Effects of repeated burning on woody vegetation structure and composition in a semi-arid southern African savanna

Edson Gandiwa
Department of Environmental Science and Health, National University of Science and Technology, P.O. Box AC 939, Ascot, Bulawayo, Zimbabwe
Present address: Scientific Services, Gonarezhou National Park, Parks and Wildlife Management Authority, Private Bag 7003, Chiredzi, Zimbabwe
egandiwa@gmail.com

ABSTRACT

The objective of this study was to investigate the effects of repeated dry season annual hot fires on woody plants in a semi-arid southern African savanna in Zimbabwe. Parts of the National University of Science and Technology (NUST) research fields in Bulawayo, Zimbabwe have been burnt annually in the dry season between 1994 and 2003 in order to control bush encroachment. The present study was carried out in both the burnt and unburnt sites of the NUST research fields consisting of *Acacia karroo-Colophospermum mopane* vegetation. The study adopted a randomised block design and woody vegetation data were collected from a total of 10 plots. Variables measured and recorded included woody plant height, density, number of stems per plant, proportion of multi-stemmed plants, proportion of dead stems, basal area, fire damage and number of species per plot. The study results indicate that there were significant differences ($P < 0.05$) in woody plant heights, proportion of multi-stemmed plants, proportion of dead stems and basal areas between the burnt and unburnt sites. However, there were no significant differences ($P > 0.05$) in density, number of species per plot and number of stems per plant in woody plants between the burnt and unburnt sites. The study results suggest that repeated dry season annual hot fires leads to thinner and short-stemmed plants in semi-arid savanna ecosystems. Repeated burning also increased the proportion of multi-stemmed plants and proportion of dead stems in the burnt site. Despite burning sections of the study area annually, bush encroachment control has not been effectively achieved. The study findings points to the need of adaptive management strategies in the use of fires in managing vegetation in semi-arid savanna ecosystems.

Key words: Ecosystem, Fire regime, Fuel load, Monitoring, Resprouting, Woody plants, Zimbabwe

1. Introduction

Tropical savannas are characterized by a co-dominance of trees, shrubs and herbaceous plants, whose proportions are determined by environmental, ecological and human parameters and fashioned by fire (Scholes and Archer, 1997; Mlambo and Mapaure, 2006; Furley et al., 2008). Fire as a management tool has caused dramatic changes in the structure and function of ecosystems (Lavorel et al., 2001). Anthropogenic fires in Africa are an ancient form of environmental disturbance, which probably have shaped the savanna vegetation more than any other human induced disturbance (Sheuyange et al., 2005). In savannas, fire is used to control the establishment of woody vegetation among other uses (Skarpe, 1992). Fire, a major disturbance factor, is regarded as an essential determinant of the structure and function of savanna vegetation, and acts to modify broad patterns set primarily by rainfall and edaphic

458

factors (Scholes and Walker, 1993). Trollope (1982) revealed that the long-term effects of fire on a landscape vary according to sequences of fire events, rather than to a single fire event. Fires are driven by biotic and abiotic factors that dictate their temporal (seasonality and frequency), spatial (size and patchiness), and magnitude (intensity, severity and type) components (Van Wilgen and Scholes, 1997; Pyke et al., 2010). Fire frequency is an important characteristic of a fire regime. How frequently a site burns affects many aspects of ecosystem function from nutrient cycling, to grass productivity, to tree recruitment (Bond and Keeley, 2005; Kraaij and Ward, 2006; Holdo et al., 2007; Prior et al., 2009). Although fire is a natural component and a key determinant of savanna vegetation structure, an increase in the frequency of fires may offset the advantages that occasional natural fires bring upon the vegetation communities (Parr and Brockett, 1999; Shackleton and Scholes, 2000; Gandiwa and Kativu, 2009).

Frequent fires may affect recruitment of young trees into higher size classes. Fire frequency determines the length of time that a plant has to recover before the next fire occurs. The slower the rate to recover, the more likely it is that the structure and composition of the vegetation will be altered, particularly where fires occur frequently. The rate of recovery depends on the extent of damage sustained by the plants, the method of regeneration and the favourability of the post-fire environment and temporal distribution of rainfall (Frost and Robertson, 1987). Fire intensity is one of the most important aspects of a fire regime, which describes the severity or impact of the fire on biotic and abiotic components of the ecosystem. In South Africa, it was established that there was a significantly greater topkill of the bush with increasing fire intensities (Trollope et al., 1999). Elsewhere in Zambia, complete protection from fire resulted in an increase in woody canopy height and biomass (Trapnell, 1959).

