i>	<i>Combade</i>	1.43697	-0.98435	-1.21477	-1.44218
6	<i>Combretum molle</i>	<i>Combamol</i>	1.10907	0.63572	-2.07793	0.00998
7	<i>Crossopteryx febrifuga</i>	<i>Crossfeb</i>	0.73281	0.56705	0.85527	-1.35375
8	<i>Daniellia oliveri</i>	<i>Danioli</i>	1.84663	1.62923	2.72577	1.67001
9	<i>Detarium microcarpum</i>	<i>DetaMic</i>	2.60704	0.25563	0.04271	-0.00333
10	<i>Diospyros mespiliformis</i>	<i>Diosmes</i>	-0.96724	-2.17128	0.85821	-0.46706
11	<i>Ficus glumosa</i>	<i>Ficuglu</i>	1.86513	1.30171	1.94847	2.33044
12	<i>Hymenocardia acida</i>	<i>Hymeaci</i>	1.69914	-0.38232	-0.85521	-0.73953
13	<i>Isobertina doka</i>	<i>Isobdok</i>	2.83713	0.25013	0.12545	-0.26326
14	<i>Lannea acida</i>	<i>Lannaci</i>	-0.27369	-0.87929	0.70419	1.06220
15	<i>Maytenus senegalensis</i>	<i>Maytsen</i>	0.98164	0.74973	-0.61405	0.19461
16	<i>Nauclea latifolia</i>	<i>Nauclat</i>	1.57774	0.21470	-0.32188	-0.39953
17	<i>Piliostigma thonningii</i>	<i>Pilitho</i>	-0.54676	-2.44933	-0.97840	-2.38029
18	<i>Pseudocedrela kotschy</i>	<i>Pseukot</i>	-1.31058	-2.56941	0.97544	-0.42235
19	<i>Pteleopsis suberosa</i>	<i>Ptelsub</i>	2.66741	0.60521	-0.42404	-0.77325
20	<i>Pterocarpus erinaceus</i>	<i>Ptererin</i>	2.00578	-0.68689	1.04378	-2.18235
21	<i>Terminalia avicennioides</i>	<i>Termavic</i>	0.56041	0.60214	0.57052	0.87279
22	<i>Trichilia rubescens</i>	<i>Tricrub</i>	2.08811	-1.03902	-3.09279	-2.31349
23	<i>Vitellaria paradoxa</i>	<i>Vitepar</i>	-1.12293	-0.67721	0.21280	-0.13401
24	<i>Ximenia americana</i>	<i>Ximeame</i>	-0.01935	0.69281	-0.60435	0.70300

indicating low diversity. Thus, as diversity increases and approaches 1, the distribution of species becomes more even -i.e., the dominance of a few species decreases (Moore, 2013).

Results

Woody species composition

Twenty-seven (27) woody species, belonging to fourteen (14) families were identified across the three burning treatments (Table 1). The TWINSpan classified the samples (and associated) species into four sub-divisions (Table 2, Figure 5). The first division with an Eigenvalue of 0.35 and *Cochlospermum angolense* as the indicator species separated two late burn plots (plots 5 and 6) from the rest of the plots (Table 2). This first division yielded the first species group dominated by *Cochlospermum angolense*, *Ficus glumosa*, *Daniellia oliveri*, *Nauclea latifolia* and *Hymenocardia acida* (Figure 5).

The second division with an Eigen value of 0.31 and *Pseudocedrela kotschy* as the indicator species, separated two other plots (no-burn plots, 9 and 10) from the remaining ten plots (Table 2). This second group is dominated by *Crossopteryx febrifuga*, *Diospyros mespiliformis*, *Pseudocedrela kotschy*, *Anogeissus leiocarpa* and *Piliostigma thonningii* (Figure 5).

The third division failed, as a result of too few samples, but the fourth division with an Eigenvalue of 0.33 and *Combretum mole* as indicator species further separated one early burn plot from the remaining plots. The species group created was dominated by *Burkea africana*, *Combretum mole*, *Detarium microcarpum* and *Isoberlinia doka*. The remaining seven plots were further divided (Eigenvalue of 0.34) with *Ximenia americana* as indicator species, yielding a group dominated by *Afrormoxia laxiflora*, *Ximenia americana*, *Lannea acida* and *Anogeissus leiocarpa* (Table 2, Figure 5).

