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Influence of fire frequency on woody vegetation structure and composition in Lake Chivero Recreational Park, northern Zimbabwe

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Abstract: Fire plays an important role in vegetation structure and composition configuration in savanna ecosystems. We investigated the influence of fire frequency on woody vegetation structure and composition across different fire frequency classes in Lake Chivero Recreational Park (LCRP), northern Zimbabwe. Using a 25 year fire history, we stratified the study area into the following three fire frequency classes: high (every 1–2 years), medium (every 3–4 years) and low (every 5–6 years). Data were collected from a total of 15 plots (five plots per stratum) measuring 20 m × 60 m between April and May 2014. The following variables were recorded in each plot: species name, plant height, and number of woody plants. A total of 37 woody plant species comprising 1,208 individual plants (59% trees and 41% shrubs) were recorded across the three fire frequency strata. Our results showed significant differences ($P < 0.05$) in woody plant height with the low fire frequency stratum having the tallest woody plants whereas the high fire frequency stratum had the shortest woody plants. Tree density was highest in the medium fire frequency stratum and lowest in high fire frequency stratum whilst shrub density was highest in the low fire frequency stratum and lowest in the high fire frequency stratum (both, $P < 0.05$). In contrast, no significant differences ($P > 0.05$) were recorded for woody plant evenness and species diversity across the three fire frequency strata. We recommend for the development of a robust fire management plan for LCRP encompassing patch mosaic and early burning as strategies of minimizing fire impacts on sensitive habitats.

Key words: Habitat, miombo woodland, protected area, savanna, species diversity, wildlife.

Introduction

Savanna ecosystems are estimated to cover about 20% of the earth's surface and they are the largest biome (Sankaran *et al*. 2005; Scholes & Archer 1997; Trollope *et al*. 2014). African savannas are fire-prone, and fire is important in determining the vegetation structure and composition of these ecosystems (Bachinger *et al*. 2016; Gandiwa & Kativu 2009; Mudongo *et al*. 2016). Different fire frequencies cause variation in vegetation structure and composition (Bond & Keeley 2005; Govender *et al*. 2006) which may have important implications for wildlife habitat, biotic diversity and risk of

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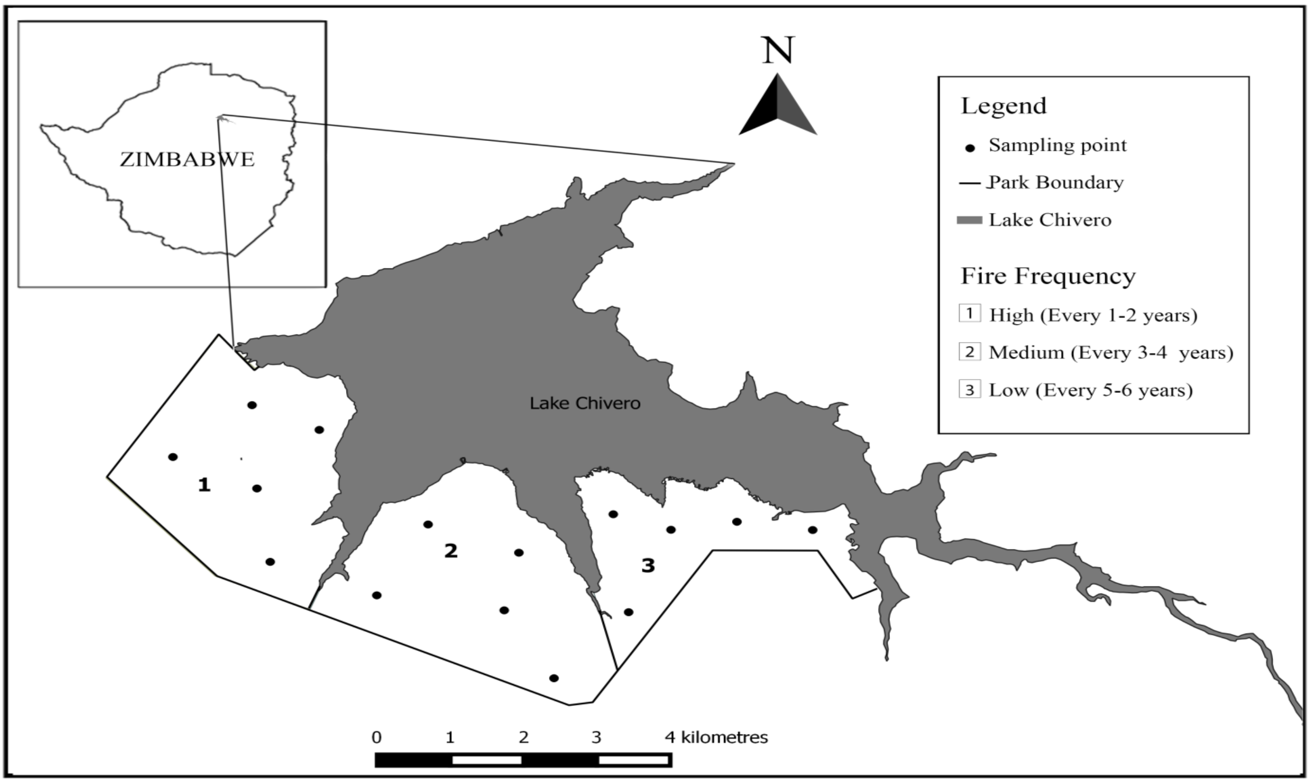

