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Structure and composition of *Spirostachys africana* woodland stands in Gonarezhou National Park, southern Zimbabwe

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ABSTRACT

We investigated the structure and composition of *Spirostachys africana* woodlands in Gonarezhou National Park (GNP), southeast Zimbabwe. We divided the GNP into three strata, namely northern, central and southern GNP, based on physical feature such as major perennial rivers. The main objective was to determine whether the structure and composition of *S. africana* woodlands varied across the GNP. In addition, we evaluated whether herbivory and fires played important roles in influencing the structure and composition of *S. africana* woodland stands. A stratified random sampling design was used and data were collected from a total of 60 sample plots. The following variables were recorded in each study plot: woody plant height, species name, plant status (alive or dead), fire or browse evidence and number of stems per plant. A total of 2,588 woody plants comprising of 73 woody species were recorded from the sampled *S. africana* woodlands in the GNP. Our results showed that woody species diversity, woody plant heights, shrub density, density of dead plants, sapling density, density of fire damaged plants, and number of stems per plant were significantly different across the *S. africana* woodlands in GNP. In contrast, only densities of trees and browsed plants did not differ significantly across the GNP. Most plots in the southern GNP had higher tree and sapling densities and taller trees whereas those in the northern GNP had higher densities of fire damaged plants. In addition, plots from central GNP were characterised with higher shrub densities of *S. africana* woodlands. Overall, our results suggest that there are both structural and compositional differences of *S. africana* woodland stands across the GNP. Evidence of herbivory did not differ significantly across the GNP suggesting that plants were uniformly affected by herbivores. However, fire evidence seemed to vary across the GNP, with areas having frequent fires being more degraded and having to some extent more woody vegetation species diversity.

Key words: Africa, fire, herbivory, monitoring, Tamboti, savanna, species diversity

1. Introduction

Savanna ecosystems are characterized by the co-dominance of two contrasting plant life forms, trees and grasses (Frost et al., 1986; Scholes and Archer, 1997; Sankaran et al., 2004; Sankaran et al., 2005; Lehmann et al., 2011). Savannas occupy a fifth of the earth's land surface (Sankaran et al., 2005), covering about 54% of Southern Africa and 60% of sub-Saharan Africa, and mostly occur in hot regions with seasonal rainfall distribution (Scholes and Walker, 1993). Fires are an intrinsic component of many ecosystems throughout the world, and are one of the controlling factors in maintaining the balance between grassy and woody vegetation in the semi-arid savannas of Southern Africa (Bond and Keeley, 2005; Pricope and Binford, 2012). Other environmental factors characterizing savannas include

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herbivory, droughts, nutrient availability and human disturbances which play important roles in shaping their structure and function (Frost et al., 1986; Scholes and Archer, 1997; Eckhardt et al., 2000; Luoga et al., 2004; Holdo, 2007; Chafota and Owen-Smith, 2009; Allen et al., 2010; Mligo et al., 2011; Shannon et al., 2011).

Savanna woodlands play an important role in providing ecosystem goods and services. Changes in woody vegetation structure and composition may have important implications for wildlife habitat, biotic diversity and risk of future catastrophic disturbances (Peterson and Reich, 2001). For instance, the intermediate disturbance hypothesis states that local species diversity is maximized when ecological disturbance is neither too rare nor too frequent (Connell, 1978). Therefore, high disturbance in savanna ecosystems is likely to negatively affect woody species composition. Woody vegetation structure plays an important role in savannas by modifying the microclimate, soil moisture, nutrient availability under canopies, and by producing spatial heterogeneity in plant resources (Peterson and Reich, 2001). Although the demography of woody plants in savannas has long been shown to be influenced by many factors, there still is no consensus as to the relative importance of the top-down processes of fire and herbivory, nor on how fire and herbivory affect plant demography (Midgley et al., 2010).