Conflicting results have however been obtained on the effect of frequency of burning on the density of tree and shrub vegetation. For example, Van Wyk (1971) suggested that frequency of burning appears not to have any significant effect on density of woody plants whilst Skarpe (1992) revealed that frequent fires, under some conditions may lead to an increase in woody density as competition for moisture from grasses decreases. Trees and shrubs are probably more susceptible to fire at the end of the dry season when the plant moisture and food reserves are depleted due to new spring growth (West, 1965). Disturbance events, such as fire, can affect a system's capacity to withstand impacts that may cause it to shift from one state to another i.e. its resilience (Parr and Brockett, 1999). Tafangenyasha (1997) outlined that vegetation is modified by drought, fire and herbivory as well as human activities. Schwilk et al. (1997) postulated that disturbances such as fire are important mechanisms for producing and/or maintaining spatial heterogeneity. Fire, therefore, plays a role in structuring ecological systems by producing a spatio-temporal mosaic of patches at different successional stages (Parr and Brockett, 1999). Bond and Van Wilgen (1996) concluded that fire is a very general and influential ecological phenomenon. In southern Africa, temporal variability in fire regimes promotes grass-tree existence hence the structural diversity of the savanna systems (Trollope et al., 1999).

Fire can influence woody vegetation biomass, composition, and structure. Despite the importance of fire in shaping savannas, it remains poorly understood how the frequency, seasonality, and intensity of fire interact to influence woody vegetation structure, which is a key determinant of savanna biodiversity (Smit et al., 2010). Dry season annual hot fires have been used to control bush encroachment in some sections of the National University of Science and Technology (NUST) research fields from 1994 to 2003. These dry season hot

fires occur once a year at fixed times and these burn out same areas. It is likely that the repeated burning may have contributed to the changes in woody community structure and species composition. These changes may lead to a degraded landscape. Therefore, the specific objective of this study was to determine the effects of repeated burning on the structure and composition of woody vegetation in the NUST research fields in Bulawayo, Zimbabwe.

2. Materials and Methods

2.1 Study area

The study area measuring 1.17 km^2, is located at the NUST research fields, Bulawayo, in the southern highveld of Zimbabwe. The study area lies at 20° 33' S and 28° 70' E at an altitude of 1,350 m above sea level (Tabex Encyclopaedia, 1989). The climate of the study area is semi-arid. The mean annual rainfall is 600.8 mm (Department of Meteorological Services, 2003). Rainfall is not evenly distributed throughout the year and droughts are a frequent phenomenon. The greatest amount of rainfall about 535.6 mm is received between November to March and the least, 31.6 mm, between July and October. April to June period receives 33.6 mm. Mean annual maximum and minimum temperatures for the study area is 25.8 °C and 12.7 °C, respectively. Daily mean temperatures tend to be comparatively high. The mean night daily temperature range can be as low as 8.7 °C. Mean temperature for the hottest month (October) is 22 °C whilst the mean temperature for the coldest month (June) is 12 °C. The period May to mid-August experiences mean temperatures of 17.5 °C (range: 14.6–20.4 °C). This period is also characterised by cloudless days and cold nights (Department of Meteorological Services, 2003).

The annual average surface wind speed is 6.7 knots ranging from 6.0 knots in December to 7.8 knots in September (Department of Meteorological Services, 2003). The vegetation of study area is predominantly dry *Acacia karroo-Colophospermum mopane* woodland. The *Acacia* species is found on all soils of the calcimorphic order and is often the dominant species, the density of the species is highly variable. Other common woody species are *Dichrostachys cinerea, Ziziphus mucronata, Peltophorum africanum* and *Combretum hereroense*. The grass cover is sparse and dominated by perennial species but varies according to the local rainfall. A more detailed description of the study area has been provided by Gandiwa (2004), Mlambo et al. (2005) and Mlambo and Mwenje (2010). The study area is underlain by Greenstone rock of the Precambrian shield, which hosts of gold mineralization and characterized by abundant greenstone, a dark green meta-basic rock (basalt, dolerite, and gabbro) that owes its colour to the presence of chlorite, actinolite or epidote. The Greenstone bedrock gives rise to soils of the calcimorphic order. The soil of the study area constitutes of very limited leaching, large reserves of weatherable minerals and a predominance of active clays. The dominant soil type is the silallitic soils composed dominantly of less active clays (Tabex Encyclopaedia, 1989).

2.2 Experimental design

The present study used the randomised block design. The study was conducted in two sites (blocks) in areas of the same vegetation type (*Acacia karroo-Colophospermum mopane* woodland). The burnt site measured 0.65 km^2 whilst the unburnt site measured 0.52 km^2. The burnt site was located in an area that had been subjected to dry season annual hot fires from 1994 to 2003 and the unburnt site was located in an area that had not been burnt in the same period. The unburnt sites were the 'control sites' whereas the burnt sites were the 'treatment

sites'. A total of 10 plots were randomly placed in the two study sites. The plots were square and measured 20 × 20 m (0.04 ha). Plots were randomly chosen using random number tables and pegged on the ground in both sites. Sample plots were located at least 10 m from roads so as to exclude the road effect.