Fig. 1. Location of Lake Chivero Recreational Park, northern Zimbabwe.

frequencies cause variation in vegetation structure and composition (Bond & Keeley 2005; Govender *et al.* 2006) which may have important implications for wildlife habitat, biotic diversity and risk of future disturbances (Peterson & Reich 2001; Suryabhagavan *et al.* 2016). However, heterogeneity of vegetation is also driven by the interaction of both biotic and abiotic factors, and anthropogenic activities (Gandiwa *et al.* 2016; Govender *et al.* 2006; Ndoro *et al.* 2016; Seymour *et al.* 2016).

Vegetation fires in savanna ecosystems are usually surface fires of different intensity and they interact with post-fire conditions to affect plant survival and reproduction (Govender *et al.* 2006; Higgins *et al.* 2000). Fire also stimulates the germination of seeds of different species to various extents (Barton *et al.* 2014). Frequent fires reduce woody plant densities in moist savannas, primarily by killing or suppressing individuals in the smaller size classes (Drewa 2003; Smit *et al.* 2010; Trollope *et al.* 2014). Smaller trees are more prone to fire damage as compared to mature trees (Smit *et al.* 2010).

Fire occurrences have been a common phenomenon in savanna ecosystems (Archibald *et al.* 2010; Barton *et al.* 2014; Trollope *et al.* 2014) and hence, justifying the need for more research to understand fire effects across the diverse habitats. For example, Lake Chivero Recreational Park

Table 1. Woody vegetation structure and composition attributes in relation to fire frequency strata and significance levels from one-way ANOVA tests.

Variable	Stratum			$F_{(2,12)}$	P
	LFF	MFF	HFF		
Woody plant height (m)	3.56 ± 0.19[a]	3.21 ± 0.46[a]	2.22 ± 0.35[b]	19.99	0.002
Shrub density (shrubs/ha)	18.26 ± 4.16[a]	14.61 ± 2.95[a]	3.32 ± 2.63[b]	27.69	0.000
Tree density (tree/ha)	215.00 ± 50.89[a]	253.75 ± 76.63[a]	99.88 ± 61.76[b]	7.83	0.007
Evenness (E)	0.09 ± 0.68[a]	0.82 ± 0.09[a]	0.77 ± 0.09[a]	0.51	0.614
Species diversity (H')	1.13 ± 0.22[a]	1.13 ± 0.55[a]	0.97 ± 0.12[a]	0.36	0.707

Notes: LFF = low fire frequency, MFF = medium fire frequency, HFF = high fire frequency; different superscripts in the same row indicate significant differences (Tukey's HSD, $P < 0.05$).

