

## Original Research Paper

# Vegetation structure and composition in the semi-arid Mapungubwe Cultural Landscape

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**ABSTRACT:** Mapungubwe Cultural Landscape (MCL) woody vegetation was characterized to establish structural and compositional attributes. Stratified random sampling based on major soil types was used and nine plant variables were measured in 137(20x30) m<sup>2</sup> sampling plots; these being genera, species and family names; basal circumference; plant height; depth and diameter of tree canopy; number of stems per plant; plant life status; number of trees and shrubs; and number of saplings. A total of 3114 woody plants were sampled, comprising an assemblage of 28 families, 63 genera and 106 species. The results suggest alluvial floodplain flanking the Limpopo River is a biodiversity hotspot with high plant species diversity ( $H' = 1.8-2.2$ ) 1/ha, taller trees ( $P < 0.05$ ) with median height per plot ranging between 6.1-10 m, high canopy volume at 105783 (443155m<sup>3</sup>/ha) and basal area (16.9-111m<sup>2</sup>/ha). The Arenosols-Regosol stratum had significantly shorter trees ( $P < 0.05$ ) with median height per plot between 3-4 m, low species diversity ( $H' = 0.8-2.3$ ) 1/ha, low basal area (3.23-48.2m<sup>2</sup>/ha) and low canopy volume (6687.08(155965.00) m<sup>3</sup>/ha). The Cambisol-Luvisol stratum in the western section of MCL had high number of stems/plant at 1.65 (1.40), high woody plant density 483.33 (900.00) 1/ha,  $F_{3,137} = 19.07$ ,  $P < 0.05$ , high density of dead plants 16.67 (133.30) 1/ha and high sapling density 208.33 (850.00) 1/ha. The present study suggests soil type is a key determinant of woody vegetation structure and composition. The study recommends regular vegetation monitoring, periodic update of plant species inventories in protected areas, control of exotic invasive woody plant species found along the Limpopo river floodplain within the biodiversity management framework of Greater Mapungubwe Transfrontier Conservation Area initiative.

**KEYWORDS:** *Family assemblage; Mapungubwe Cultural Landscape (MCL); Soil substrate; Species composition; Vegetation dynamics; World Heritage Site*

## INTRODUCTION

Tropical ecosystems have long been considered important repositories of the global biodiversity (Apgaua *et al.*, 2015), with the savanna covering approximately 50% of the African landscape which

makes them one of the most important biomes (Sankaran *et al.*, 2005, Scholes and Walker, 2004). Approximately 65% of the global savanna ecosystems where most biodiversity hotspots with high levels of endemism are found in Africa (Southworth *et al.*, 2015). One of the most striking characteristics of semi-arid savanna is the mosaic of vegetation communities, with savanna woodlands comprising most of the tropical

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and sub-tropical woodland cover in sub-Saharan Africa. These ecosystems support large human and animal populations (Huntley and Walker, 2012) which have both ecological and economic significance to the human–environment nexus (Solbrig et al., 2013), however scientific long-term data on vegetation changes remain scarce in the sub-tropical savanna ecosystems. Conserving savanna ecosystems is a challenge in an environment where global ecosystems are not in equilibrium due to changing climatic conditions (Buitenwerf et al., 2012) at varying scales and magnitudes, for the next decades and centuries (Mitchell, 2013, Midgley and Bond, 2015). Such changes have inevitable consequences for savanna vegetation. Much work has focused on estimating the impact of climate change on vegetation (Truc et al., 2013, Bruch et al., 2012) and projected future anthropogenic-driven climate scenarios that are expected to unfold (Breman et al., 2012, Sinclair, 2012, Willis et al., 2013), however, without comprehensive characterization and baseline understanding of functional vegetation attributes that are affected by climatic and ecological factors, understanding savanna vegetation dynamics remains limited.

The ecosystem functionality of savannas (Charles-Dominique et al., 2015) is determined by various factors operating at different scales including herbivore dynamics (Doughty et al., 2015) and plant invasions (Rouget et al., 2015). Recently, the stability of the savanna ecosystem components has received increasing attention due to three major threats: bush encroachment, agricultural conversion, and climate change (Southworth et al., 2015). Such threats inevitably put savannas to the test of resilience and vulnerability. Non-resilient systems are known to succumb to the changes or perturbations while maintaining the same diversity and function, usually resulting in permanent state changes (Peterson, 2009, Berryman, 1983) and such dynamics usually manifest in considerable changes in vegetation at various scales (Gillson, 2015, Gillson and Marchant, 2014).