Species that came out as “non-preferentials”, in all divisions, were *Terminalia avicennioides*, *Combretum adenogonium*, *Vitellaria paradoxa* and *Afrormosia laxiflora*. These species were found in most plots regardless of burning regime.

The follow-up DCA showed a strong positive association between burning time and species composition (envfit, r^2 goodness of fit = 0.80, $p = 0.005$). The first two axes alone

explained a cumulative 65% of variation in the data. On the first DCA axis (DCA1) which explained the most variation (53% versus 12% for DCA2), site scores (axis loadings) did not differ significantly ($F_2 = 1.46$, $p = 0.283$) among burning regimes despite three early burn plots having relatively large scores (Table 3). However, site scores were positive for both early burn and late burn plots and negative for no-burn plots on the same axis (Table 3). Thus, DCA1 correlated positively with fire plots and negatively with no-fire plots. Also, site scores did not differ among burning regimes on DCA2. One plot each of early burn and late burn and two plots of no-burn correlated negatively while the rest correlated positively with DCA2, but two plots each of late burn (5 and 6) and no-burn (9 and 12) were particularly more influential as their site scores were relatively large (Table 3, Figure 6).

Species scores (loadings) on DCA1 were large and positive for species such as *Isoberlinia doka*, *Detarium microcarpum*, *Pteleopsis suberosa*, *Trichilia rubescens*, *Pterocarpus erinaceus*, *Cochlospermum angolense*, *Daniellia oliveri*, *Ficus glumosa* and *Hymenocardia acida*. Species with medium to large negative scores on this axis include *Anogeissus leiocarpa*, *Diospyros mespiliformis*, *Pseudocedrela kotschy*, *Vitellaria paradoxa* (Table 4). On DCA2, *Anogeissus leiocarpa*, *Daniellia oliveri*, *Cochlospermum angolense* and *Ficus glumosa* had large and positive scores while *Pseudocedrela kotschy*, *Piliostigma thonningii* and *Diospyros mespiliformis* had large negative scores.

DCA1 thus represents the “fire axis”, separating fire plots and associated species from no-fire plots and associated species. DCA2 captures small amounts of variation in species associations to burning regimes in the data, but appears to represent variability within treatment.

Woody species richness, frequency, density and diversity

A total of 21 different species were identified in the early burn treatment (Table 5). Two species, *Terminalia avicennioides* (at 30%) and *Combretum adenogonium* (at 19%) were found in relatively high frequencies in this treatment (Table 1). Sixteen (16) species were identified in the late burn treatments (Table 5), with the highest relative frequency recorded for *Terminalia avicennioides* (at 54%). No-burn treatment had a total of 18 different species, with *Vitellaria paradoxa* having

Table 5. Species richness, evenness and diversity of three prescribed burning regimes in the Mole National Park.

	Species richness	Shannon Diversity index (H')	Shannon Evenness (J)	Gini-Simpson index (1-D)
Early burn	21	1.93 ± 0.10	0.83 ± 0.05	0.83 ± 0.03
Late burn	16	1.58 ± 0.23	0.70 ± 0.08	0.70 ± 0.10
No-burn	18	1.24 ± 0.21	0.37 ± 0.09	0.59 ± 0.12