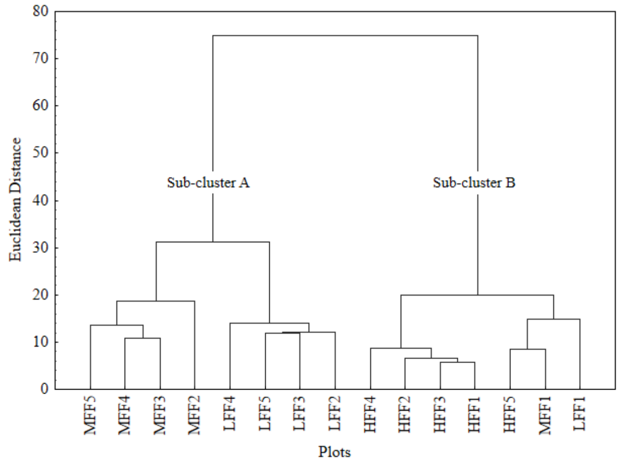

Fig. 2. Hierarchical cluster analysis dendrogram of sample plots in Lake Chivero Recreational Park, northern Zimbabwe. Notes: LFF = low fire frequency, MFF = medium fire frequency and HFF = high fire frequency.

(LCRP), northern Zimbabwe is burnt each year for a number of reasons such as tick control with burning occurring at different intervals. Given that woody plant species differ widely in their tolerance of fire and in their capacity to recover from fire (Drewa 2003), thus, different fire frequencies on woody vegetation have potential implications on wildlife management and also tourism experiences. Therefore, the objective of this study was to determine the effects of fire frequency on vegetation structure and composition in LCRP.

Materials and Methods

Study area

The study focused on LCRP, northern Zimbabwe (17.90°S, 30.79°E) which is located in a typical savanna ecosystem (Fig. 1). The vegetation is characteristic of Miombo woodland and is dominated by *Brachystegia spiciformis* and *Julbernardia globiflora*. Much of the park is characterized by patches in the form of large vegetated termitaria (termite mounds) usually without grass cover with plants such as *Schotia* spp., *Brachypetala* spp. and *Euphobia ingens* tree species. The entire LCRP covers 6,100 ha consisting of 2,630 ha of water body and 3,470 ha of land.

LCRP's terrain is characterised by gentle topographic variation (altitude range: 1,300–1,600 m above sea level) and red-brown clay shallow soils (ZPWMA 2013). Three climatic seasons can be recognized, characterised with a short dry winter season (May–July), hot dry summer season (August–October) and a hot wet summer season (November–April). Mean annual rainfall of LCRP is about 825 mm with annual temperatures ranging from 18 °C to 30 °C. Manyame River is regarded as the major inflow into Lake Chivero with 92% of the lake's watershed drained by this river (Vambe 2013).

Experimental design

Three fire frequency classes were defined based on the estimated number of times the areas recorded to have been burnt over a period of 25 years as follows: high (every 1–2 years), medium (every 3–4 years) and low (every 5–6 years) following Gandiwa & Kativu (2009). Fire history data were retrieved from the research archives kept at LCRP main offices. A stratified random sampling method based on fire frequency of LCRP was used to select 15 plots (five plots per stratum). Plot locations were randomly generated in a Geographic Information System (GIS) environment (Fig. 1) and their positions on the ground tracked using a Garmin Geographic Positioning System (GPS) 60 receiver unit (Garmin Ltd., Olathe, Kansas, USA).

Data collection

Field data were collected between April and May 2014. The following variables were recorded and/or measured within plots measuring 20 m × 60 m: species name, plant height and number of woody plants. Woody species identification was aided using a field identification guide (Coates-Palgrave 1997). Woody plant height was measured using a 6 m graduated pole. A tree was defined as a plant that was ≥ 3 m tall whereas a shrub was defined as a plant that was < 3 m (Witkowski & O'Connor 1996).

Data analyses

The following were calculated for each of the sampled plot: densities for trees and shrubs, and these were converted per ha following Gandiwa & Kativu (2009). Shannon-Weiner diversity index (H'), Pielou's evenness index (E), and Jaccard Index of community similarity were calculated for the three different fire frequency strata (Ludwig & Reynolds 1988). Data were tested for normality and homogeneity of variance using Kolmogorov Smirnov test and Levene's test, and were found to conform to the normality assumptions. A one-way analysis of variance (ANOVA) was used to test whether there were significant differences in woody vegetation structure and composition variable

Table 3. Percent community similarity and sample plot classification based on fire frequency.

