THE EFFECTS OF FIRE ON COMPOSITION AND STRUCTURE OF MIOMBO WOODLANDS IN NYANGA NATIONAL PARK, EASTERN ZIMBABWE

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DEDICATION

I dedicate this piece of work to my beloved parents Mr. and Mrs. Dzamara, my brothers for immense contribution to my upbringing and their greatest support.
ACKNOWLEDGEMENTS

I would like to thank and express my appreciation to my field supervisors the late Mr. Mudangwe, Mr. O. Bepe and the staff members of Nyanga National Park for their assistance in conducting this research. I am also grateful to Mr. P. Makumbe and Mr. G. Chikorowondo my academic supervisors for continual encouragement, guidance and support. I am indebted to a student from Mushandike College of Wildlife, Mr. Nyamvura for assistance during data collection and Mr. Mutsikwi for his assistance in tree species identification. I would also want to thank Professor E. Gandiwa and Mr. Mashapa for their assistance in this project.

My gratitude also goes to my father and mother for their greatest support from the beginning to the end; I do not know how I would have managed without you. You have always been a pillar of support for me no matter how hard it was. Am also grateful to the Dzamara family as a whole an instrumental soul surviving machine you were, I could not have done this without your support.

In everything I do my greatest gratitude goes to the alpha and omega, the creator of mankind, the Almighty God for giving me the strength that keeps me going. I love you God and will magnify your holy name always.
ABSTRACT

Despite the importance of fire in shaping savannas, it remains poorly understood how the frequency, influence woody vegetation structure, which is a key determinant of savanna biodiversity. The objective of this study was to investigate the influence of fire frequency on the composition and structure and composition of miombo woodlands in Nyanga National Park, eastern Zimbabwe. The present study was carried out in both the burnt and unburnt sites of the NNP consisting of miombo woodland. The study adopted a stratified random sampling method on four different fire frequencies which are high, medium, low and control and woody vegetation data were collected from a total of 40 plots. The species richness of 16 different species and abundance of 823 species were recorded altogether during the survey. A total of 126 (15.3%) plants were recorded for a high frequent burn plot, 182 (22.1%) for medium frequent burn plot, 213 (25.9%) for low frequent burn plot and 302 (36.7%) for control plot. Variables measured and recorded included woody plant height, canopy cover, density, basal area, fire damage and number of species per plot. Data were tested for normality using Kolmogorov Sminorv test. In cases where data were not normal a non-parametric Kruskal Wallis test was used. A One way ANOVA was used where data were normal. To compare mean species diversity, damage as well as basal area, canopy volume and tree height across the four fire gradients an ANOVA was used. The study results indicate that there were significant differences ($P < 0.05$) in woody plant heights, density number of species per plot, height and canopy volume. However, there were no significant differences ($P > 0.05$) in diversity, basal area and damage. This present study has shown that fire frequency is the major factor that is significantly changing and modifying the structure and composition of miombo woodland. In areas with high fire frequencies, the miombo woodland was characterized by few mature trees, low species diversity and low tree densities. Fire was responsible for the compositional differences among woodlands with the high diversity in unburnt areas. The open woodland structure with short plants was a common phenomenon in areas of high frequently burnt areas. The study findings points to the need of adaptive management strategies in the use of fires in managing vegetation in semi-arid savanna ecosystems.
CHAPTER I

INTRODUCTION

1.1 Background to the study

Fire has been part of the miombo woodlands since the Early Stone Age, about 60 000 years ago and it has been associated with the development and maintenance of tropical savannas. Plants differ widely in their response and tolerance to fire and in their capacity to recover afterwards. Owing this, the influence of fire on the structure and composition of miombo woodlands cannot be seen in isolation from the influence of other biotic and abiotic factors. Dry savannas (which include miombo habitat) are today one of the most extensively protected vegetation types in southern Africa (Chenje and Johnson 1994). However, in recent years miombo has been facing increasing pressure due to human population expansion and activities. Aside from protected areas, there is little undisturbed miombo left (Chenje and Johnson 1994).

Fire is a common, natural phenomenon in African savannah and can be seen as one of the determinants of savanna ecosystem structure and functioning (Walker, 1981). Wildfires have occurred long before the advent of humans, shaping landscape structure, pattern and ultimately the species composition of ecosystems (e.g., Frost and Robertson, 1987). The structure and composition of the ecosystem is affected by a fire regime. Van Wilgen and Scholes, (1997) defined a fire regime as a combination of frequency, season, intensity and type of fire that prevails in a particular area.