Previous studies in the Gonarezhou National Park (GNP), southern Zimbabwe, suggest that herbivory and fires has influenced the structure of some woodlands (e.g. O'Connor and Campbell, 1986; Tafangenyasha, 1997), including *Brachystegia glaucescens* (Tafangenyasha, 2001), *Colophospermum mopane, Combretum apiculatum* (Gandiwa and Kativu, 2009), *Androstachys johnsonii* (Gandiwa et al., 2011a), *Acacia tortilis* (Gandiwa et al., 2011b) and *Adansonia digitata* woodlands (Mpofu et al., 2012). Furthermore, past droughts have also been reported to have led to significant die-offs of some tree species in GNP (Tafangenyasha, 1998). Successful management of large areas of natural vegetation depends to a large measure on knowledge of vegetation composition, the extent to which the vegetation is used, and changes which take place in response to fire and other disturbances (Walker, 1976). *Spirostachys africana* Sond. (Tamboti tree), belongs to the family Euphorbiaceae and is wide spread in Southern Africa and Central Africa (Palgrave, 1990). *S. africana* occurs in clumps, sometimes forming pure stands of its own woodlands. *S. africana* is also utilised in the woodcraft industry (Shackleton and Shackleton, 2004) and also has various medicinal uses (Mathabe et al., 2008). In this study we limit ourselves to *S. africana* woodlands. The main objective was to determine whether the structure and composition of *S. africana* woodlands varied across the GNP. In addition, we evaluated whether herbivory and fires played important roles in influencing the structure and composition of *S. africana* woodland stands.

2. Materials and methods

2.1 Study area

Established in the early 1930s as a Game Reserve, GNP was upgraded into a national park under the Parks and Wildlife Act of 1975. GNP has been part of the Great Limpopo Transfrontier Park since 2000. Covering an area of 5,053 km^2, GNP is located in southeast Zimbabwe (Figure 1), between 21° 00'–22° 15' S and 30° 15'–32° 30' E. Altitude varies between 165 and 575 m above sea level. The study area experiences three seasons, hot dry, hot wet and cool dry. Annual average rainfall for GNP is about 466 mm, with November to March being the wettest months. The dry season normally lasts from April to October. Average monthly maximum temperatures are 26 °C in July and 36 °C in January. Average monthly minimum temperatures range between 9 °C in June and 24 °C in January (Gandiwa et al., 2012).

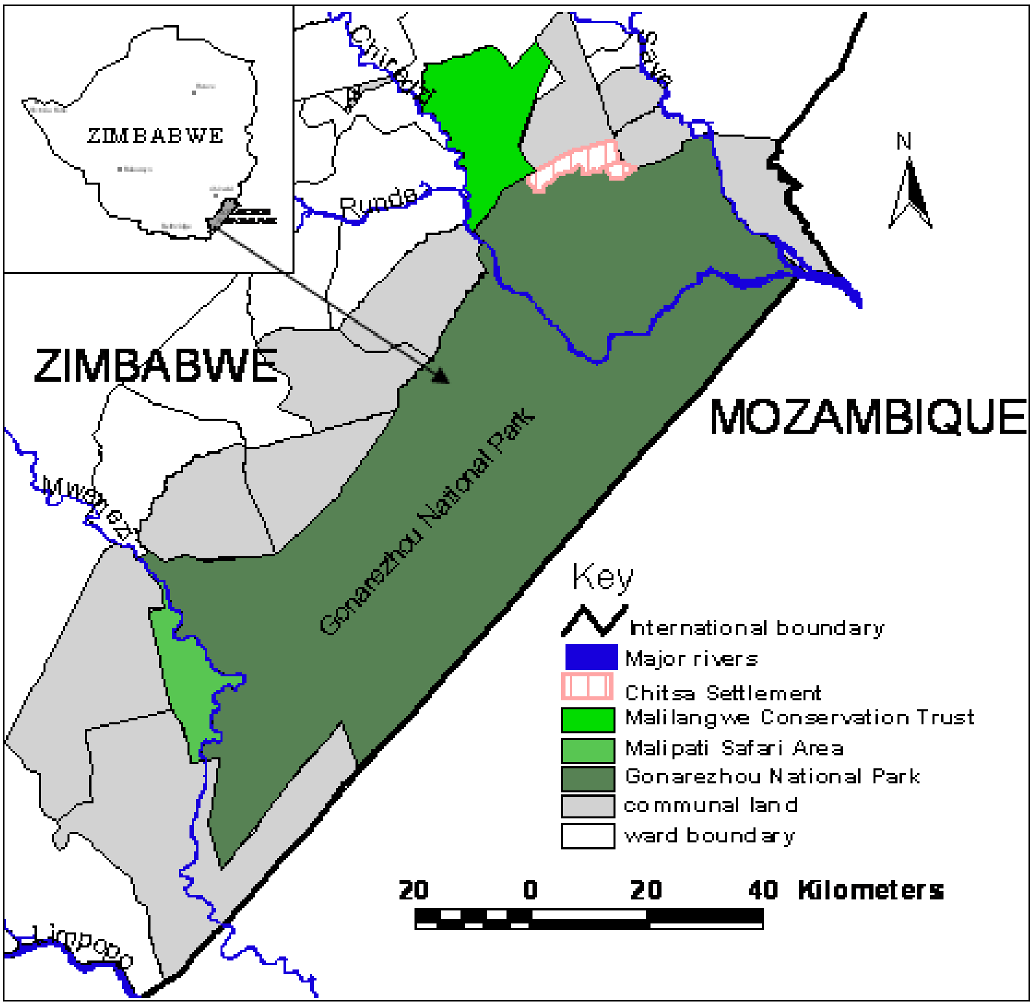


Figure 1: Location of the Gonarezhou National Park and adjacent areas in southern Zimbabwe. Source: Gandiwa & Zisadza (2010)