Fire frequency stratum	HFF	MFF	LFF
LFF	59	70	100
MFF	65	100	70
HFF	100	65	59

Notes: LFF = Low fire frequency, MFF = medium fire frequency and HFF = high fire frequency

among the three different fire frequency strata. The Tukey's Honestly Significant Difference (HSD) post *hoc* analysis was to determine variations among strata for variables with showed significant differences. The Statistical Package for Social Sciences (SPSS) version 16.0 for Windows (SPSS Inc, Chicago, USA) was used for ANOVA tests. Moreover, a hierarchical cluster analysis (HCA) using the Ward's method and Euclidean distance was used to group (or cluster) sample plots based on similarity of species abundance data in STATISTICA version 7 for Windows (StatSoft Inc., Tulsa, OK, USA).

Results

Vegetation structure and composition across different fire frequency

A total of 1,208 plants (59% trees and 41% shrubs) were assessed, and 37 woody species were recorded from the 15 plots in the three fire frequency strata. Woody plant height was significantly different ($P < 0.05$) with the low fire frequency stratum dominated by *Brachystegia spiciformis* having the tallest woody plants whilst the high fire frequency stratum dominated by *Brachystegia spiciformis* and *Julbernardia globiflora* had the shortest woody plants (Tables 1 and 2). Shrub density was significantly higher ($P < 0.05$) in the low fire frequency stratum dominated by *Grewia flavescence* and lowest in the high fire frequency stratum dominated by *Terminalia sericea*. Tree density was significantly ($P < 0.05$) higher in the medium fire frequency stratum and lowest in high fire frequency stratum. In contrast, no significant differences ($P > 0.05$) were recorded for woody plant evenness and species diversity across the three fire frequency strata. Overall, there was a high similarity in terms of woody vegetation species between the three fire frequency strata (Table 3).

Clustering of plots based on abundance data of species

The 15 study plots were grouped into two sub-clusters, i.e., sub-cluster A and sub-cluster B (Fig. 2). Sub-cluster A comprised of species recorded in plots from medium fire frequency stratum (50%) and low fire frequency stratum (50%) which were characterised by these species: *Grewia monticola, Bridelia mollis*, *Lannea discolour* and *Ziziphus mucronata.* Sub-cluster B comprised of species found in plots from high fire frequency (72%), low fire frequency (14%) and medium fire frequency (14%) characterised by these species: *Brachystegia spicifomis*, *Julbernardia globiflora*, *Combretum molle*, *Peltophorum africanum* and *Vangueria infausta*.

Discussion

We set out this study to determine the influence of fire frequency on woody vegetation structure and composition in LCRP. Our results showed that woody plant height decreased with increasing fire frequency and this finding could be attributed to the top kill of woody plants by fire resulting in retarded growth of some plants. Recurrent top kill of woody plants makes the woody plants particularly susceptible to the 'fire trap', which prevents recruitment into adult size classes hence affecting their height (Higgins *et al*. 2007; Hoffmann *et al.* 2012).

There was a noticeable decrease in tree and shrub densities in relation to increasing fire frequency. This finding could be related to the direct impact of frequent fires resulting in mortality of some fire intolerant woody plant species. Pyke *et al.* (2010) suggested that fires can change plant communities by reducing dominance of some plants while enhancing the abundance of others, hence altering the woody plant densities as recorded in this present study. Our results showed persistence of species in areas with high fire frequency both in the shrub and tree layers. It is, therefore, important to note that the vegetation in LCRP could naturally be fire adapted and resilient, a common phenomenon of savanna vegetation (Furley *et al.* 2008; Higgins *et al.* 2000), as some plants sprouted from the base after being burnt (Hoffmann *et al.* 2012). Some trees were observed to cluster on termite mounds in the study area across the three strata. Termitaria act as refugia, thus, this may have reduced the damaging effect of fire on woody plants (Seymour *et al.* 2016).

Table 2. Common species based on percentage occurrence in the shrub and tree layers across the three fire frequency categories in Lake Chivero Recreational Park, northern Zimbabwe. Notes: – denotes not recorded in the stratum; LFF = low fire frequency, MFF = medium fire frequency, HFF = high fire frequency.