Fire frequency is an important characteristic of fire regime. The frequency of burn within a particular area affects the ecosystem function (Bond and Keeley 2005). Fire frequency affects vegetation both when the frequency is too high or too low and they tend to eliminate the more sensitive species and thus favour the more resistant species, (Wilkinson et al 1993). Fire is the largest consumer of vegetation biomass within an ecosystem globally (Bond et al.2005) and has
been suggested as markedly influencing vegetation structure and composition (Higgins et al., 2007). Fire consumes vegetation and acts as a top-down control on ecosystem structure (Bond, 2008).

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).

In review of the changes in woody vegetation structure and composition as a result of fire, Stronach, (1989) observed that woody plant growth was greatest when fire was excluded in Tanzania, Serengeti National Park. He also observed that late dry season fires in Serengeti National Park had destructive effects on woody vegetation than were early season fires. Recently, Prior et al. (2009) observed that an increase in the frequency or severity of fires is likely to change the density and stand of savannas.

In another study in Southern Africa, Sholes and Walker, (1993) recorded an increase in woody biomass with reduction in fire frequency and intensity in a Nysvley study. On the other hand, Enslin et al. (2000) reported that frequent fires in Kruger National Park (KNP), South Africa led to reduced height of woody plants through top kill, however, with decrease in species composition with increasing fire frequency.

Zimbabwe has recorded an increase in fires over the past decade and protected areas have not been spared by these fires. In Gonarezhou National Park, Zimbabwe, Gandiwa and Kativu, (2009) recorded a decreasing trend in mean height with increasing fire frequency in *Colophospermum mopane* and where a decrease in woody plant height in frequently burnt sites may be attributable
to plant tissue top kill. They also observed that fire frequency had no significant influence on woody species diversity in *C. apiculatum* and *C. mopane* woodland in Northern Gonarezhou for the period 1972-2005. Enslin also found no relationship between species diversity and increasing fire frequency in KNP. Alternatively, species vary in their responses to fire (Andersen *et al.* 2005). Fire is regarded as a landscape scale disturbance agent, and many descriptors are used to describe disturbance, frequency, predictability, extent and magnitude, synergism and timing (Pickett and White, 1993; Agee, 1993; Morgan *et al.*, 2001).

Although fire is a natural and key component of savanna vegetation structure, an increase in the frequency of fire may offset the advantages that occasional natural fires bring upon vegetation communities (Parr and Brockett, 1999; Shackleton and Scholes, 2000). Whelan (1995) pointed out that the occurrence of occasional fire events in plant community allows the formation of different succession communities, whereas in communities where fire is recurrent, soil erosion and local extinction of native plants and animals become a problem. Wildfires in Zimbabwe are a national catastrophe and major management issue in parks and wildlife estates (Robertson, 1993; Mapaure, 2001). Tafangenyasha (1997) documented the effects of fire in GNP and showed that large areas of woodlands are destroyed or modified partly because of frequent fires, drought and herbivory.

Nyanga National Park, despite its status as a protected area and a biodiversity hotspot in fire prone area has not been spared by fires. Following some studies that were done about fire in NNP that on the influence of fire on the composition and structure of miombo woodland was left out. The objective of this study is to find out if fire frequency has an influence on the structure and composition of semi-arid miombo woodland under the influence of fire.

1.2 Problem statement

Fire can influence woody vegetation biomass, composition, and structure and despite its importance in shaping savannas, it remains poorly understood how the frequency influence woody vegetation structure, which is a key determinant of savanna biodiversity (Smit *et al.*, 2010). Although several studies have established the effect of fire in semi-arid savannas, little is known on how fire frequency influences the spatial distribution of vegetation in the cooler savannas located on high
altitudes like Nyanga National Park. Fire disturbance regimes appear to have some significant influence on abundance, structure and composition of Miombo woodlands in NNP. Fires frequently occur in NNP, and they are perceived to impact on woody vegetation dynamics, however this impact has not been explicitly explored.

1.3 Justification
Zimbabwe has recorded an increase in fires over the past decade (EMA, 2012) and protected areas have not been spared by these fires and one such protected area is Nyanga National Park (Zisadza-Gandiwa et al., 2014). Previous researches done in Nyanga National Park did not investigate if fire frequency has an influence on the composition and structure of miombo woodland community that is reported to be on a decline. The present project results aim to inform Nyanga National Park authority in regards to fire management and conservation of Miombo woodlands. There is a record of degradation of miombo woodlands in Zimbabwe (Muboko et al. 2014), hence knowledge contribution on miombo woodlands management and conservation is justified in Zimbabwe. Currently, there is a paucity of information on fire impact on structure and composition of woody vegetation in Nyanga National Park, despite its status as a protected area and a biodiversity hotspot in fire prone area. Against this background, assessing the vegetation structure and composition of Nyanga National Park could guide current management on its woodland management strategies. Many studies have been carried within Nyanga National Park but the one on the influence of fire on the composition and structure of Miombo woodland was not done. Miombo woodland is very important and it is assumed the frequency of fire in Miombo woodland in Nyanga National Park has led to the decline of the animal population due to the deterioration of forage within the woodland since it provides the best forage and cover to animals. The present study will contribute to the available knowledge on the understanding of vegetation change necessitated by fire in NNP. The intended results of this study will help the management in formulating a fire management policy.