The major vegetation type is *C. mopane* woodland, which covers approximately 40% of GNP. Fires are a common phenomenon in GNP with approximately 22% of the park being burnt each year (Gandiwa and Kativu, 2009). There is a wide variety of large herbivore species in the GNP and these include African elephant (*Loxodonta africana*), hippopotamus (*Hippopotamus amphibius*), buffalo (*Syncerus caffer*), giraffe (*Giraffa camelopardalis*), plains zebra (*Equus quagga*), waterbuck (*Kobus ellipsiprymnus*), roan antelope (*Hippotragus equinus*), sable antelope (*Hippotragus niger*) and blue wildebeest (*Connochaetes taurinus*). The park has a number of large carnivores such as African lion (*Panthera leo*) and spotted hyena (*Crocuta crocuta*) (Zisadza et al., 2010). Recent elephant population estimates for the GNP are estimated at about 1.84 elephants/km^2 (Dunham et al., 2010).

2.2 Sampling design and data collection

We used a stratified random sampling design. We divided the GNP into three strata, namely, the northern GNP stratum which comprised of the area north of the Runde River, the central

GNP stratum which comprised the area south of the Runde River to the railway line and lastly, the southern GNP stratum which comprised of the area south of the railway line to the Mwenezi River. In each stratum, we randomly placed 20 sample plots using the random number tables. Plot sizes of 30 × 50 m were used. These plot sizes were determined following Walker's (1976) consideration of having at least 15 to 20 trees of the dominant vegetation inside a sample plot.

Floristic composition and structure of woody vegetation component were assessed in June and July 2011. At this time of the year, species composition is most conspicuous. In each sample plot, the following variables were recorded or measured: woody plant height, woody plant species, browsed plants, fire damaged plants, saplings and number of stems per plant. Data collection procedures used in this study followed those outlined by Gandiwa and Kativu (2009). Trees were defined as woody plants greater than 3 m in height and greater than 6 cm basal diameter, above buttress swelling. All woody plants within a plot were recorded and measured. Woody plants occurring along plot margins were included if at least half of the canopy was inside the plot. For multi-stemmed plants located at edges of plots, only stems with more than half their base inside the plot were measured and recorded.

2.3 Data analysis

Plant heights for all trees were averaged for each plot. The total number of stems for all trees in each plot was divided by number of plants to give an average number of stems per plant. Tree densities for each plot together with woody plants affected by herbivores or fire were calculated using the formula: density (e.g., trees or plants affected by fire or herbivores ha^{-1}) = $[(x \times 10{,}000\ m^2)/(\text{plot area}, m^2)]$, where *x*, for example, is the recorded number of trees or plants affected by herbivores. In order to determine the changes in species composition in different strata, we calculated the Shannon Index (H'). The Shannon Index for each plot was calculated using the following formula: $H' = -\sum (p_i \times Ln(p_i))$, where p_i is the fraction of the entire population made up of species *i*, and *Ln* is the natural logarithm (Ludwig and Reynolds, 1988).

Data were analysed using two methods. First, a one-way Analysis of Variance (ANOVA) was used to analyse woody vegetation structure and composition data using SPSS version 19 (SPSS Inc., Chicago, Illinois). Post-hoc tests were conducted using the Tukey's Honest Significant Difference (HSD) test. Descriptive statistics, namely box plots, were used to summarise the measured woody vegetation data using STATISTICA for Windows, version 6 (StatSoft, 2001). All data were first tested for normality using the Shapiro-Wilk test (Shapiro and Wilk, 1965) and we found all the measured variables data to be non-normal. Data for all measured variables were $\log_{10}(x+1)$ transformed prior to analysis. Second, we used ordination techniques to explore the structure in the woody vegetation structure and composition data of *S. africana* woodlands across the park. We used an indirect ordination approach, namely the Principal Component Analysis (PCA), to extract the main components of variation in the woody vegetation structure and composition using CANOCO version 4.5 software for Windows and CanoDraw for Windows (Ter Braak and Šmilauer, 2002). Data were square root transformed to meet the multivariate normality requirements.