2.3 Field data collection

All vegetation assessments were conducted in the month of December 2003 to avoid bias by seasonal disparities. Each plot was assessed once during the study. Edges of the plots were maintained straight using a 100 m tape measure. For every woody plant rooted within the plot, the following were recorded: height, number of stems per plant, species type, proportion of fire damage, dead stems and basal stem circumference. Woody species occurring within the study plots were identified using field identification guides (Coates-Pelgrave, 1997; Van Wyk and Van Wyk, 1997; Timberlake et al., 1999). Height of woody plants was measured using two methods; first, for woody plants of heights 2.5 m and below, a 2.5 m graduated pole was held against the tree and height recorded. Second, for woody plants whose heights exceeded 2.5 m, heights were visually estimated. Proportion of fire damages was recorded to assess the impact of fire on the woody plants (Table 1). Fire damage was noted if there were black burn marks evident on the stems.

Table 1: Fire damage classifications used in this study

Class	Fire damage scale (%)	Comment
1	0	No evidence of fire damage
2	5–49	Few burn marks
3	50–74	Several burn marks
4	75–94	Almost completely burnt
5	95–100	Completely burnt

Dead stems were also included in the assessment, although species identification was a challenge. Woody stems were denoted as dead if there were no signs of regeneration and having dry stems, branches and barks. All standing and fallen dead woody plants were recorded and the cause of death ascertained where possible, i.e. fire or 'other' (insects, wind, drought, old age or disease). Basal circumferences for each woody stem were measured using a 1.5 m flexible tape measure on all woody stems within the plots at a height of 30 cm above the ground. Care was taken to exclude herbaceous species. All woody stems below 30 cm were ignored because these were too small and could not easily be identified. Multi-stemmed plants denote plants with at least two stems and for these, basal circumferences were recorded as per single stem. The numbers of stems per plant in the case of multi-stemmed plants were physically counted, basal circumference and height measurement taken on each stem on the plant.

2.4 Data analysis

Variables examined were woody plant density, height, number of stems per plant, number of species per plot, fire damage, basal area, proportion of dead stems and proportion of multi-stemmed plants. Densities were determined for each plot by using the number of stems. All woody stems in the plot were summed to provide the total number of stems per plot. Plot densities were found by dividing the total number of stems by 400 m^2, providing stems/m^2 value for each plot. For each study site, density was calculated by averaging densities of the five plots. Mean heights for each plot were determined by summing all the individual tree

heights and then dividing the total sum by the total number of stems. The basal area of each stem was calculated from the stem basal circumference using equations 1 and 2 (below) and mean plant basal area per plot was determined by summing the basal area of each woody stem in the plot and then dividing by 400 m^2 to give the cm^2/m^2 value for each plot.

Basal area calculations used in the present study:

Equation 1: Stem diameter (d): $d = C/\pi$; where: C is circumference;

Equation 2: Basal area (g): $g = \frac{1}{4} \times \pi \times d^2$; where: g is in cm^2/m^2 and d is diameter.

Mean proportion of fire damage for the plots were found by summing the individual stem fire proportion of damage and dividing by the total number of stems in the plot to give the mean plot proportion of fire damage value. In order to attain the mean proportion of fire damage for each site, the five plots mean fire damage values were averaged respectively for the burnt and unburnt sites. The numbers of stems per plant values were determined by dividing the total number of stems in the plot by the number of plants in each respective plot. The mean proportion values for dead stems for each plot were established by dividing the total number of dead stems in the plot by the total number of stems (both live and dead) in each plot and later converting the value as a proportion. For each site, the five plot values were averaged to give the mean proportion of dead stems value per site. The proportion of multi-stemmed plants in each plot was determined by the ratio: number of plants with at least two stems divided by total number of plants in the plot. The ratios were further converted to proportion of multi-stemmed plant values and averaged to yield the proportion of multi-stemmed plant values for each site. Averaging the species values for the respective plots in each site attained the mean species values per site.

Species diversity indices for the burnt and unburnt sites were computed using the Shannon-Wiener Index (*H'*). Further, an analysis of species composition similarity between the burnt and unburnt sites was computed using the Jaccard Index of Community Similarity. The Jaccard Index is based on the presence-absence relationship between the number of species in each site and the total number of species in the study area (Ludwig and Reynolds, 1988). The level of significance between the differences of each study variable in the burnt and unburnt sites and descriptive statistics were determined using the Student *t*-test for unequal variances in Microsoft Excel. Data were first tested for normality and found to be normal. The assumption in the Student *t*-test is that any difference in response is due to the treatment or lack of treatment and not to other factors.

3. Results

3.1 Woody vegetation structure changes

A total of 2,285 woody stems were identified, measured and assessed in the study plots. Height of woody stems on the unburnt site was higher than that recorded on the burnt site ($P < 0.05$, df = 8; Table 2). Average basal areas were high on the unburnt site than on the burnt site ($P < 0.001$, df = 8). A higher proportion of multi-stemmed plants were recorded on the annual burnt site as compared to the unburnt site ($P < 0.05$, df = 8). There was a high proportion of fire damaged plants on the burnt site and hence, mean fire damaged plants was significantly different between the burnt and unburnt sites ($P < 0.001$, df = 8). Higher proportion of fire damage values were recorded on relatively short trees (30 cm to 1.5 m) with tall trees (> 5 m), having the least proportion of fire damage on the burnt site.