1.4 Aim of study
To assess the influence of fire frequency on the composition and structure of Miombo woodlands in Nyanga National Park, eastern Zimbabwe.
1.5 Objectives

1. To determine woody species diversity in miombo woodlands across various fire frequencies (low, medium, high and control).
2. To determine the density and structure of woody species in miombo woodlands across various fire frequencies (low, medium, high and control).
3. To determine the level of damage on woody species in miombo woodlands under different fire frequencies (low, medium, high and control).

1.6 Research questions

1. What is the diversity of woody species in Miombo woodlands across various fire frequencies in Nyanga National Park?
2. What is the density and structure of trees and shrubs in Miombo woodlands across various fire frequencies in Nyanga National Park?
3. What is the level of fire damage on woody species in miombo woodlands across various fire frequencies in Nyanga National Park?

1.7 Null hypothesis

$H_0$: There is no significant difference in the diversity of woody species in Miombo woodlands across various fire frequencies.

$H_0$: There is no significant difference in the density and structure of woody species in miombo woodland across various fire frequencies.

$H_0$: There is no significant difference in the level of damage of woody species in miombo woodlands under different fire frequencies.
CHAPTER 2

LITERATURE REVIEW

Miombo woodland is woodland which is dominated by Brachystegia and Julbernadia species. It is unique to Africa, it spreads throughout Southern Africa and it is distributed in several portions across the central African plateau. It covers central Zimbabwe and extends to Mozambique, Southern Zambia and Malawi where the landscape is flat. Miombo soils are often shallow and stony characteristically leached and acid with a restricted rooting environment (BUCKLE 2010). In Zimbabwe miombo woodlands are mainly found in the Highveld areas like natural region 1, 2 and 3 which are classified by ecologists as deciduous miombo savanna woodlands. This type of miombo extends from the eastern side of the Great Dyke to the south of Masvingo, north to Mvurwi and to the eastern highlands.

2.1 Influence of fire frequency on species diversity

Competitive exclusion, disturbance processes and environmental heterogeneity are three determinants of species diversity in terrestrial ecosystems (Whittaker, 1975; Connell, 1978, Huston, 1994). Competitive exclusion reduces species diversity as strong competitors first suppress lesser competitors and later drive them to local extinction.

Disturbances can reduce plant species diversity by eliminating disturbance-sensitive species, increase species diversity by opening up growing space and resources for use by colonising species, maintain species richness by slowing or preventing competitive exclusion and latter spatial heterogeneity in plant community composition (Houston, 1994).

Fire frequency may also influence composition and diversity in savannas and often varies across gradient in under-storey light and soil resources associated with spatial variability in over-storey tree cover (Scholes and Archer, 1997; Brewer, 1998).
2.2 Influence of fire frequency on species density

Increasing density in the woody component of savannas has been widely reported after alternative periods of fire (Rocques et al. 2001; Archer, 1989; Scott; Grossman, 1989) with reference to *Acacia karoo* and *Dichrostachys cinerea* in Hluhluwe-iMfolozi Park. Rocques et al. (2001) also revealed that fire frequency may affect the direction of change in woody plant density.

It has been also suggested that fire may increase fire tolerable species densities (Sabiiti et al. 1999). Induced fire of alternative frequencies is also used to clear bush encroachment. This contradictory situation in the literature concerning the effect of fire necessitates further research, as it is clear that continuous use of incorrect burning practices may have disastrous consequences.

Shackleton and Scholes (2000) revealed that high fire frequencies have differing effects on various attributes of vegetation structure. In certain instances results increased number of stems per plant and increased plant density. More recent work in North Australian savannas suggests that an increase in the frequency or severity of fires is likely to change the tree density and basal area of vegetation stand of savannas (Prior et al. 2009).

2.3 Influence of fire frequency on species height and structure

It has been suggested that fire markedly influences the structure of woody vegetation species in savannas (Higgins et al. 2007) and acts as the most important 'consumer' globally, depressing biomass from its climate potential (Bond et al. 2005). Fire consumes vegetation and acts as a top-down control on biome structure (Bond 2008). Fires thus always reduce plant biomass and, depending on their frequency and severity, can also replace trees with shrub lands or grasslands (Bond et al. 2005).