Whilst some schools of thought believe vegetation patterns are responsive and adapt (Pulla et al., 2015) to changing climatic conditions, some species are inevitably lost along the survival path and species distribution patterns also shift on a temporal scale. Thus, species inventories should be continuously updated to keep track of historical assemblages in determining how vegetation responds to varying

environmental drivers and disturbance (Moncrieff et al., 2015). This makes generating new information at relevant scales for decision making in protected savanna ecosystems with a global significance an important undertaking.

The Mapungubwe Cultural Landscape is a world heritage site significant to southern African human history (Fouche and Gardner, 1933) and conservation. As more light is shed on Mapungubwe story (Galloway, 1937, Gardner, 1955, Gardner, 1958, Gardner, 1963, Meyer, 2000, Carruthers, 2006, Meyer, 2011, Forssman, 2010, Forssman, 2014), there remains inadequate information on the vegetation status of the area. The land use system of the Mapungubwe Cultural Landscape has evolved over time from early Stone Age (Pollarolo and Kuman, 2009), to middle Stone Age and late Stone Age when the hunter-gatherers resided in the area, followed by Khoi pastoralists (Hall and Smith, 2000). The iron age communities used the landscape extensively for animal and crop production (Voigt, 1983, Huffman et al., 2004, Huffman, 2005). In the recent past, land near the Limpopo River has been occupied by farmers practicing irrigation crop agriculture, and in the areas away from the river for cattle and/or wildlife-based land use. Past military activities, mining, commercial agricultural ventures and conservation, all characterize land usage in Mapungubwe area over the past century (SANParks, 2010) and such land use changes have inevitable influence on vegetation dynamics.

There is archeological evidence of past droughts that affected primary productivity of the area (Murimbika, 2006) and lifestyle of the iron-age communities that depended on the natural resource base (including vegetation) for livelihood in the Shashe-Limpopo basin. Other schools of thought believe the demise of the Mapungubwe kingdom (O'Connor and Kiker, 2004, Huffman, 1996) can be attributed to agro-pastoral failure and climate-related changes (Huffman and Woodborne, 2015). Past vegetation studies in the area covered various components that assisted with mapping generalized vegetation communities found in Mapungubwe Cultural Landscape (Götze, 2002) with some specific vegetation communities for example the sandstone ridges (Gotze et al., 2008), whilst other studies focused on the threatened riparian vegetation communities (O'Connor, 2010b, Götze et al., 2003). With the changing gradients of climate over the past millennia (Tyson et al., 2002), drainage (Kotze, 2015), restoration attempts (Scholtz, 2007), and land use

changes, there is need to understand the emerging dynamics and closely monitor vegetation in protected areas. Ecosystems can only be effectively protected if their key attributes including vegetation is well-understood, for what is unknown is at risk of facing serious threats without being checked. The main objectives of this study were i) to determine the vegetation structure and composition across different soil substrates, and ii) to establish the species and family assemblage of the Mapungubwe Cultural Landscape. This study was done in Mapungubwe Cultural Landscape in northern Limpopo Province of South Africa in 2014.

## MATERIALS AND METHODS

### Study Area

This research was conducted in the Mapungubwe Cultural Landscape (MCL) in Limpopo Province of South Africa with 22p†2’S 29p†36’E / 22.033p†S 29.600p†E / -22.033; 29.600 (Fig. 1). The Limpopo River marks the northern boundary whilst the Alldays-Pontdrift road (R521) marks the western boundary, the Messina-Pontdrift road (R572) and the boundary of Riedel farm define the southern boundary, whereas the eastern boundary ends where Riedel farm and Weipe farmland meet (Henning and Beater, 2014).

Mapungubwe Cultural Landscape is 28 168.66ha in extent, from 22 original farms (DEA, 2013) which collectively became Vhembe Dongola National Park in 1995 (Berry and Cadman, 2007) and officially declared Mapungubwe National Park in 1998 (Sinthumule, 2014). The park was declared Mapungubwe National Heritage Site in South Africa in December 2001, then

subsequently inscribed as a Cultural World Heritage Site known as the Mapungubwe Cultural Landscape (Fleminger, 2008) by the United Nations Educational, Scientific and Cultural Organisation (UNESCO) in July 2003 (SANParks, 2010) becoming a modern protected area (Meskell, 2013) that it is today.

The topography in MCL is generally flat along the Limpopo river, with sandstone and conglomerate ridges and koppies (Gotze *et al.*, 2008) and (Bezuidenhout, 2002) identified six major vegetation mapping units and fourteen soil types. In this study, the sandstone ridges (Bezuidenhout 2002’s 1b land type) assessed by (Gotze *et al.*, 2008) were not sampled. Vegetation data were collected from 5 other land types that were identified by Bezuidenhout (2002); (Ae-Deep sandy red and yellow soils; Db-Deep red-brown clayey soils; Fb-Rock with shallow lithosols; Fc-Shallow lithosols and 1a-Deep red-brown alluvial soils) which were then collapsed into four broad soil groups following the United Nations Food and Agriculture Organisation (FAO, 2012) soil classification system.