Furthermore, it was evident that fire damage was higher on woody stems with small basal areas (< 20 cm^2), whilst the stems with larger basal areas (> 20 cm^2) had the least fire damage on the burnt site. The burnt site had a higher proportion of dead stems compared to the unburnt site ($P < 0.001$, df = 8). In contrast, there were no significant differences in mean woody plant stem densities, number of stems per plant and species per plot between burnt and unburnt sites ($P > 0.05$, df = 8; Table 2).

Table 2: Summary of statistical values of the study variables in burnt and unburnt sites

Variable	Burnt site		Unburnt site		Significance
	Mean	S.E.	Mean	S.E.	
Height (cm)	153.59	7.08	196.75	11.27	*
Density (stems/m^2)	0.66	0.09	0.49	0.04	NS
Number of stems per plant	2.19	0.14	**1.85**	0.06	NS
Number of species per plot	12.6	0.81	15.2	1.65	NS
Basal area (cm^2/ m^2)	9.27	1.11	20.66	1.14	**
Proportion of multi-stemmed plants	0.60	0.03	**0.48**	0.03	*
Proportion of fire damaged plants	**0.81**	0.03	0.00	0.00	**
Proportion of dead stems	0.40	0.04	0.09	0.03	**

Notes: NS (Not significant) = $P > 0.05$; * = $0.001 < P < 0.05$ and ** = $P < 0.001$; S.E. = Standard Error.

3.2 Woody vegetation composition changes

A total of 46 woody plant species were recorded in both the burnt and unburnt sites in this study. Shannon-Wiener diversity indices values declined from the unburnt to the burnt sites, revealing that there was slightly more species of woody plants on the unburnt site as compared to the burnt site. However, the Jaccard Index of Community Similarity showed that there was a 39.13 % similarity in species composition between the burnt and unburnt sites (Table 3). Table 4 shows the different species classifications in both the burnt and unburnt sites in the study sites.

Table 3: Woody species composition in the study sites

Variable	Unburnt site	Burnt site
Number of woody plant species	34	30
Shannon-Wiener Index (*H'*)	2.90	2.36
Jaccard Index of community similarity	0.39 or 39.13%	

Table 4: Woody species classifications in the burnt and unburnt sites showing the common woody plant species for each category

Variable	Burnt site	Unburnt site
Tallest species	1. *Acacia galpinii* 2. *Acacia karroo* 3. *Acacia nilotica* 4. *Dombeya rotundifolia* 5. *Lannea discolor*	1. *Acacia nilotica* 2. *Acacia polyacantha* 3. *Azanza garckeana* 4. *Colophospermum mopane* 5. *Commiphora marlothii*
Shortest species	1. *Albizia harveyi* 2. *Combretum molle*	1. *Combretum hereroense* 2. *Diplorhynchus condylocarpon*

	3. *Flacourtia indica* 4. *Rhus leptodictya* 5. *Rhus pyroides*	3. *Rhus pyroides* 4. *Securidaca longipedunculata* 5. *Turraea nilotica*
Most dense species	1. *Albizia harveyi* 2. *Combretum collium* 3. *Combretum hereroense* 4. *Peltophorum africanum* 5. *Rhus pyroides*	1. *Combretum hereroense* 2. *Dichrostachys cinerea* 3. *Grewia monticola* 4. *Peltophorum africanum* 5. *Ziziphus mucronata*
Least dense species	1. *Acacia nilotica* 2. *Bridelia mollis* 3. *Combretum molle* 4. *Lannea discolor* 5. *Ziziphus mucronata*	1. *Acacia galpinii* 2. *Acacia rehmanniana* 3. *Commiphora edulis* 4. *Elephantorrhiza goetzei* 5. *Turraea nilotica*

4. Discussion

The present study results suggests that woody vegetation on the burnt site is being transformed into a lower woodland community interspersed with a low density of large trees but high density of short and small plants, together with significant basal area changes. In this study, the burnt site had a mean height of woody stems shorter than that of the unburnt site, suggesting negative effects of repeated burning including topkill of woody plants (also see Enslin et al., 2000; Gandiwa and Kativu, 2009). Repeated topkill of small trees makes them particularly susceptible to the 'fire trap', which prevents recruitment into adult size classes (Hoffmann et al., 2009; Ryan and Williams, 2011). Enslin et al. (2000) suggested that perhaps density of stems is an inadequate index of fire impact. It is likely that in this present study, 10 years is a short period to contrast fire treatments in terms of woody plant density because of low rainfall in the study area resulting in inadequate fuel load to give high heat intensity from burns which can easily kill woody plants. Although the burnt and unburnt sites had almost the same number of woody species, these species were basically different, and fewer in the burnt site. Thus, this is a pointer to the fact that some species were lost to burning and replaced by some relatively fire tolerant species. The fire tolerant species are adapted to burning by prolific production of coppices hence the higher values of multi-stemming in burnt sites as compared to the unburnt sites. In addition, the present study showed significant differences in height between burnt and unburnt sites. The results support those of Trapnell (1959), Spence and Angus (1971), Strang (1974), Shackleton and Scholes (2000), Gandiwa (2006) and Gandiwa et al. (2011a). However, the results, contradict those of Tafangenyasha (2001), which showed that burnt sites have relatively taller woody plants than unburnt sites in Gonarezhou National Park, southeast Zimbabwe, probably due to differences in woody species and soil conditions in the study areas.