Kennedy and Potgieter, (2003) recorded significant differences in tree height with different fire seasons in *Colophospermum mopane* woodland in South Africa. In another study, dry season fires in a *Combretum apiculatum* savanna in South Africa led to the formation of short, open, extensively coppiced shrub vegetation while wet season fires produced taller and closed vegetation (Tainton et al. 1993). Enslin et al. (2000) reported that frequent fires in the Kruger National Park
Gandiwa and Kativu, (2009) commented that vegetation communities also vary in their response to period of exposure to fire. The specific impact of fire varies with the fire regime and the vegetation type affected (Heinl et al. 2007). Some plant species may not survive when fires are too frequent, too early or too late in their growth life (Chandler et al. 1983), and the overall effects of fire on growth and survival of plants vary among and within species (Gambiza et al. 2005). Other early studies in savanna ecosystems suggest that fire can have a marked effect on savanna vegetation. For example, in Zambia, complete protection from fire resulted in an increase in woody canopy height and biomass (Trapnell, 1959).

2.4 The adaptation and effects of fire in the miombo woodlands

The disturbance of fire also creates a selective response of the species and an adaptation to the fire. The adaptation increases the resilience in the community to fire disturbance. Fire adaptation can be defined by the characteristics of the organisms in a fire-prone ecosystem. A fire-prone ecosystem is an ecosystem where many of the species have evolved to tolerate the fire in different ways (Whelan 1995: 280-283). However, it is difficult to determine an adaptation to one factor and it is difficult to generalize the adaptation to fire.

Annual plants normally survive the fire because their seeds are buried and protected by the soil. By scheduling the growing and regeneration the species protect themselves from fire. Most of the woody suffrutices have small sprouts in the absence of fire (Chidumayo 1994:64-65). If fire appears before all the leaves have fallen, the fire accelerates the leaf fall and the leaves will later protect the surface from solar radiation and raindrops. The biggest ignition to fire is grass that normally is burned during the first occurrence of fire and it reduces the possibility for the area to be burned again during the dry period. If the fire occurs after leaf fall the ground is left bare without protection for heavy rain or sun radiation (Chidumayo 1994:62).
2.5 Fire and savanna vegetation

Worldwide, fire remains an important component of ecosystems particularly those in which rainfall is not enough to produce continuous vegetation cover and where conditions are periodically dry allowing for the accumulation of inflammable herbage (Stronach, 1989). As could be demonstrated, fire is definitely a key factor for the existence of savannas (Heinl, 2005) and the main prerequisites for fire occurrences are drought conditions, adequate fuel loads and sources of ignition. In view of the ongoing use of fire as a management tool in conservation areas, a better understanding of the effects of fire on woody species is needed (Sheil and Salin, 2004), especially with respect to the determination of acceptable limits of change (Eckhardt, et al, 2000)

CHAPTER 3

METHODOLOGY

3.1 Description of the study area

The study was carried out in Nyanga National Park (NNP) which is on the eastern-highlands of Zimbabwe. It covers an area of 47 km² and is characterized by a cool and wet climate with an
annual rainfall of between 1500 and 3500mm. Mean annual temperatures range from a minimum of 9 to 12 degrees Celsius to a maximum of 25 to 28 degrees Celsius. The rainfall period stretches from October to April. The study was carried out within four discrete areas of Nyamuziwa, Chaomera, Udu and Warren dale of Nyanga National Park. Historical data from NNP give insights to the fact that fires are a common phenomenon in the park. Extensive grass fires occur in the high-elevation grasslands from August to November (ZPWMA, 2011; Jimu et al., 2013).

3.1 Methods of data collection
3.1.1 Experimental layout and selection of sampling plots
The study was based on stratified random sampling method on four different fire frequencies which are high, medium, low and control. Similar studies have previously been conducted but
under controlled experimental condition whereby blocks in the forest were selected and subjected to different treatments (Trapnell, 1959, Chidumayo, 1988, Kennard et al 2002). The following frequency of burn categories were observed 1-4 years (low fire frequency), 5-8 years (medium fire frequency), and 9-12 years (high fire frequency) and control were there was no fire and the area identified with this frequency of burn became the study sites for this research.