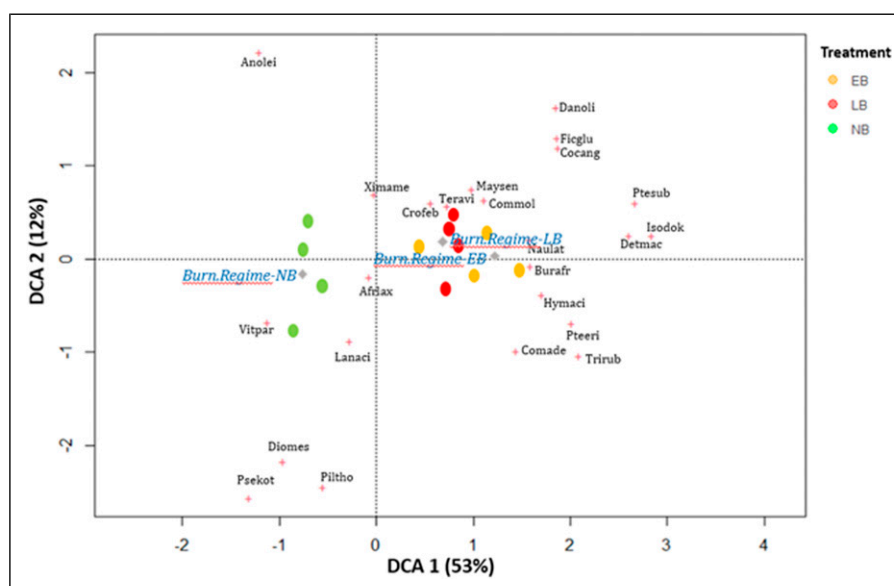


Figure 6. DCA ordination plot of 24 species and three prescribed burning treatments (used here as environmental factor with function “envfit” in vegan package). The species are listed by the first three letters of the genus and species. Species codes and corresponding full species names have been included in [Table 4](#).

the highest relative frequency (at 58%). *Lannea acida*, *Burkea africana* and *Combretum molle* were amongst the least occurring species in the no-burn treatment ([Table 1](#)). Six species including *Afrormosia laxiflora* and *Combretum molle* were common to all the treatments but had varying frequencies ([Figure 7](#)).

Species with high relative frequencies belonged to Fabaceae, Combretaceae, Sapotaceae, Celastraceae, Meliaceae and Rubiaceae, while those occurring in low frequencies belonged to Anacardiaceae, Olacaceae, Ebenaceae, Moraceae, Cochlospermaceae, Phyllanthaceae, and Asparagaceae. Combretaceae had the highest taxa frequencies of individual species - *Terminalia avicennioides* for instance, was 30% in the EB treatment, 54% in LB treatment and 15% in no-burn treatment. *Combretum nigricans* also a Combretaceae, on the other hand, had the lowest frequency in early burning and no records in late and no-burn treatments ([Table 1](#)).

Seven species, including *Diospyros mespiliformis* had high frequencies in the early burn and no-burn treatments ([Table 1](#)). *Anogeissus leiocarpa* was found in relatively high frequency (at 13%) in the no-burn treatment but low frequency in late burn treatment (at 0.6%) and *Trichilia rubescens* (at 1%) and (at 2.3%), *Pterocarpus erinaceus* (1%) and (1.3%), *Combretum nigricans* (0.5%) and (0.3%), occurred in low frequencies in early burn and no-burn treatments respectively. Some species were exclusive to the different burning treatments but, had relatively low frequencies such as 0.2% for *Dracaena palm* in the no-burn treatment and 1.6% for *Detarium microcarpum* ([Table 1](#)).

Data on woody species stem density were characterised by large variability within treatment. Stem density ranged from 2200-1200 stems ha^{-1} (mean \pm sd of 1508 ± 466 stems ha^{-1}) in early burn, 5200-1400 stems ha^{-1} in late burn (mean \pm sd of 2583 ± 1794 stems ha^{-1}) and 6633-3833 stems ha^{-1} (mean \pm sd of 4850 ± 1300 stems ha^{-1}) in no-burn treatments.

Stem density differed significantly ($F_2 = 8.19$, $p = 0.009$) among burning regimes, the large within treatment variability regardless. Tukey post hoc contrasts revealed that stem density in the no-burn treatment differed significantly from early burn ($p = 0.008$) but not from late burn ($p = 0.070$) treatments. Also, stem density did not differ significantly between early burn and late burn treatments ($p = 0.376$).