It has been suggested that savanna landscapes respond variably to long-term burning (Higgins et al., 2007). The results of this study seem to suggest that fire had little effect on density of stems between the burnt and unburnt sites. Similar findings were recorded by Strang (1974), Trollope (1982), Van Wyk (1971) and Tafangenyasha (2001). In addition, Higgins et al. (2007) found that fire did not influence tree density, but influenced the size structure and biomass of tree populations in an African savanna. Perhaps the non-significant differences in stem density recorded in this present study could be attributed to resprouting by woody plants after burning. Savanna vegetation is typically fire-adapted and resilient (Furley et al., 2008). For example, Marrinan et al. (2005) observed that resprouting was more common in burnt sites than in unburnt sites in a study in Australia. Prior et al. (2009) suggests that an increase in the frequency or severity of fires is likely to change the tree density and basal area of

savannas in North Australia. Another factor that could affect the impact of fires on the density of trees is tree clustering. For instance, Groen et al. (2008) found that clustering reduces the damaging effect of fire on trees in African savannas.

It has been reported that fires can change plant communities by reducing dominance of some plants while enhancing the abundance of others (Pyke et al., 2010). However, in this present study there was no concerted monitoring trend of woody plant species loss. Although the densities were almost the same between the burnt and unburnt site, they were densities, mainly of different woody plant species. Thus, repeated fires may have reduced densities of fire-intolerant plants and failed to do so for fire tolerant species. The number of stems per plant in this study was not statistically significantly different between the burnt and unburnt sites. However, there was higher number of stems per plant on the burnt site as compared to the unburnt site, probably due to the adaptation of plants to withstand fires possibly by having lingo-tubers or underground-unaffected portion with food resources and regeneration parts. This trend in the number of stems per plant support the findings of San Jose and Farinas (1983), Scholes and Walker (1993) and Enslin et al. (2000) who recorded the greatest number of stems per plant on the burnt sites as compared to the unburnt sites. Tchie and Gakahn (1989) mentioned that the number of stems per plant is species specific and in this present study, the same species, which had higher number of stems per plant, were found on both the burnt and unburnt sites, thus contributing to the non-significance in the difference between the burnt and unburnt sites.

Although the unburnt site had slightly more species than the unburnt site, the difference in number of species between the two sites was not significant. Elsewhere, Enslin et al. (2000) and Govender et al. (2006) found that changes in woody vegetation after burning did not involve a marked decrease in species composition in the Kruger National Park, South Africa. However, woody species were shown to be generally negatively affected by frequent fires in the Okavango Delta, Botswana (Heinl, 2005). O'Connor (1985) suggests that reduced species diversity has been recorded in a number of fire experiments, mostly in mesic savannas. A significantly higher proportion of multi-stemmed plants were evident on the burnt site than on the unburnt site, perhaps due to basal coppicing of short plants. Scholes and Walker (1993) reported an increase in the proportion of multi-stemmed plants with burning in other African savanna. Enslin et al. (2000) stated that the proportion of multi-stemmed plants induced by burning is species specific. The proportion of dead stems was found to be significantly different between the burnt and unburnt sites. The presence of dead stems on the unburnt site might be due to other contributory factors such as drought, wind, insects, disease and/or age. Tafangenyasha (1998) suggest that dry spells and the drought of 1992 resulted in die-offs of some woody plant species in the southeast lowveld in Zimbabwe. Since, both study sites were located in the same environmental setup, the results indicate that the dry season annual hot fires caused additional mortality on plants in the present study, particularly in the burnt sites.

A significant difference was recorded in basal areas between the burnt and unburnt sites. Woody plants on the unburnt site were significantly larger, i.e. had higher basal areas and also heights, as compared to those on the burnt site. The dry season annual hot fires probably produced more extreme topkill, resulting in basal coppicing, i.e., the killing above ground surface parts of plants and generation of smaller plants with narrower basal areas, on the burnt site (Enslin et al., 2000). The opposite seems true for the unburnt site, where tall, single stemmed plants mostly resulted in wide basal areas. The annual burning regime makes the study area unique among *Acacia* stands and woodlands for studying the survival of trees in

the presence of fire and the absence of large herbivores, for example, African elephants (*Loxodonta africana*). The effects of herbivory, mostly from large herbivores particularly elephants, and fire are inextricably intertwined with herbivores creating conditions which allow the easier spread of fire by opening up thickets and allowing more combustible grassland to encroach or can keep short plants in the fire zone (Smart et al., 1985; Trollope et al., 1998; Archibald et al., 2005; Mourik et al., 2007; Ribeiro et al., 2008; Mapaure and Moe, 2009; Gandiwa et al., 2011b).