3. Results

3.1 Structure and composition of *Spirostachys africana* woodland

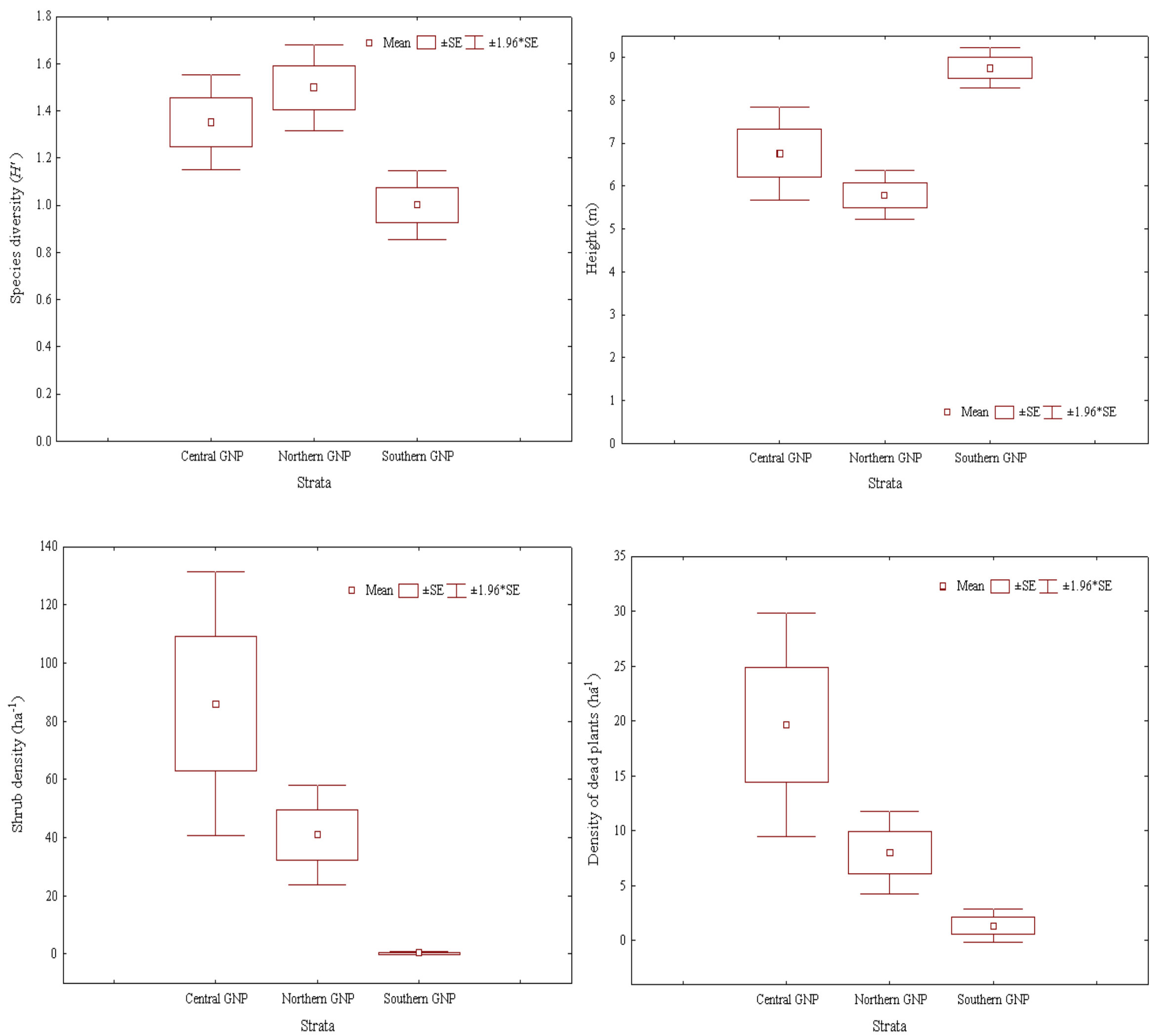
We recorded 2,588 individual woody plants with a total of 3,577 stems and 73 woody plant species in the 60 sample plots. One-way ANOVA test results showed that woody species diversity was significantly higher in northern GNP compared to the central and southern GNP (Table 1; Figure 2); woody plants heights were significantly higher in the southern GNP; shrub density was significantly higher in the central GNP; density of dead plants was significantly higher in the central GNP; sapling density was significantly higher in the northern GNP; density of fire damaged plants were significantly higher in central GNP and similarly, number of stems per plant were significantly higher in the central GNP compared to the northern and southern parts of the park (Table 1; Figure 2). In contrast, densities of trees and browsed plants did not differ significantly across the GNP.