Species	Family	Shrub layer			Tree layer		
		HFF	MFF	LFF	HFF	MFF	LFF
Albizia amara	Fabaceae	–	2	1	–	5	5
Brachystegia spiciformis	Fabaceae	8	45	10	32	37	51
Bridelia mollis	Phyllanthaceae	–	–	2	–	1	2
Burkea africana	Caesalpiniaceae	–	–	–	5	–	6
Cassia abbreviata	Caesalpiniaceae	–	–	–	1	–	–
Celtis africana	Cannabaceae	–	1	4	–	1	5
Combretum apiculatum	Combretaceae	–	–	–	1	–	2
Combretum molle	Combretaceae	–	–	1	–	–	5
Combretum mossambicense	Combretaceae	–	5	–	–	9	–
Diplorhynchus condylocarpon	Apocynaceae	–	1	–	–	–	2
Euclea divinorum	Ebenaceae	–	1	10	–	8	1
Euphorbia confinalis	Euphorbiaceae	–	–	–	–	1	2
Euphorbia ingens	Euphorbiaceae	–	2	1	1	3	
Faurea saligna	Proteaceae	–	–	–	–	–	1
Ficus capensis	Moraceae	–	–	5	–	–	1
Garcinia livingstonei	Clusiaceae	–	–	–	–	1	–
Gardenia volkensii	Rubiaceae	–	–	–	–	2	–
Grewia flavescence	Malvaceae	–	14	30	–	–	1
Grewia monticola	Malvaceae	1	3	12	–	1	–
Grewia occidentalis	Malvaceae	–	–	4	–	–	–
Julbernardia globiflora	Fabaceae	6	8	–	29	10	1
Lannea discolor	Anacardiaceae	–	1	–	2	–	1
Monotes glaber	Dipterocarpacea	2	1	–	1	1	1
Parinari curatellifolia	Chrysobalanaceae	–	5	3	4	8	1
Peltophorum africanum	Fabaceae	–	1	1	3	4	–
Piliostigma thonningii	Fabaceae	–	–	–	–	1	–
Pterocarpus angolensis	Fabaceae	–	–	1	1	1	1
Rhus longipes	Anacardiaceae	–	–	2	–	–	1
Salix mucronata	Salicaceae	–	1	–	–	1	–
Senegalia polyacantha	Fabaceae	2	–	–	4	–	–
Terminalia mollis	Combretaceae	–	–	–	3	–	–
Terminalia sericea	Combretaceae	79	–	–	12	–	–
Terminalia stenostachya	Combretaceae	–	–	1	–	–	2
Vangueria infausta	Rubiaceae	2	8	11	–	1	4
Vitex payos	Verbenaceae	–	–	–	1	–	2
Ximenia caffra	Olacaceae	–	1	1	–	–	1
Ziziphus mucronata	Rhamnaceae	–	–	–	–	4	1

We recorded no significant differences in woody plant evenness and species diversity across the three fire frequency strata. This could be attributed to the relatively small size of the LCRP resulting in high similarity of habitats in terms of woody plant species as postulated by Tobler's First Law of Geography (Tobler 2004). It has also been reported that fires may not always lead to marked decrease or changes in woody plant species in savanna ecosystems due to species adaptability to fires (Gandiwa & Kativu 2009; Govender *et al*. 2006). However, we did not monitor trends of woody plant species loss in the present study, but such is an important factor to consider in future studies.

In conclusion, our study has shown the impact of fire frequency on woody vegetation structure through altering plant height and densities. However, woody plant evenness and species diversity were not significantly altered. Our results contribute to the broader literature of environmental determinants, in particular, the role of fire in shaping savanna ecosystem. Our results have implications for wildlife management and also tourism experiences (e.g., through influencing animal visibility based on vegetation structural transformation) in LCRP and other similar protected areas in savanna ecosystems. However, it should be noted that the effects of different fire frequencies are difficult to generalise because biotic and abiotic interactions that influence post-fire effects are complex and vary from one area to the other (Arévalo *et al*. 2001). Our study was based on historical data collected over 25 years and there could be limitations in terms of accuracy of the fire records. We therefore recommend for the (i) development of a robust fire management plan for LCRP encompassing strategies such as patch mosaic and early burning (Parr & Brockett 1999) so as to ensure sustainable habitat management, and (ii) establishment of a comprehensive fire occurrence database and fire research program.

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