For each of the four frequencies 10 replicate plots were selected based on the fire and vegetation map of NNP. Sampling plots within the woodland were located according to the frequency of fires using fire and vegetation maps from the surveyor general showing fires of 2000 to 2011 figure 1. Fire frequency data of the study area were obtained from the surveyor general and imported to an Excel spreadsheet and plotted on map. A number was assigned to individual coordinate of fire point per group of fire frequency and using random number table, ten numbers in each group was picked up to represent the location of the 40 replicates sample plots, ten in each of the four treatments. The coordinates were then entered in the GPS handset and after identifying the burnt frequencies on the map, a field visit was conducted to validate the vegetation types and locate the study sites based on fire frequencies and similarities in vegetation types with the aid of vegetation cover map of NNP.

3.1.2 Sampling
For this study plots measuring 20 m x 20m were randomly selected from each of the four study plots. This plot size is considered adequate for surveys in savanna vegetation by Walker (1976) and Sabiiti and Wein (1988) of including at least 15-20 trees of the most important species in the study plot. However, inaccessible areas were rejected and the next sample plots were considered. A total of 40 sample plots across the entire Nyanga National Park were selected from the study sites based on the defined four fire gradients strata of fire disturbance regime categories. Trees were defined as rooted, woody, self-supporting plants ≥3m high with a basal stem diameter ≥6cm, whereas shrubs were defined as rooted, self-supporting<3m high and <6cm in stem basal diameter (Ben-Shahar, 1998). All woody plants rooted within the plot were recorded and measured. Woody
plants occurring along plot margins were included if at least half of the rooted system was inside the plot (Walker, 1976).

### 3.1.3 Measurement Techniques

**Table 3.1 Measured variables and methods used in this study**

<table>
<thead>
<tr>
<th>Assessment method</th>
<th>Assessment method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Species Composition</strong></td>
<td>Woody plant species were identified using a field guide by Coates-Pelgrave (1977) and with the aid of an experienced research technician.</td>
</tr>
<tr>
<td><strong>Tree height</strong></td>
<td>The height of woody vegetation was measured by placing a calibrated 6m pole against a tree. For trees &gt;6m, the pole was manually uplifted or height visually estimated by observing it at a distance away from the tree. On multi-stemmed plants, only the height of the tallest stem was considered.</td>
</tr>
<tr>
<td><strong>Basal Circumference</strong></td>
<td>The basal circumference of each stem was measured just above the buttress swelling (to the nearest centimeter) using a flexible 5m tape measure.</td>
</tr>
<tr>
<td><strong>Canopy depth</strong></td>
<td>Canopy depth of every living tree in the plot was measured using a calibrated 6m pole held against a tree. For taller trees (&gt;6m), it was visually estimated or calculated from the height.</td>
</tr>
<tr>
<td><strong>Canopy Diameters</strong></td>
<td>Greatest canopy diameters (D1 and D2) were measured at 90° using a 30m tape measure.</td>
</tr>
<tr>
<td><strong>Fire damage</strong></td>
<td>Fire damage indicators were fire scars, scorch marks on branches, dead, burnt stems and charred plant remains and the damage was assessed to scale from 0 to 4: (0)-no damage; (1)-few burn marks; (2)-several burn marks; (3)- almost completely burnt; (4)-completely burnt (Gandiwa and Kativu, 2009).</td>
</tr>
</tbody>
</table>
3.1.4 Data analyses

Descriptive statistics were used to explain the trends in the data sets. On all measured variables (Table 3.1), descriptive statistics (mean, median and standard deviation and variance) were calculated per plot using Microsoft Excel package.

Using data from the recorded species composition, species diversity was calculated using the Shannon-Weiner diversity index using the following formula (Ludwig and Reynolds, 1988):

\[
\text{Shannon Index (H')} = H' = - \sum p_i \ln p_i
\]

Where \( H' \) is Shannon-Weiner diversity index, \( p_i \) the proportion of individuals in the community and \( \ln \) is the natural logarithm.

All calculated variables were converted to per hectare to enable comparisons between plots. Densities (stems/ha) for woody species in the plot were calculated using the formula:

\[
\text{Density (y/ha)} = \left( \frac{x \times 10,000 \, \text{m}^2}{\text{plot area, m}^2} \right),
\]

Where \( y \) denotes any of trees, shrubs or stems and \( x \) is the recorded number of trees, shrubs and stems.

Basal area was calculated from stem circumference using the formula:

\[
\text{Basal area (A)} = \frac{C^2}{4 \pi}
\]

Where, \( A \) is m\(^2\)/ha and \( C \), is basal circumference.

Canopy volume was calculated from greatest canopy diameters and canopy depth using the formula (Anderson, 1973):

\[
\text{Tree canopy volume} = \frac{1}{4} \pi CD D1 D2
\]

Where CD is canopy depth, D1 and D2 are greatest canopy diameters.