Densities calculated for individual species ([Table 1](#)) show that species such as *Vitellaria paradoxa*, *Anogeissus leiocarpa* and *Afrormosia laxiflora* tend to have higher mean densities under no-burn while others such as *Terminalia avicennioides*, *Trichilia rubescens*, *Pterocarpus erinaceus*, *Nauclea latifolia*, *Hymenocardia acida*, *Ficus glumosa*, *Daniellia oliveri*, *Combretum adenogonium* and *Cochlospermum angolense* appear to have higher mean densities under late burn. *Detarium microcarpum*, *Combretum molle*, *Diospyros mespiliformis*, *Crossopteryx febrifuga*, *Maytenus senegalensis*, *Pteleopsis suberosa* appear to have higher densities under early burn.

The Shannon-Wiener diversity index in no-burn was (1.24 ± 0.21), which was lower than estimated for both late burn (at 1.58 ± 0.23) and early burn (1.93 ± 0.10). Similarly, both Gini-Simpson index and Shannon evenness were lowest in no-burn and highest under early burn ([Table 5](#)).

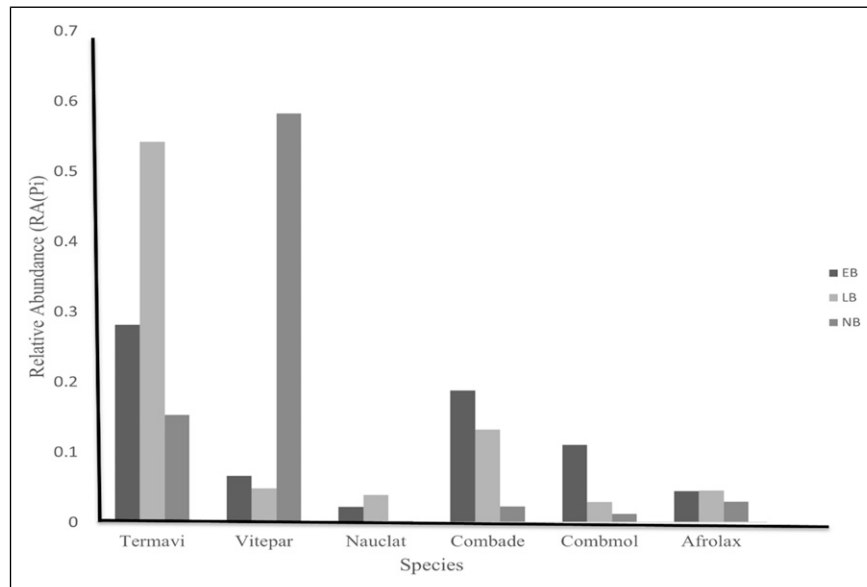


Figure 7. Most common and abundant species identified in the three burn treatments. The species are listed by the first four letters of the genus and the first three of specific epithet recorded - Termavi= *Terminalia avicennioides*, Vitepar = *Vitellaria paradoxa*, Nauc-lat=*Nauclea latifolia*, Combade=*Combretum adenogonium*, Combmol= *Combretum mole*, Afrolax =*Afromosia laxiflora*).

Discussion

Effect of prescribed burning regime on woody species composition

The total number of species recorded across the three prescribed burning plots in the Mole National Park (27 species) is about one-fifth the number of species recorded by Schmitt & Adu-Nsiah (1993) in the same Park. This is because data presented in this study come from a small portion of the Park designated for experimental burn research (see methodology).

The TWINSpan and follow-up DCA both revealed that burning regime significantly influenced woody species composition. The first species group revealed by the TWINSpan (Figure 5) are all species capable of thriving under late dry season fire. These species also had positive correlation to DCA 1 which represents the fire axis (Figure 6). Three such species, namely *Cochlospermum angolense*, *Ficus glumosa* and *Daniellia oliveri*, showed complete fidelity to late season burn plots (Table 2). Together with other species such as *Nauclea latifolia* and *Hymenocardia acida*, this species group represents resprouters; which have large below-ground storage structures and are, therefore, capable of repeated top-kill and resprouting (Higgins et al., 2000; Lovett & Haq 2000; Sackey & Hale, 2008b; Boonman et al., 2020). *Cochlospermum angolense*, for example, which is also the indicator species for this group, is a known rhizomatous species with a preference for annually burnt savanna (Burkill, 2000).