### Experimental design

Stratified random sampling design based on dominant soils (FAO, 2012) found in Mapungubwe Cultural Landscape was used (Table 1).

This study used the United Nations Food and Agriculture Organisation (FAO, 2012) soil classification system, and the International Soil Reference and Information Center (ISRIC), adapted in the planning framework of the Greater Mapungubwe Transfrontier Conservation Area (GMTFCA) by the Peace Parks Foundation, of which the Mapungubwe Cultural

Table 1: Description of major soil types (FAO, 2012) found in Mapungubwe Cultural Landscape, Limpopo Province, South Africa

Soil group	Description
Luvvisols	They are deposited by flood water and are characterized by a rich organic and nutrient content. Below the latter lies a layer of mixed clay accumulation that has high levels of available nutrient ions comprising calcium, magnesium, sodium, or potassium. These soils are very fertile, well-drained and have very high in moisture retention capacity (Herbrich <i>et al.</i> , 2015). Luvvisols are often associated with Cambisols
Cambisols	These are well drained, very deep brown course loamy soils, often do not have a layer of accumulated clay, humus, soluble salts, or iron and aluminum oxides (McGregor, 2008)
Arenosols	They are commonly known as Kalahari sands, with high sand and low nutrient content. Arenosols cover about 13% in Sub-Saharan Africa and are widely spread in the southern part of the continent (Hartemink and Huting, 2008)
Regosols	These soils are moderately well drained, very deep, brown to very pale brown, friable, fine loamy to clayey soils with very weak profile development and are imperfectly drained (Driessen <i>et al.</i> , 2000). They are characterized by relatively shallow soils with unconsolidated parent material, lacking a significant soil horizon formation (Harmse, 1978)

Landscape is a core component. Luvisols and Cambisols (FAO, 2012) occur along the Limpopo river valley; the MCL area is interspersed with Arenosols and Regosols (GMTFCA TTC, 2010) in the central, southern and eastern sections (Fig. 1).

Two hundred random points were generated using DNR Garmin tools in a Geographic Information System (GIS) environment (50 points per stratum). The random points were tracked using a handheld Global Positioning System (GPS) unit and 137 plots were sampled in the four soil groups. Thirty-four (34) plots were sampled in the western Luvisol-Cambisol (WLC), 39 plots in the central Arenosol-Regosol (CAR), 31 plots in the Floodplain-Alluvium (FA) and 33 plots in the eastern Arenosol-Luvisol (EAL).

Annual rainfall ranges between 350 and 400 mm and usually falls between November and April. Summer temperatures in the area can rise to 45°C (SANParks, 2010)

#### Data collection

Vegetation data were collected when the floristic composition was most conspicuous, i.e. soon after the end of rain season (between April-July) in 2014. A total of 137 sampling plots measuring 0.06ha (20x30 m<sup>2</sup>) were used. The following variables were recorded for all woody plants: family, genus, and species names; basal circumference; plant height; canopy

depth, canopy diameter; number of stems per plant; plant life status (whether it is alive or dead), number of trees, number of shrubs; and number of saplings. The elephant exclusion plots along the Limpopo floodplain on the central and western section of MCL were avoided.

#### Plant species

The species were identified with the aid of plant field guides (Palmer and Pitman, 1961, Palgrave, 1977), and for unknown species, high-resolution photos leaf and inflorescence were taken and verified or identified with the assistance of botanists. The plant nomenclature adopted follows that of Germishuizen *et al.*, (2006).

#### Plant height

Any plant that was  $\geq 3\text{m}$  in height was regarded as a tree; shrubs were defined as any woody plant that was  $< 3\text{m}$  but greater than 50cm. Where multi-stemmed plants were encountered, the height of the tallest stem was recorded.