Damage was assessed to scale from 0 to 4: (0)-no damage; (1)-few burn marks; (2)-several burn marks; (3)- almost completely burnt; (4)-completely burnt (Gandiwa and Kativu, 2009).

3.2 Statistical analysis
Data were tested for normality using the Kolmogorov-Smirnov test. In cases where data were not normal, a non-parametric Kruskal Wallis test was used. A One way ANOVA was used where data were normal. To compare mean species diversity, damage as well as basal area, canopy volume and tree height across the four fire gradients, an ANOVA was used. The Kruskal Wallis was used to test for significance for plot species density. Where there was significant difference, an LSD post hoc (for ANOVA) or Mann Whitney U was performed. All analyses and graphical construction were performed in the statistical package SPSS version 21 (IBM, 2012). A 5% level of significance was used in all cases.

CHAPTER 4

RESULTS
4.0 Changes in species diversity

The species richness of 16 different species and abundance of 823 species were recorded altogether during the survey (see appendix 1). A total of 126 (15.3%) plants were recorded for a high frequent burn plot, 182 (22.1%) for medium frequent burn plot, 213 (25.9%) for low frequent burn plot and 302 (36.7%) for control plot. There was no significance difference in woody species diversity as measured by Shannon Weiner indices among the different fire frequencies (F=1.239; df=3; P=0.744; Table 4.2)

Table 4.1 Diversity indices in HFF, MFF, LFF and Control

<table>
<thead>
<tr>
<th>Parameter</th>
<th>H.F.F</th>
<th>M.F.F</th>
<th>L.F.F</th>
<th>CONTROL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Richness</td>
<td>126</td>
<td>182</td>
<td>213</td>
<td>302</td>
</tr>
<tr>
<td>Shannon-Weiner Index(H’)</td>
<td>0.31</td>
<td>0.32</td>
<td>0.32</td>
<td>0.33</td>
</tr>
</tbody>
</table>

4.2 Changes in woody species density

The mean species density calculated per plot show that, there is a decrease in species density as the frequency of burn also increases. Mean species density of 437.5 species/ha was found in high frequent burn plot, 455 species/ha for medium frequency burn plot, 532 species/ha for low frequent burn plot and755 for control plot. There is a markedly high species density for control plot as compared to the other three plots.

There was a significance difference on woody species density among different fire frequencies, (high, medium, low and control) (F=0.654; df=3; P=0.0001). The highest mean density of 755 trees was found in the control plot and the lowest mean density of 437.5 trees in high fire frequency plot. Table 4.2 show Mean (±SE) tree density counted in high, medium, low and control plots. Significant differences are indicated by different letters (control vs. high p<0.0001, control vs. medium p<0.0001, and control vs. low p<0.001; LSD post hoc test).

4.3. Changes in woody species structure
This was determined by results obtained from basal area, height and canopy volume

4.3.1 Changes in woody species basal area
There was no significance difference in the basal area among the different fire frequencies. (F=3.312; df=3; P=0.31; Table 4.2)

4.3.2 Changes in species height
The mean height for low fire frequency plot was 3.54 m, 4.12 m for medium frequency burn plot, 3.78 m high frequency burn plot and 4.78 m for control plot. The results show that there is a decrease in species mean height as fire frequency decrease. There were significant differences in the mean heights of woody species among the different fire frequencies (F=2.538; df=3; P=0.001; Table 4.2). Significant differences were observed between control and high (p<0.001), control and low (p<0.0001), low and medium (p=0.033) using an LSD post hoc test.

4.3.3 Changes in species canopy volume
The mean canopy volume for low fire frequency plot was 6 m, 7 m for medium frequency burn plot, 9 m high frequency burn plot and 19 m for control. The results show that there is a constant decrease in species canopy cover as fire frequency decrease. There was significance difference on canopy volume of woody species among the different fire frequencies (F=334.134; df=3; P=0.0001) Table 4.2 Mean (±SE) canopy volume in high, medium, low and control plots. Significant differences are indicated by different letters (control versus high p<0.0001, control versus medium p<0.0001, and control versus low p<0.0001: LSD post hoc test)

4.4 Changes in species damage by fire
The mean damage for low fire frequency plot was 0.69, 1.1 for medium frequency burn plot and 0.75 high frequency burn plot. The results show that there is a decrease in species damage as fire frequency decrease. There was no significance difference in damage of woody species among the different fire frequencies. (F=1.692; df=2; P=0.207; Table 4.2).
Table 4.2: A summary of attributes of woody vegetation structure and composition for plots in the High Fire frequency (H.F.F), Medium Fire Frequency (M.F.F), Low Fire frequency (L.F.F) and Control strata (Mean ± Standard Error, SE) SE – denotes variation from the mean, μ – mean