The TWINSpan also revealed a species group which contrasts with the first group of resprouters. This second group prefers less fire as their strategy for surviving in the savanna is not based on “investing” in large storage structures needed for repeated resprouting (Boonman et al., 2020). These species; *Diospyros mespiliformis*, *Pseudocedrela kotschyi*, *Anogeissus leocarpa* and *Piliostigma thonningii*, avoid late burn plots because they are only moderately fire tolerant (Abdoulaye et al., 2012; Hall & Swaine, 1976; Hennenberg et al., 2005) and therefore not adapted to repeated top-kill and resprouting. The DCA provided confirmation that members in this group showed strong negative correlation to the first group which had *Cochlospermum angolense* as the indicator species (Figure 6).

Two other species groups (Figure 6) were revealed, but these are not so easily distinguishable as the first two groups. The two species groups are a complex mix of species which have somehow intermediate fire tolerances relative to the first two species groups. These species were found in some no-burn, early burn and late burn plots, but the specific plots where they occurred were grouped differently from others of the same treatment by the TWINSpan (Table 2). This is, perhaps, because those plots may be less characteristic of the burning regimes to which they were assigned a priori. Some of the species such as *Burkea africana*, *Detarium microcarpum* and *Anogeissus leocarpa*, tend to have clumped distribution as they are often associated with certain edaphic characteristics (Schmitt & Adu-Nsiah, 1993) which may override influences of fire and may explain the occurrences of these species as observed in this study. The group which had

Ximenia americana as the indicator species (Figure 5) had more individuals in two no-burn samples (plot 11 and 12 and including plot 4 which was supposed to be an early burn plot) as these species are incapable of repeated resprouting and therefore thrive under moderate-to-no fire.

The influence of burning regime on tree species composition in the Park could have been via regeneration as fire serves as a filter for differential juvenile recruitment of tree species (Issifu, 2020; Gignoux et al., 2016, 2009). Influence of burning regime on woody species composition could also have been via effects on adult survival as fire may cause differential adult mortality of woody species (Sackey & Hale, 2008b).

True non-preferential species (i.e., species which did not have affinity to any of the treatments and therefore occurred in all plots) were also revealed by the TWINSpan (Table 2). Species such as *Terminalia avicennioides*, *Combretum adenogonium*, *Vitellaria paradoxa* and *Afrormosia laxiflora* appear indifferent to fire treatment in this study. They thrive in environments with or without fire, perhaps, because the biophysical conditions that limit their distribution do not include fire. Therefore, communities that include *Terminalia avicennioides* constitute most of the vegetation of the Mole National Park (Schmitt & Adu-Nsiah, 1993).

Notwithstanding the general patterns revealed in species composition as influenced by fire regime, results also revealed large variability within fire treatments. For example, for both late burn and no-burn treatments, two plots each were particularly influential in the classification of tree species (Table 2). The second axis of the DCA (DCA2) also showed this variability (Table 3). Plots that stood out may be the ones that reflected the true characteristics of their respective treatments (i.e. burning regimes) while the other plots had characteristics similar to plots of contrasting fire treatments. This heterogeneity within fire treatments could reflect the effect of location as factors such as fuel (herbaceous vegetation) characteristics (e.g. type, biomass and moisture content, (Cardoso et al., 2018, 2016) as well as edaphic and microclimatic factors (Hoffmann et al., 2012) which were not measured in this study, may differ among locations put under similar burning regimes (defined here as the timing of fire event). The factors mentioned above may have played an important role as the ecology of an area and local fire conditions including microclimate have important influences on fire effects on vegetation (Russell-Smith et al., 2012; Laris et al., 2017; N'dri et al., 2018). The observed heterogeneity could also reflect the effect of other non-uniform disturbance factors such as elephant damage (Sackey & Hale, 2008a).

Effect of burning regime on woody species richness, frequency, density and diversity

The most abundant and widespread species belonged to the Fabaceae and Combretaceae families (Table 1), typical of the Sudano-Guinean savanna woodlands (Aubréville, 1958) and

also noted by some authors (Tom-Dery et al. 2012; Asase et al., 2009). Most species in Combretaceae and Fabaceae families are tolerant to drought and fires, as well as fire exclusion, with a high probability of regeneration by resprouting after fire and other disturbances (Ouedraogo & Thiombiano, 2012; Sackey & Hale, 2008b; Higgins et al., 2000).