#### The total number of stems per woody plant

This was determined from direct enumeration. Where multi-stemmed plants were encountered, such multi-stemming was recorded only when the stems started underground (Gandiwa *et al.*, 2013)

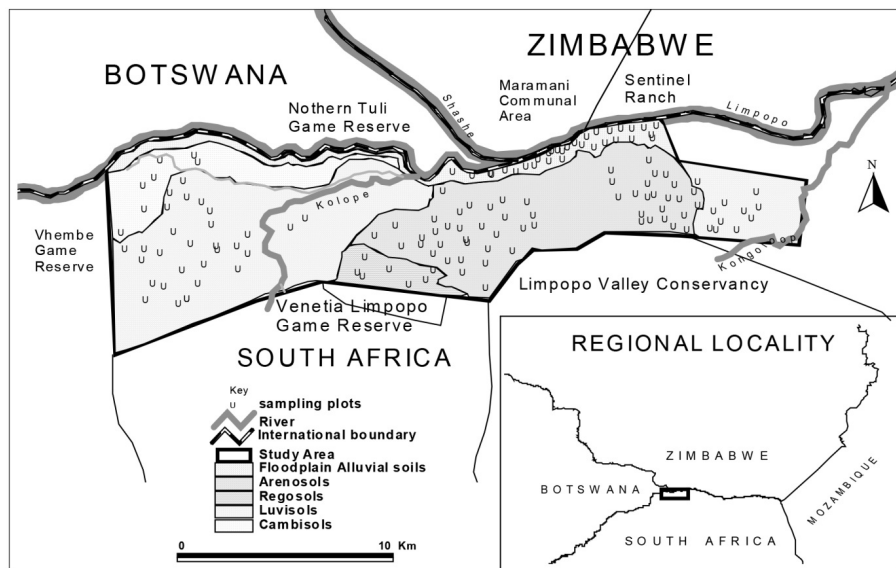


Fig. 1: Location of the study area Mapungubwe Cultural Landscape (MCL), main soil substrates and sampling plots, Limpopo Province, South Africa

*Plant status (dead or alive)*

On assessing the life status of individual plants, dead plants were regarded as plants lacking any living leaves, with dry and cracking trunk, bark and stems (Zisadza-Gandiwa *et al.*, 2013b).

*Canopy depth and diameter:* tree canopy depth (CD) was measured using a 7m graduated pole. Visual estimation (if >7m) was also used, and widest canopy diameters (D1 and D2) at 90° angle were measured with the aid of a tape measure (Gandiwa and Kativu, 2009). Canopy measurements for shrubs (any plant less <3m) were not recorded in this study.

*Number of saplings*

Saplings refer to plants that were (≤50cm)

*Data Analysis*

*Preliminary data analysis*

Descriptive statistics were used to summarise all data. The mean tree height and mean height of shrubs were calculated (sum of height for trees and shrubs/ number of trees and shrubs in a plot). The sum of stems in a plot was divided by the total number of standing plants to calculate average number of stems per plant. The measured Basal Circumference (BC) records per plant were used to calculate basal area for all woody plants. Basal Area (BA) was calculated per plant and per plot using the following method:

Basal Area (m<sup>2</sup>)=(BC<sup>2</sup>/4π), where BC is basal circumference recorded (Gandiwa *et al.*, 2011). The BA per plot was calculated by summing all tree BAs in a plot in m<sup>2</sup>/ha. The density of woody plants per hectare(ha)were calculated per plot as follows:

Density(y/ha)=[(x\*10.000 m<sup>2</sup>)]/ (plot area m<sup>2</sup>), where y=trees, shrubs or stems and x denotes the total number of trees, shrub and stems (Zisadza-Gandiwa *et al.*, 2013a).

Canopy volumes of trees were calculated using the Eq. 1:

$$\text{Tree Canopy Volume (TCV)}(\text{m}^3)=1/4(\text{CD})(\text{D1})(\text{D2}),$$

where CD is Canopy Depth. (1)  
(Gandiwa and Kativu, 2009)

Index (H') was calculated (Brown, 1988). H' was calculated per plot using the Eq. 2:

$$H' = -\sum(p_i \times \ln p_i) \text{ (Ludwig and Reynolds, 1988) (2)}$$

*Normality tests*

When all data variables were summarized per plot, normality tests were performed using the Kolmogorov-Smirnov test in STATISTICA(version 6) for Windows (StatSoft, 2001) and data were found to be not normal.

*Multivariate analysis*

To test if vegetation structure and composition were different across different soil types we performed One-Way Kruskal-Wallis Analysis of Variance (ANOVA) tests. Z-test Post-hoc analyses of multiple comparisons were performed to establish differences amongst variables between strata.

A Principal Component Analysis (PCA) was performed to establish differences between plots based on soil type, woody plant structure, species and family composition. The authors considered the following variables per plot: plant height, number of species, number of families, number of stems per plant, canopy volume, basal area, tree and shrub density, sapling density, dead plant density and species diversity. A Hierarchical Cluster Analysis (HCA) was also done. The HCA was performed using Ward's method with a matrix of 137 plots and the absolute species abundance data recorded in each plot, for all 106 woody plant species.