Fire can damage and/or destroy young trees and inhibit the regeneration of some species whilst encouraging those, which are fire-resistant (Smart et al., 1985). Trollope (1973) demonstrated how fynbos on the Eastern Cape, South Africa could be turned into grassland under a frequent burning regime. The floristic changes in the study sites remain to be established in the long-term. It is essential that floristic changes be quantified on the basis of the soil-vegetation complex. Studies by other researchers show that soil organic matter, organic carbon, nitrogen and the labile fraction of organic and inorganic phosphorous show marked increases following burning (O'Connor, 1985; Smart et al., 1985). It is possible that at a later seral stage in the development from grassland to woodland *Acacia* woodland stands may be replaced by other tree species but this aspect will require considerable long-term monitoring.

Dry season annual hot fires cannot be maintained without substantial loss to fire sensitive species. A major long-term objective would be to restrict the disappearance of fire sensitive species by increasing the burning intervals. Fire regimes are having a major impact on fire sensitive species that include *D. cinerea, L. discolor, Z. mucronata* and *G. monticola* in the study area. Fire resistant species in the study area include *A. karroo, A. galpinii, A. harveyi, Combretum zeyheri, D. condylocarpon* and *P. africanum*. Conservative fire management constitutes a major challenge both for the study area and for other extensive areas of semi-arid lands in savanna ecosystems. Adaptive fire management offers a framework (see Van Wilgen et al., 2011) for addressing burning issues at the research fields in the study area and beyond. Future studies should evaluate the effects of fire on specific species of woody plants to aid in the understanding of how burning is impacting on the woody species in the study area. In addition the importance of the human factor in modifying the vegetation in the study area through past management practises needs examination.

Acknowledgements

5. References

1. Archibald, S., Bond, W.J., Stock, W.D. and Fairbanks, D.H.K (2005), Shaping the landscape: fire–grazer interactions in an African savanna, Ecological Applications, 15, pp 96-109.

2. Bond W. and Van Wilgen J (1996), Fire and Plants, Chapman and Hall, London.

3. Bond W.J. and Keeley J.E (2005), Fire as a global "herbivore": The ecology and evolution of flammable ecosystems, Trends in Ecology and Evolution, 20, pp 387-394.

4. Coates-Pelgrave K (1997), trees of Southern Africa, 2nd Edition, Kyodo Printing Company Private Limited, Singapore.

5. Department of Meteorological Services (2003), Climate data records of Bulawayo, Goetz Observatory Weather Station, Bulawayo.

6. Enslin B.W., Potgieter A.L.F., Biggs H.C. and Biggs R (2000), Long-term effects of fire frequency and season on the woody vegetation dynamics of the *Sclerocarya birrea/Acacia nigrescens* savanna of the Kruger National Park, Koedoe, 43(1), pp 27-37.

7. Frost P.G.H. and Robertson F (1987), The ecological effects of fire in savannas. In: B.H. Walker, (ed.), Determinants of tropical savannas. IUBS Monograph Series, 3, pp 93-140.

8. Furley P.A., Rees R.M., Ryan C.M. and Saiz, G (2008), Savanna burning and the assessment of long-term fire experiments with particular reference to Zimbabwe. Progress in Physical Geography, 32(6), pp 611-634.

9. Gandiwa, E (2004), The ecological effects of fire on woody plants at the National University of Science and Technology Campus, Zimbabwe, BSc Thesis, National University of Science and Technology, Bulawayo, 61p.

10. Gandiwa, E (2006), Influence of fire frequency on woody vegetation structure and composition in northern Gonarezhou National Park, Zimbabwe, MSc Thesis, University of Zimbabwe, Harare, 120p.

11. Gandiwa E. and Kativu S (2009), Influence of fire frequency on *Colophospermum mopane* and *Combretum apiculatum* woodland structure and composition in northern Gonarezhou National Park, Zimbabwe, Koedoe, 51(1), Art. #685, 13 p, DOI: 10.4102/koedoe, v51i1.685.

12. Gandiwa E., Chikorowondo G., Zisadza-Gandiwa P., and Muvengwi J (2011a), Structure and composition of *Androstachys johnsonii* woodland across various strata in Gonarezhou National Park, southeast Zimbabwe, Tropical Conservation Science, 4(2), pp 218-229.

13. Gandiwa, E., Magwati, T., Zisadza, P., Chinuwo, T. and Tafangenyasha, C (2011b), The impact of African elephants on *Acacia tortilis* woodland in northern Gonarezhou National Park, Zimbabwe, Journal of Arid Environments, 75(9), pp 809-814.