Early burn treatment was the most species-rich and had the highest diversity and evenness of woody species (Table 5). Compared to no-burn plots, both burn treatments had higher diversity and evenness because burning (particularly early burning when fuel moisture is not too low and therefore burns with lower intensity) prevents only very few species from becoming dominant. Also, by keeping the vegetation open, burning creates many different niches allowing for many more woody species to establish compared to fire exclusion (Pueas & Ribeiro, 2017). Early burn has a greater positive influence on diversity and evenness because only a specialised group of species (capable of repeated resprouting) may thrive in late burn due to higher intensity fires leading to higher dominance of fewer species relative to early burn.

Species such as *Diospyros mespiliformis*, *Anogeissus leiocarpa* and *Dracaena marginata* which avoided fire plots also had lower relative frequencies in early burn and late burn treatments (Table 1). Although, early burn has higher diversity, the occurrence of rare and fire-sensitive, but fairly drought tolerant, species on the IUCN Red list such as *Dracaena marginata* (Aubréville, 1958; Marrero et al., 1998) may increase with fire exclusion.

Some of the species which occurred at very high frequencies in all plots include *Vitellaria paradoxa*, *Terminalia avicennioides* and *Combretum adenogonium* (Table 1, Figure 5). This may explain why these species are key components of communities that constitute the vegetation of the Mole National Park (Schmitt & Adu-Nsiah, 1993). However, whereas the highest frequency of occurrence for *Vitellaria paradoxa* was in the no-burn treatment, it was in the late burn and early burn treatments for *Terminalia avicennioides* and *Combretum adenogonium* respectively. This suggests that there are species like *Vitellaria paradoxa* which regenerate easily by seed and also by resprouting (Lovett & Haq, 2000), but there are also species like *Terminalia avicennioides* and *Combretum adenogonium* which seed dispersal and germination are enhanced by fire (Gomes et al., 2020; Ouedraogo & Thiombiano, 2012).

There were large variations in stem densities within treatments, suggesting heterogeneity in plots that make up the same burning regime. This heterogeneity could also reflect the effect of location and elephant damage as earlier discussed. Nonetheless, stem densities differed significantly among burning regimes. Overall, the highest stem density was observed in no-burn plots and the least in early burn plots. Thus, there were more individuals of the few dominant species, *Vitellaria paradoxa*, *Terminalia avicennioides* and

Anogeissus leiocarpa, as is typical of less diverse plant communities (Grime 1973).

Implications for Conservation

This study revealed that generally, burning has a negative effect on tree density, relative to no-burn treatments but has a positive effect on diversity, consistent with predictions of this study. No-burning promoted tree density, rather than diversity. Burning promoted the occurrence of *Terminalia avicennioides* and some *Combretum* species, whereas no-burning was a desirable condition for *Vitellaria paradoxa* (Sapotaceae). Thus, no-burning practices would increase the populations of species that are not fire-dependent. The protection of *Vitellaria paradoxa* from fire and other disturbances would increase populations which would have greater benefits for communities in the north of Ghana because of the role it plays in rural livelihoods.

As observed by many authors, fire plays an important role in sustaining savanna ecosystems. However, no-burning practices can be encouraged to restore species in fire-degraded habitats (which result from too frequent and repeated fire cycles without monitoring). The observation is that both prescribed burning, and no burning have good implications for the tree species density, diversity and richness and that management objectives may be paramount in deciding burning regimes. Hence, the Park's policy of burning different sites at different times of the year is protective of indigenous species and maintaining the woodland savanna. However, there is a need to monitor the effects of the seasonal fires in the study site to ascertain what the Park is gaining or losing in terms of animal species' diversity and density.

This study could be scaled-up for studies on burning, species diversity and density and also for further studies on unmanaged areas with unplanned fire regimes. It is therefore, recommended for community sensitization and collaborative stakeholder engagement to be undertaken on the impact of burning practices on species including economic species like *Vitellaria paradoxa*, whose fruits and nuts are highly valued non-timber forest product in the Guinea savanna.

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