**RESULTS AND DISCUSSION**

*Structure and Composition of woody vegetation across different soil substrates*

A total of 3114 woody plants were measured and the structural and compositional attributes were assessed.

Tree height varied significantly across four soil types (one-way Kruskal Wallis ANOVA,  $P < 0.0001$ ; Table 2) with the Alluvial Floodplain having the tallest trees whereas the central section of Mapungubwe Cultural Landscape which is dominated by Arenosol-Regosol substrate, had the shortest median height of woody plants. The greatest number of stems per plant were recorded in western Luvisol-Cambisol stratum with median(range) 1.65(1.4), which was significantly different from the other three soil strata ( $P < 0.05$ ). Similarly, the number of woody plant species were significantly different ( $F_{3,137} = 24.67, P < 0.05$ ) across the four soil strata. The floodplain alluvium strata had the greatest species diversity with 8(14) plant species/plot.

Total number of plant families differed significantly ( $F_{3,137}=16.44, P<0.05$ ) across the four soil strata with floodplain alluvium having the highest 5(9) plant families/plot and the central Arenosol-Regosol stratum had the least with 3(6) families/plot. Tree canopy volume (CV) had a similar outcome with floodplain alluvium recording the highest CV at 105783.2(443154.6) m<sup>3</sup>/ha, which was significantly different ( $F_{3,137}=34.90, P<0.05$ ) from the western Cambisol-Luvisol and the eastern Arenosol-Regosol vegetation. Basal Area of woody plants (trees and shrubs) in the central Arenosol-Regosol (3.23(48) m<sup>2</sup>/ha) was the least, whilst the Floodplain Alluvium had the highest with 16.9(111) m<sup>2</sup>/ha and all strata were significantly different from each other ( $F_{3,137}=24.01, P<0.05$ ). Woody plant density was significantly different across the four soil types ( $F_{3,137}=19.07, P<0.05$ ).

Western Luvisol-Cambisol had the highest density of 483.33(900) woody plants/ha, and the central section had the lowest density of 83.33(750) woody plants/ha. Sapling density of western Luvisol-Cambisol was highest with 208.33(850) saplings/ha and eastern Arenosol-Luvisol had the least at 16.67(317) saplings/ha. All soils types had significantly different sapling density/ha (One-way Kruskal Wallis ANOVA,  $P<0.05$ ). However, the density of dead plants/ha was not significantly different ( $F_{3,137}=5.49, P>0.05$ ) across the four soil strata. The western Luvisol-Cambisol strata had the highest with 16.67(133.3) dead plants/ha.

The Shannon Weiner Indices ( $H'$ ) were significantly different ( $F_{3,137}=21.73, P<0.05$ ) across all strata. The Floodplain Alluvium had the highest species diversity  $H'=1.8(2)$ , followed  $H'$  by eastern Arenosol-Luvisol with  $H'=1.27(2.3)$ , then western Luvisol-Cambisol with  $H'=1.02(2.60)$  whereas the central Arenosol-Regosol had the lowest diversity of plant species at  $H'=0.84(2)$ .

*Association of vegetation sampling plots in relation to soil types*

Principal component 1 (variance explained = 37.41%; eigen value = 3.74) represents the gradient from an area with taller trees, high diversity of species, high species and family richness, higher basal area and higher canopy volume (Fig. 3). Principal component 2 (variance explained = 17.65%; eigen value = 1.76) represents the gradient from an area with high number of stems per plant, higher plant density, higher sapling density but with lower canopy volume and lower diversity of species. There was a strong association of plots in the central Arenosol-Regosol and eastern Arenosol-Luvisol strata that had low woody plant density, lower density of sapling, lower total number of stems per plant and lower diversity of plant species.

*Grouping of sample plots in relation to species abundance*

The Hierarchical Cluster Analysis (HCA) dendrogram grouped the 137 plots into two main clusters and four sub-clusters that, to a large extent,

Table 2: Attributes of vegetation structure and composition across selected soil strata in Mapungubwe Cultural Landscape