Only the first and second principal components are illustrated in the PCA biplot (Figure 3) as they explained the most variation in species structure and composition across the GNP. PCA output of study vegetation variables shows Principal Component 1 accounting for 49.6% and Principal Component 2 accounting for 23.2% of the variance (Table 2). Principal component 1 defines a gradient from sample plots with higher sapling density and taller trees to sample plots with higher shrub densities. Several sample plots in southern GNP were negatively correlated with Principal Component 1 whilst most plots in central GNP were positively correlated with Principal Component 1 (Figure 3). Principal component 2 defines a gradient from sample plots with taller trees to sample plots with higher densities of fire damaged plants. Principal Component 2 was negatively correlated to sample plots from southern GNP and positively correlated to sample plots from northern GNP. Species diversity was however best explained by Principal component 3.

Table 1: Summary results from one-way ANOVA tests on the differences and similarities of the structure and composition of *S. africana* woodlands in Gonarezhou National Park, Zimbabwe. Notes: S.E.–Standard Error. Different letter superscripts within column for each variable denote significant differences (Tukey's HSD, $P < 0.05$). Significant values are indicted in bold.

Variable	Stratum	Mean	S.E.	df	*F*	Significance
Species diversity (*H′*)	Central GNP [a]	1.35	0.10	2, 59	8.75	**0.000**
	Northern GNP [a]	1.49	0.09			
	Southern GNP [b]	1.00	0.07			
Height (m)	Central GNP [a]	6.76	0.55	2, 59	13.34	**0.000**
	Northern GNP [a]	5.79	0.29			
	Southern GNP [b]	8.76	0.24			
Shrub density (number/ha)	Central GNP [a]	86.00	23.13	2, 59	18.99	**0.000**
	Northern GNP [a]	41.00	8.68			
	Southern GNP [b]	23.33	0.33			
Density of dead plants (number/ha)	Central GNP [a]	39.67	5.19	2, 59	12.17	**0.000**
	Northern GNP [a]	36.10	1.91			
	Southern GNP [b]	27.33	0.78			
Sapling density	Central GNP [a]	38.67	16.70	2, 59	9.03	**0.000**

(number/ha)	Northern GNP [b]	115.00	25.47			
	Southern GNP [b]	113.00	19.97			
Tree density (number/ha)	Central GNP [a]	148.00	10.19	2, 59	0.07	0.934
	Northern GNP [a]	143.33	5.57			
	Southern GNP [a]	141.33	6.28			
Density of browsed plants (number/ha)	Central GNP [a]	137.50	14.35	2, 59	0.53	0.592
	Northern GNP [a]	122.00	8.12			
	Southern GNP [a]	135.17	5.84			
Density of fire damaged plants (number/ha)	Central GNP [ab]	42.00	15.95	2, 59	5.72	**0.005**
	Northern GNP [a]	41.67	11.01			
	Southern GNP [b]	20.67	10.69			
Mean number of stems per plant	Central GNP [a]	2.61	0.18	2, 59	4.43	**0.016**
	Northern GNP [ab]	2.35	0.22			
	Southern GNP [b]	1.90	0.16			