<table>
<thead>
<tr>
<th>Variable</th>
<th>H.F.F (μ±SE)</th>
<th>M.F.F (μ±SE)</th>
<th>L.F.F (μ±SE)</th>
<th>CONTROL (μ±SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (m)</td>
<td>3.78 ± 0.22a</td>
<td>4.12 ± 0.22ab</td>
<td>3.54 ± 0.11ac</td>
<td>4.70 ± 0.17c</td>
</tr>
<tr>
<td>Tree density/ha</td>
<td>437.5 ± 28.93a</td>
<td>455.00 ± 33.30a</td>
<td>532.50 ± 28.40a</td>
<td>755.00 ± 72.44b</td>
</tr>
<tr>
<td>Canopy volume (m/ha)</td>
<td>5.99 ± 0.86a</td>
<td>6.98 ± 0.84a</td>
<td>8.52 ± 1.05a</td>
<td>18.54 ± 2.20b</td>
</tr>
<tr>
<td>Basal area (m/ha)</td>
<td>0.73 ± 0.04a</td>
<td>0.79 ± 0.06a</td>
<td>0.67 ± 0.03a</td>
<td>0.85 ± 0.04a</td>
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<td>Diversity (H')</td>
<td>0.31 ± 0.03a</td>
<td>0.32 ± 0.01a</td>
<td>0.32 ± 0.02a</td>
<td>0.33 ± 0.01a</td>
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<tr>
<td>Fire damage (%)</td>
<td>0.69 ± 0.16a</td>
<td>1.10 ± 0.16a</td>
<td>0.75 ± 0.17a</td>
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Letters a show that there was no significance difference across all fire frequencies, where there is a and b it means there is a significant difference as and there was a significant difference between ab and ac.

CHAPTER 5
DISCUSSION
Fire not only influences the total biomass of savanna systems it also markedly influences the structure of savannas. This study was based on the influence of fire on the composition and structure of miombo woodlands in NNP. It has been suggested that increased burning frequency
has differing effects on several attributes of woody community structure (Shackleton & Scholes, 2000). This study recorded significant differences in height, basal area, tree density and species diversity of miombo woodland in NNP. The structural and compositional differences in miombo woodland in NNP probably result from factors such as fires and droughts. Miombo woodland in the eastern section of NNP, an area with high fire frequency seems to be degraded. The reduced heights in woody species show that fire is influencing the woodland. Repeated fires are known to stress normal growth and affect the health of the woodland hence miombo species fail to grow to their maximum attainable height and become dwarf Brachystegia.

Results obtained from the study revealed that fire frequency had no significant influence on woody species diversity in Nyanga National Park, Zimbabwe during the period of 2000-2011 and this agrees with the stated hypothesis. Enslin et al. 2000 also found no significant relationship between species diversity and increasing fire frequency in Kruger National Park. Govender et al. 2006, studying fire effects in the KNP concluded that fire has no marked effect on woody species composition. Anderson et al. 2005 commented that species vary in their responses to fire, and as well tolerance among woody species depends on species sensitivity, the duration and intensity of the fire and physiological and developmental state of individual plants.

Several other studies of savanna ecosystems have reported that fire frequency influence savanna woodland structure and composition. In this study, low frequent burnt site had a mean height of woody stems shorter than that of the control site, suggesting negative effects of repeated burning. 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, 11 years is a short period to contrast fire treatments in terms of woody plant density. Although the burnt and control sites had almost the same number of woody species, these species were basically different, and fewer in the burnt sites. Thus, this is a pointer to the fact that some species were lost to burning and replaced by some relatively fire tolerant species. In addition, the present study showed significant differences in height across various fire frequencies. 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 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 trees in high fire frequent areas, together with significant basal area changes. 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, 11 years is a short period to contrast fire treatments in terms of woody plant density because of very high rainfall which affect growth of grass species in the study area resulting in inadequate fuel load to give high heat intensity from burns which can easily kill woody plants. This is because most savanna fires are surface fires that burn the grassy herbaceous layer of the vegetation and fire intensity is directly related to the amount of accumulated grass biomass on the ground (Miranda et al., 1993). Although the burnt and control sites had almost the same number of woody species, these species were basically different, and fewer in the high frequent burnt site. 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.

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). 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). 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 significant differences in tree density recorded in this present study could be attributed to resprouting by woody plants after burning. 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.