Variables	Strata				Kruskal-Wallis One Way ANOVA	
	Strata 1 (WLC) N=34	Strata 2 (CAR) N=39	Strata 3 (FA) N=31	Strata 4 (EAL) N=33	F <sub>3, 137</sub>	Sig.
Height (m)	3.29 (6.70) <sup>a</sup>	3.08(4.00) <sup>bc</sup>	6.1(10.7) <sup>ab</sup>	4.42(4.9) <sup>c</sup>	32.89	0.000*
No. of stems/plant	1.65 (1.40) <sup>ab</sup>	1.40 (1.40) <sup>c</sup>	1.1(1.5) <sup>a</sup>	1(2) <sup>bc</sup>	33.16	0.000*
No. of Species	5.00 (14.00) <sup>a</sup>	4.00 (10.00) <sup>b</sup>	8(14) <sup>abc</sup>	5(11) <sup>c</sup>	24.67	0.000*
No. of Families	3.50 (9.00)	3.00 (6.00) <sup>a</sup>	5(9) <sup>a</sup>	4(8)	16.44	0.001*
Canopy Volume (m <sup>3</sup> /ha)	16547.47 (185919.60) <sup>a</sup>	6687.08 (155965.00) <sup>bc</sup>	105783.2 (443154.6) <sup>abd</sup>	31941.47 (379686.8) <sup>cd</sup>	34.90	0.000*
Basal Area (m <sup>2</sup> /ha)	5.40 (48.00) <sup>a</sup>	3.23(48.20) <sup>b</sup>	16.9(111) <sup>ab</sup>	7.88(936.3)	24.01	0.000*
Woody plant density (1/ha)	483.33 (900.00) <sup>ab</sup>	316.67(600.00) <sup>a</sup>	383.3(366.7)	333.33(383.3) <sup>b</sup>	19.07	0.001*
Dead plant density (1/ha)	16.67 (133.30)	0.00 (116.70)	0(66.7)	0(100)	5.49	0.139 <sup>ns</sup>
Sapling density (1/ha)	208.33 (850.00) <sup>ab</sup>	83.33(750.00) <sup>c</sup>	33.3(150) <sup>bc</sup>	16.67(316.7) <sup>b</sup>	55.44	0.000*
Diversity ( $H'$ )	1.02 (2.60) <sup>a</sup>	0.84(2.30) <sup>b</sup>	1.8(2.2) <sup>abc</sup>	1.27(2.3) <sup>c</sup>	21.73	0.000*

Notes: Western Luvisol-Cambisol (WLC); Central Arenosol-Regosol (CAR); Floodplain-Alluvium (FA); Eastern Arenosol-Luvisol (EAL); N=Number of plots sampled in a stratum; Values represent median and range (in brackets); Alphabetical letters a, b, c, d denotes Z-test post-hoc test for multiple comparisons, where significant differences are present, the strata are labeled with different letters; Sig.=statistical significance ( $P$  Value), n.s.= not significant ( $P>0.05$ ), \*= $P<0.05$ .

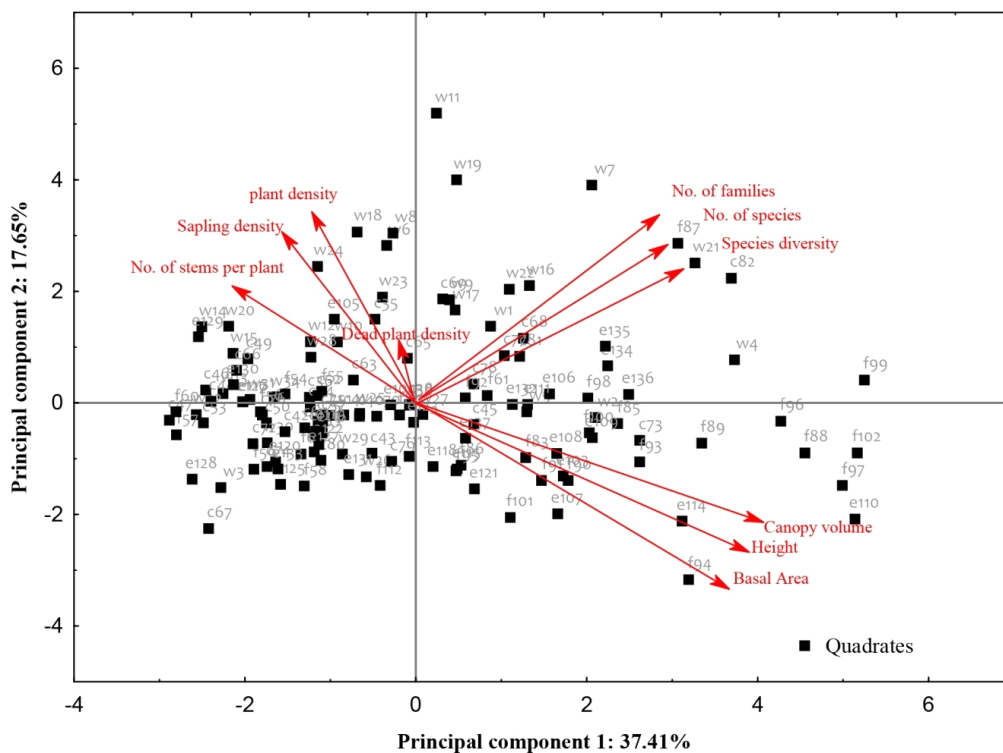


Fig. 3: PCA bi-plot of plots in selected soil types, Mapungubwe Cultural Landscape, northwestern Limpopo province, South Africa  
 Notes: The coded numbers represent all plots sampled in the four soil strata defined in Table 2. w = strata 1(western); c=strata 2(central); f=strata 3(floodplain) and e=strata 4(eastern).