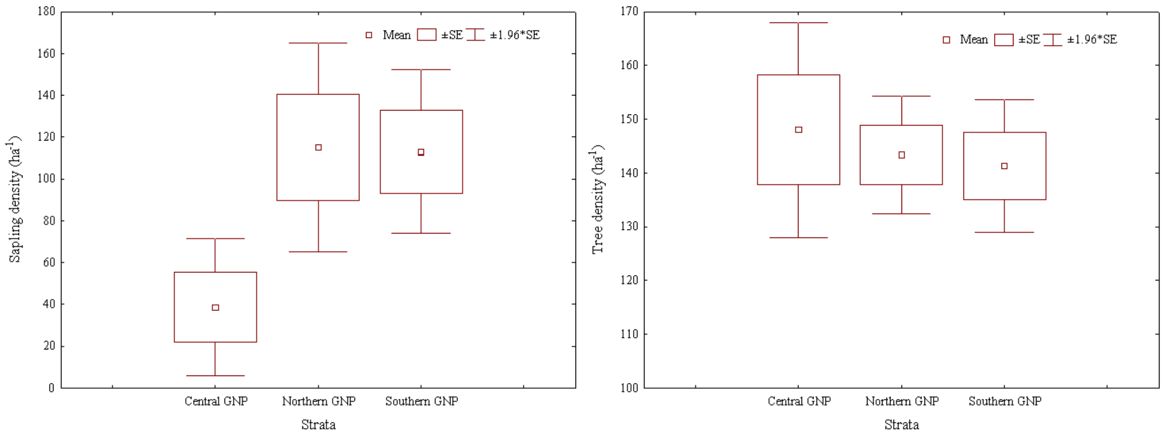


Figure 2: Box plots of measured study variables in the *S. africana* woodland across the Gonarezhou National Park, Zimbabwe

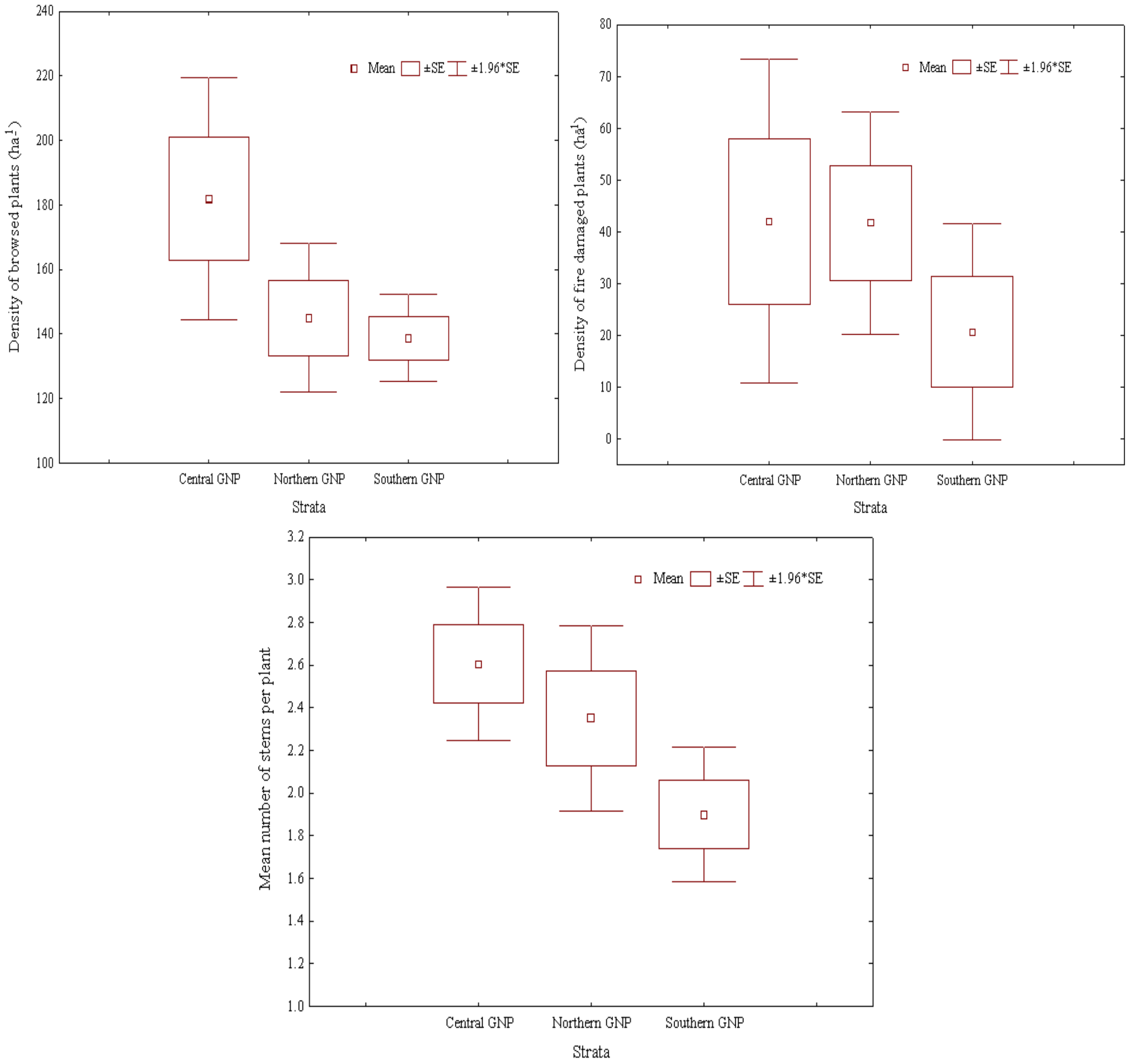


Figure 2 (continued): Box plots of measured woody vegetation variables in *S. africana* woodland across the Gonarezhou National Park, southern Zimbabwe