14. Govender N., Trollope W.S.W. and Van Wilgen B.W (2006), The effect of fire season, fire frequency, rainfall and management on fire intensity in savanna vegetation in South Africa, Journal of Applied Ecology, 43(4), pp 748-758.

15. Groen T.A., Van Langevelde F., Van De Vijver C.A.D.M., Govender N. and Prins, H.H.T (2008), Soil clay content and fire frequency affect clustering in trees in South African savannas, Journal of Tropical Ecology, 24, pp 269-279.

16. Heinl, M (2005), Fire regime and vegetation response in the Okavango Delta, Botswana, Dissertation at the Chair of Vegetation Ecology, Technische Universität München, Freising Weihenstephan, Germany, 133p.

17. Higgins S.I., Bond W.J, February E.C., Bronn A., Euston-Brown D.I.W., Enslin B., Govender N., Rademan L., O'regan S., Potgieter A.L.F., Scheiter S., Sowry R., Trollope L. and Trollope W.S.W (2007), effects of four decades of fire manipulation on woody vegetation structure in savanna, Ecology, 88(5), pp 1119-1125.

18. Hoffmann W.A., Adasme R., Haridasan M., De Carvalho M.T., Geiger E.L., Pereira M.A.B., Gotsch S.G., and Franco A.C (2009), Tree topkill, not mortality, governs the dynamics of savanna-forest boundaries under frequent fire in central Brazil, Ecology, 90(5), pp 1326-1337.

19. Holdo R.M (2007), Elephants, fire, and frost can determine community structure and composition in Kalahari woodlands, Ecological Applications, 17(2), pp 558-568.

20. Kraaij T. and Ward D (2006), Effects of rain, nitrogen, fire and grazing on tree recruitment and early survival in bush encroached savanna, South Africa, Plant Ecology, 186, pp 235-246.

21. Lavorel S., Lambin E.F., Flannigan M. and Scholes M (2001), Fires in the earth system: The need for integrated research, IGBP Global Change Newsletter, 48, pp 7-10.

22. Ludwig A.J. and Reynolds F.J (1988), Statistical ecology a premier on methods and computing, John Wiley and Sons Inc, New York.

23. Mapaure I. and Moe, S.R (2009), Changes in the structure and composition of miombo woodlands mediated by elephants (*Loxodonta africana*) and fire over a 26-year period in north-western Zimbabwe, African Journal of Ecology, 47(2), pp 175-183.

24. Marrinan M.J., Edwards W. and Landsberg J (2005), Resprouting of saplings following a tropical rainforest fire in north-east Queensland, Australia, Austral Ecology, 30(8), pp 817-826.

25. Mlambo D. and Mapaure I (2006), Post-fire resprouting of *Colophospermum mopane* saplings in a southern African savanna, Journal of Tropical Ecology, 22, pp 231-234.

26. Mlambo D. and Mwenje E (2010), Influence of *Colophospermum mopane* canopy cover on litter decomposition and nutrient dynamics in a semi-arid African savannah, African Journal of Ecology, 48(4), pp 1021-1029.

27. Mlambo D., Nyathi P. and Mapaure I (2005), Influence of *Colophospermum mopane* on surface soil properties and understorey vegetation in a southern African savanna, Forest Ecology and Management, 212, pp 394-404.

28. Mourik A.A., Van Langevelde F., Van Tellingen E., Heitkönig I.M.A. and Gaigher I (2007), stabIlity of wooded patches in a South African nutrient-poor grassland: Do nutrients, fire or herbivores limit their expansion', Journal of Tropical Ecology, 23, pp 529-537.

29. O'Connor T.G (1985), A synthesis of field experiments concerning the grass layer in the savanna regions of Southern Africa, Council for Scientific and Industrial Research, National Scientific Programmes Unit, Southern African National Scientific Programmes Report No. 144, Pretoria.

30. Parr C.L. and Brockett B.H (1999), patch-mosaic burning: A new paradigm for savanna fire management in protected areas? Koedoe, 42(2), pp 117-130.

31. Prior L.D., Murphy B.P. and Russell-Smith J (2009), environmental and demographic correlates of tree recruitment and mortality in North Australian savannas, Forest Ecology and Management, 257(1), pp 66-74.

32. Pyke D.A., Brooks M.L. and D'Antonio C (2010), Fire as a restoration tool: A decision framework for predicting the control or enhancement of plants using fire. Restoration Ecology, 18(3), pp 274-284.

33. Ribeiro N.S., Shugart H.H. and Washington-Allen R (2008), The effects of fire and elephants on species composition and structure of the Niassa Reserve, northern Mozambique, Forest Ecology and Management, 255, pp 1626-1636.

34. Ryan, C.M. and Williams, M (2011), How does fire intensity and frequency affect miombo woodland tree populations and biomass? Ecological Applications, 21(1), pp 48-60.

35. San Jose J.J. and Farinas M.R (1983), Changes in tree density and species composition in a protected *Trachypogon* savanna, Venezuela, Ecology, 64, pp 447-453.