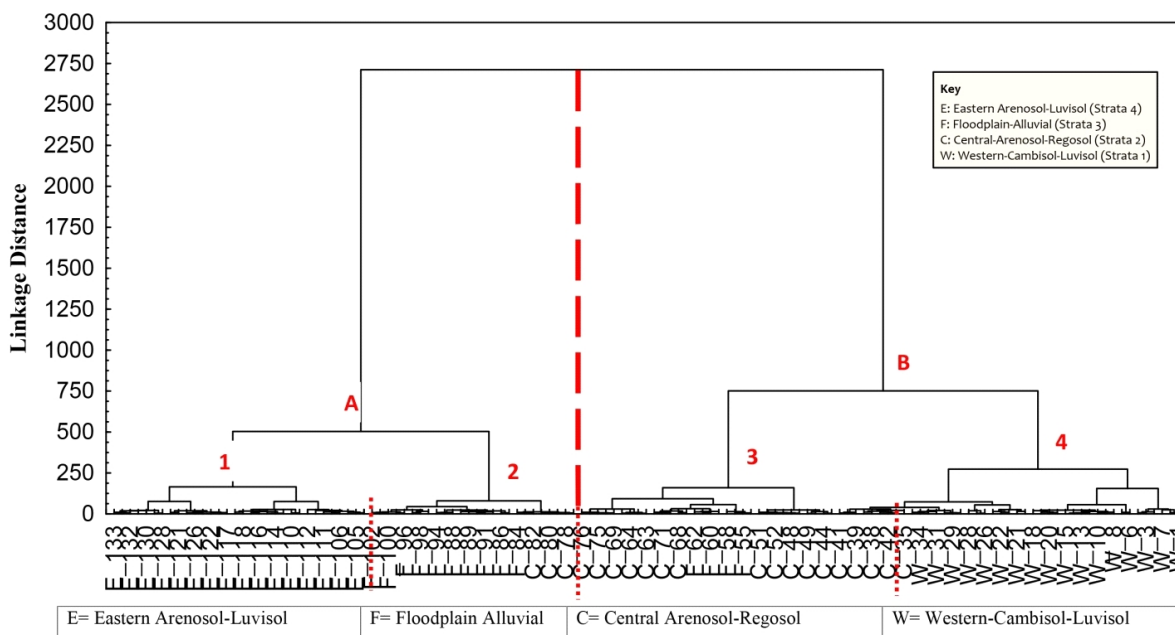


Fig. 4: Hierarchical Cluster Analysis dendrogram showing similarity of sample plots (Euclidean distance) across four soil substrates  
 Notes: The sub-clusters are labeled 1-4 and the main clusters are labeled A and B

corresponded with the dominant soil types (Fig. 4). Clearly evident are the Eastern Arenosol-Luvisol and the Western Cambisol-Luvisol strata based on species composition and frequency. The first main cluster, labeled A, comprised plots from Eastern Arenosol-Luvisol (33 plots), Floodplain Alluvium strata with 27 plots and four plots from the Central Arenosol-Regosol strata. The dominant genera in these strata are *Commiphora*, *Senegalia*, *Euphorbia*, *Vachellia*, *Croton*, *Grewia*, *Philenoptera*, *Berchemia*, *Faidherbia* and *Hypheane*. Cluster B, comprised 35 plots from the Arenosol-Regosol strata, 34 plots from Western Cambisol-Luvisol and four plots from the Floodplain Alluvium strata. The dominant genera characterizing this cluster are *Colophospermum*, *Senegalia*, *Dichrostachys*, *Salvadora*, *Euclea*, *Terminalia*, *Boscia*, *Sclerocrya*, and *Combretum*.

#### *Woody plant family and species assemblage in MCL*

An assemblage of 28 families, 63 genera and 106 species were recorded from 137 plots in Mapungubwe Cultural Landscape (Table 3). Approximately 61% (1910) of all plant species recorded are in the Fabaceae family (dominated by *Colophospermum* and several species in the genus *Vachellia* and *Senegalia*), making it the largest family group in the Mapungubwe Cultural Landscape followed by the Combretaceae (12%) and Euphorbiaceae (7%). A list of all plant species recorded was populated (Table 3). *Combretum*, *Vachellia*, *Senegalia* and *Grewia* genera were the most diverse with 5-8 species in each genera.