Table 2: Eigenvalues and variance explained by the Principal Component Analysis

Axes	1	2	3	4	Total variance
Eigenvalues	0.496	0.231	0.150	0.065	1.000
Cumulative percentage variance of woody vegetation data	49.6	72.8	87.8	94.3	

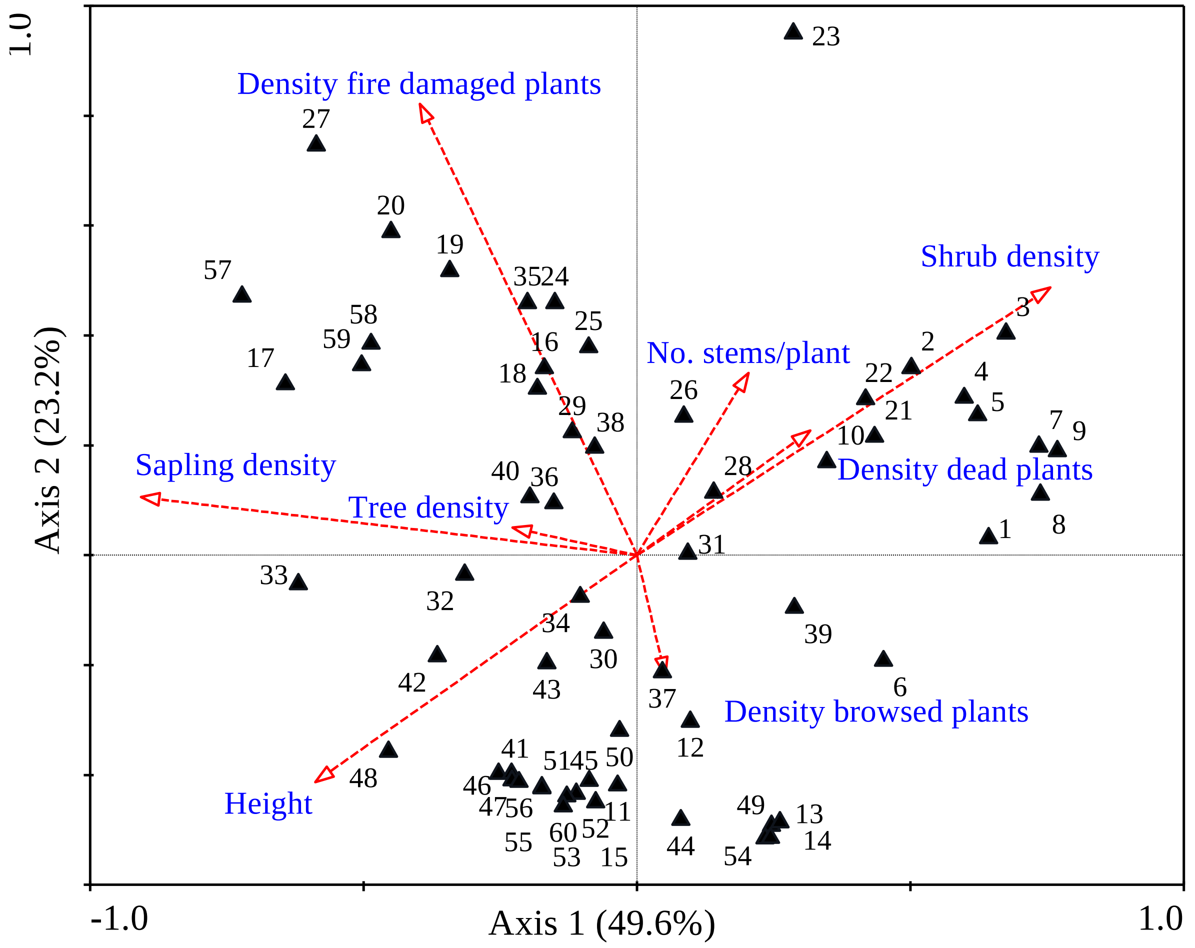


Figure 3: Scatter plot of 60 sample plots in the *S. africana* woodland and measure vegetation variables in the Gonarezhou National Park, southern Zimbabwe. Numbered data points denotes sample plot; with numbers 1–20 representing plots from central GNP, 21–40 representing sample plots from northern GNP and 41–60 representing sample plots from southern GNP.