Fire frequent treatments reduced woody vegetation canopy cover the most in the highly frequent burnt sites. Significant canopy volume changes, in miombo woodland with increasing fire frequency, are consistent with earlier observations by Tafangenyasha (2001) who observed that
frequent fires and elephant damage led to a significant loss of woody canopy cover of *B. glaucescens* woodland in northern GNP. Canopy volume is an important woody plant variable that provides an indication of areas resistant to fire damage (Melville *et al.* 1999). There was significance difference on the results obtained on the canopy volume of woody species across various fire frequencies. Low canopy volume values that were recorded, particularly in this study with increasing fire frequency, are attributed to changes in plant height. Thus, woody species in this woodland type could have failed to establish themselves as mature trees as a result of repeated exposure to fire (Cauldwelland & Zieger 2000). 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).
CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions
This present study has shown that fire frequency is the major factor that is significantly changing and modifying the structure and composition of miombo woodland in Nyanga National Park. Recurrent fires have considerable potential to influence the structure and composition of the vegetation, particularly in savannas and savannas are modified by natural fires. In areas with high fire frequencies, the miombo woodland was characterized by few mature trees, low species diversity and low tree densities. Fire was responsible for the compositional differences among woodlands with the high diversity in unburnt areas. The open woodland structure with short plants was a common phenomenon in areas of high frequently burnt areas.

This study has shown that miombo woodland in NNP is being transformed into low-density and shorter woodland. Overall, the significant structural differences in miombo woodland can be attributed to fires. Structural changes in savannas have consequences for management because of their effects on herbage quantity, composition and nutrient dynamics. Therefore, the researcher suggest the following: first, long-term monitoring in woodland composition and structure is necessary in order to determine possible changes over time and appropriate management practices, which include the maintenance of biodiversity and ecosystem rehabilitation. Knowledge of the state and dynamics of the woodlands is required to achieve a sustainable use of these resources. Hence, woodland composition and structure are some of the elements that should be addressed through establishing long-term monitoring plots in NNP.

This study revealed that high fire frequency altered the structure of miombo woodlands. In contrast; fire frequency appeared not to have altered the species diversity of miombo woodlands in NNP.
6.2 RECOMMENDATIONS
Fire can be a very good management tool when controlled. I recommend that there must be well designed fire management plan for protected areas. Fire is one of the most important factors influencing the global vegetation pattern and it has been associated with the development and maintenance of the floristic and structural composition of tropical savannas. Even though considerable practical knowledge is available on its application in savanna management, much still needs to be learnt about its different effects and how these interact with other ecological processes to influence savanna dynamics. Future fire management strategies in NNP should take into consideration different vegetation types present in the park. This study examined the influence of fire frequency on only one woodland type in NNP. However, fire frequency effects on woody vegetation need to be studied further, on a larger scale (e.g. the entire park), taking into consideration other vegetation types and the additional effects of herbivory. I also recommend a continued maintenance of a reliable and up-to-date fire database that serves as an important baseline for fire research (Parr & Chown 2003) and establishment of a long-term fire experiment programme in NNP. A long-term fire experiment programme will not only enhance the understanding of ecological processes but will also play an important role in influencing management decisions related to fire management in NNP.

With regards to the effect of fires, more consideration needs to be given to the possible contingency of effects, not only on the frequency of fire, but also intensity, timing and on the state of the organisms at the time, as well as on subsequent interactions with rainfall, drought, and other fires. 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.

It is shown that fire frequency influence patterns of vegetation three-dimensional structure, which may have cascading consequences for biodiversity. Managers of savannas can therefore use fire frequency in concert to achieve specific vegetation structural objectives.

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APPENDIX 1

SAMPLE DATA SHEET

DATE:

PLOT SIZE:

AREA OF STUDY:

GPS COORDINATES:

NAME OF RESEARCHER:

NAME OF THE RECORDER:

<table>
<thead>
<tr>
<th>PLOT NO.</th>
<th>FREQ</th>
<th>PLANT SPP</th>
<th>PLANT STATUS</th>
<th>B.C</th>
<th>H</th>
<th>C.D</th>
<th>D1</th>
<th>D2</th>
<th>F.S</th>
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B.C refers to basal circumference, h=height, C.D=canopy depth, D1 =larger diameter, D2=shorter diameter, F.S= fire score
APPENDIX 2

WOODY SPECIES CHECKLIST

1. Brachystegia speciformis
2. Combretum molle
3. Dichrostachys cineria
4. Protia niloticus
5. Combretum zeyheri
6. Parinari curatelfolia
7. Ras slancea
8. Brachystegia glauencis
9. Acacia tortilis
10. Acacia karoo
11. Syzigium guinese
12. Pinus longifolia
13. Protia gaugedi
14. Julbernadia globiflora
15. Baikea plurijuga
16. Combretum apiculatum