36. Scholes R.J. and Archer S.R (1997), Tree-grass interactions in savannas, Annual Review of Ecology and Systematics, 28, pp 517-544.

37. Scholes R.J. and Walker B.H (1993), An African savanna: synthesis of the Nylsvley study, Cambridge University Press, Cambridge.

38. Schwilk D.W., Keeley J.E. and Bond W.J (1997), The Intermediate Disturbance Hypothesis does not explain fire and diversity pattern in fynbos, Plant Ecology, 132, pp 77-84.

39. Shackleton C.M. and Scholes R.J (2000), Impact of fire frequency on woody community structure and soil nutrients in Kruger National Park, Koedoe, 43(1), pp 75-81.

40. Sheuyange, A., Oba, G. and Weladji, R.B (2005), Effects of anthropogenic fire

history on savanna vegetation in northeastern Namibia, Journal of Environmental Management, 75, pp 189-198.

41. Skarpe C (1992), Dynamics of savanna ecosystems, Journal of Vegetation Science, 3, pp 293-300.

42. Smart N.O.E., Hatton J.C. and Spence D.H.N (1985), The effect of long-term exclusion of large herbivores on vegetation in Murchison Falls National Park, Uganda, Biological Conservation, 33, pp 229-245.

43. Smit I.P.J., Asner G.P., Govender N., Kennedy-Bowdoin T., Knapp D.E. and Jacobson, J (2010), effects of fire on woody vegetation structure in African savanna. Ecological Applications, 20(7), pp 1865-1875.

44. Spence D.H. and Angus A (1971), African grassland management burning and grazing in Murchison Falls National Parks, Uganda. Symposium of the British Ecological Society, 11, pp 319-331.

45. Strang R.M (1974), Some man-made changes in successional trends on the Rhodesian Highveld, Journal of Applied Ecology, 11, pp 249-263.

46. Tabex Encyclopaedia, (1989), Zimbabwe. Arlington Business Corporations, Worcester, United Kingdom.

47. Tafangenyasha C (1997), Tree loss in Gonarezhou National Park (Zimbabwe) between 1970 and 1983, Journal of Environmental Management, 49, pp 355-366.

48. Tafangenyasha C (1998), Phenology and mortality of common woody plants during and after severe drought in south-eastern Zimbabwe, Transactions of the Zimbabwe Scientific Association, 72, pp 1-6.

49. Tafangenyasha C (2001), Decline of the mountain acacia, *Brachystegia glaucescens* in Gonarezhou National Park, Southeast Zimbabwe. Journal of Environmental Management, 63, pp 37-50.

50. Tchie N. and Gakahn G.C (1989), Responses in important woody species of Kenya's rangeland to prescribed burning, African Journal of Ecology, 27, pp 119-128.

51. Timberlake J., Fagg C., Barnes R. and Wise R (1999), Field Guide to the Acacias of Zimbabwe, CBS Publishing, Harare.

52. Trapnell C.G (1959), Ecological results of woodland burning experiments in northern Rhodesia, Journal of Ecology, 47, pp 129-168.

53. Trollope W.S.W (1973), Fire as a method of controlling macchia (fynbos) vegetation on the Amatole Mountains of the Eastern Cape, Proceedings of the Grassland Society of South Africa, 8, pp 35-41.

54. Trollope W.S.W (1982), Ecological effects of fire in South African savannas. In: Ecology of tropical savannas, Springer-Verlag, Berlin.

55. Trollope W.S.W., Potgieter A.L.F., Biggs H.C. and Trollope L.A (1999), Report on the experimental burning plots trial in the major vegetation types of the Kruger National Park. Scientific Report 9/98, Skukuza, South Africa.

56. Trollope W.S.W., Trollope L.A., Biggs H.C., Piennar D. and Potgieter A.L.F (1998), Long-term changes in the woody vegetation of the Kruger National Park, with special reference to the effects of elephants and fire, Koedoe, 41, pp 103-112.

57. Van Wilgen B.W. and Scholes R.J (1997), The vegetation and fire regimes of southern hemisphere Africa, In: Fire in southern African savannas: Ecological and atmospheric perspectives, Witwatersrand University Press, Johannesburg.

58. Van Wilgen B.W., Govender N., Forsyth G.G. and Kraaij T (2011), Towards adaptive fire management for biodiversity conservation: Experience in South African National Parks, Koedoe, 53(2), Art. #982, 9 pages. DOI:10.4102/koedoe.v53i2.982.

59. Van Wyk B. and Van Wyk P (1997), Field guide to Trees of Southern Africa, Struik Publishers, Cape Town.

60. Van Wyk P (1971), Veld burning in Kruger National Park. An interim report of some aspects of research. Proceedings Tall Timbers Fire Ecology Conference, 11, pp 9-31.

61. West O (1965), Fire in vegetation and its use in pasture management with special reference to tropical and sub-tropical Africa, Commonwealth Agricultural Bureau, Farnham Royal, England.