4. Discussion

Our results suggest that the structure and composition of the *S. africana* woodland stands across the GNP are different. The structural differences in *S. africana* woodland in GNP could probably result from disturbance factors such as frequent fires among others. Our results are consistent with earlier studies in the GNP that have reported that fires have contributed to the general modification of habitats, hence leading to the decline of canopy woodlands and herbaceous plant cover in some woodlands (Tafangenyasha, 1997, 2001; Gandiwa and Kativu, 2009). In this study only fires appeared to have a significant influence and we recorded no significance differences in browsed plant density across the GNP. Savanna woody plants have evolved with disturbances such as fire and herbivory and thus have traits to resist or tolerate fire and herbivory disturbances (Helm et al., 2011). African savannas are subject to frequent herbivory, while the occurrence of fire is highly variable (Hean and Ward, 2012). Repeated fires are known to stress normal growth and affect the health of the woodland and may top-kill woody species (e.g. Bond et al., 2003; Gandiwa, 2011). Fire consumes vegetation and acts as a top-down control on ecosystem structure (Bond, 2008). Vegetation fires are a common phenomenon in the GNP with high fire frequencies occurring in northern GNP, medium fire frequencies in central GNP and low fire frequencies in southern GNP (Tafangenyasha, 2001). Elsewhere, in the adjacent Kruger National Park, South Africa, woody vegetation cover declined as fire return periods became shorter (Eckhardt et al., 2000). Some studies have shown that elephants and/or fires and their interactions significantly influence structure and composition of woodlands in African savannas (Mapaure and Campbell, 2002; Staver et al., 2009; Valeix et al., 2011).

Differences in the sapling densities recorded in this study could be influenced by differential effects of mostly fires Fire especially acts to limit tree cover via a demographic bottleneck, limiting the recruitment of tree saplings to adults (Wakeling et al., 2011). Therefore, escaping the fire and/or seedling browsing trap is fundamental in determining the relative abundance of tree species and population dynamics in savanna communities (Wakeling et al., 2011; Hartnett et al., 2012).

Figure 4: Bark stripping by small herbivores on *S. africana* trees in southern Gonarezhou National Park, Zimbabwe. Photo credit: P. Gandiwa

Savanna woodlands of Africa offer a browse resource of considerable importance to wildlife (Witkowski and O'Connor, 1996). However, it has been reported that *S. africana* which is poisonous to man is commonly avoided by elephants but favoured by impala (*Aepyceros melampus*), kudu (*Tragelaphus strepsiceros*) and nyala (*Tragelaphus angasii*) (Shannon et al., 2008; Boundja and Midgley, 2010; O'Kane et al., 2011). In the present study, we frequently sighted impalas near *S. africana* woodlands during the field data collection. *S. africana* is often associated with low-lying thickets and has high levels of secondary compounds that are known to deter large herbivores (Midgley et al., 2005). *S. africana* plants showed evidence of resprouting from the base after being burnt and browsed. Resprouting is a response to disturbance and our study suggests that all the strata were being affected by disturbance factors. In this study, we found evidence of bark stripping of *S. africana* plants by small herbivores (Figure 4). Bark stripping was localized and common only in southern GNP and hence could be a key factor influencing the structure and composition of *S. africana* woodland stands in southern GNP.

5. Conclusion

Overall, our results suggest that there are both structural and compositional differences of *S. africana* woodland stands across the GNP. Evidence of herbivory did not differ significantly across the GNP suggesting that plants are uniformly affected by herbivores. However, fire evidence seemed to vary across the GNP, with areas having frequent fires being more degraded and having to some extent more woody vegetation species diversity. This study therefore adds to the growing list of vegetation studies in the GNP which show that disturbance factors are influencing woodland structure and composition. Other factors that could have influenced *S. africana* woodlands in the GNP which have not been investigated in this present study include past droughts and human activities inside the GNP (O'Connor and Campbell, 1986; Tafangenyasha, 1998). Fire management policy for the GNP outlines key fire susceptible vegetation communities with low fire tolerance including the *S. africana* communities (Tafangenyasha, 1997). Therefore, our findings have implications for fire management in the GNP. Our results also point to the importance of continued vegetation monitoring as well as further detailed studies that explores the interactions of environmental determinants in shaping savanna ecosystems. In addition, differences in soils, soil moisture and topography are key factors that will require further detailed investigations. Similarly, future studies are required to understand the effects of bark stripping by herbivores on the floristic composition, structure and function of the *S. africana* woodlands in the GNP.

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