Approximately 37% of woody species recorded in this study were not on the species inventory for MCL.

Edaphic factors are important determinants of vegetation structure and composition (Aerts and Chapin, 1999) and known to influence spatial pattern of woody plants over a wide range of scales as demonstrated in this study. Soils differ in terms of texture (Thompson, 1965) and soil structure, determining accessibility of nutrients for uptake by plant root systems. The cambisols had higher tree density compared to arenosols, regosols and luvisols and this is possibly explained by the physico-chemical characteristics and terrain where the soil group is found on the Mapungubwe Cultural Landscape. Like the floodplain alluvial soils, cambisols are fertile, well-drained and have high moisture retention capacity (Herbrich *et al.*, 2015), providing soil moisture essential for plant growth. Similarly, luvisols are well drained, have good depth for plant rooting system, have high clay content and humus, soluble salts, iron and aluminum oxides (McGregor, 2008).

The floodplain alluvial soils had highest median tree height, canopy volume, species diversity, and basal area yet that is one of the threatened vegetation community in Mapungubwe Cultural Landscape (O'Connor, 2010a). In contrast, the arenosol-regosol substrate dominating the highly undulating rocky terrain with very shallow soils had significantly shorter trees, lower species diversity, basal area, canopy volume and tree density. Species like *Ficus abutilifolia* and *Adansonia digitata* occur in higher densities in this nutrient poor stratum with generally lower species diversity (Aerts and Chapin, 1999). Inevitably such variations in topography and soil conditions among other factors such as the spatial and temporal distribution of surface water, can explain the heterogeneity of savanna structure and function on different scales (Coe *et al.*, 1976), as observed in Mapungubwe Cultural Landscape.

Whilst ecosystem functionality of savannas (Charles-Dominique *et al.*, 2015) is determined by various factors operating at different scales. At a local scale, the differences in soil moisture, availability of essential nutrients required for plant growth often results in a spatial mosaic of plant species density and variations in diversity of vegetation (Willis and Whittaker, 2002), resulting in remarkable floristic and physiognomic characteristics driven by the topo-edaphic factors (Witkowski and O'Connor, 1996). The woody vegetation density and canopy cover are important indicators of ecosystem condition (McNaughton and Banyikwa, 1995) and soil character. On that note, the diversity of woody plants in Mapungubwe Cultural Landscape suggests ecological significance of the Limpopo valley. Authors recorded insignificant differences on number of plant families between the Cambisol-Luvisol strata on the western section of Mapungubwe Cultural Landscape and the Arenosol-Luvisol strata on the eastern part of the area, possibly because Luvisol group is a dominant soil type common in both strata. Nevertheless, the woody plant density and sapling density of these two strata were significantly different suggesting that edaphic factors are certainly not the only factors responsible for the differences in vegetation structure and composition. Therefore other key determinants like herbivore density dynamics (Doughty *et al.*, 2015), past land use and plant invasions (Rouget *et al.*, 2015) could also influence vegetation dynamics.

Whilst the regosols may exhibit similar characteristics akin to luvisols and cambisols, they cover a very small area of the Mapungubwe Cultural Landscape, and hence they have limited influence on vegetation dynamics of the area. The unconsolidated parent material that is



Table 3: Number of individuals per family and species recorded in Mapungubwe Cultural Landscape

Family	No. of individuals recorded	Genera	No. of Species/ Family	Species
Anacardiaceae	26	<i>Ozoroa, Pavetta, Sclerocrya</i>	4	<i>Ozoroa namaensi</i> ^, <i>Ozoroa paniculosa</i> ^, <i>Pavetta gracillima</i> ^, <i>Sclerocrya birrea</i>
Annonaceae	8	<i>Artabotrys, Monodora</i>	2	<i>Artabotrys brachypetalus</i> ^, <i>Monodora junodii</i> ^
Apocynaceae	4	<i>Diplorhynchus, Tabernaemontana</i>	2	<i>Diplorhynchus condylocarpon</i> ^, <i>Tabernaemontana elegans</i> ^
Arecaceae	22	<i>Hyphaene</i>	1	<i>Hyphaene natalensis</i>
Bignoniaceae	15	<i>Markhamia, Catophrates, Kigelia</i>	3	<i>Markhamia zanzibarica</i> ^, <i>Catophrates alexandri</i> , <i>Kigelia Africana</i> ^
Bombacaceae	44	<i>Adansonia</i>	1	<i>Adansonia digitata</i> L.
Boraginaceae	13	<i>Ehretia</i>	1	<i>Ehretia amoena</i> ^
Burseraceae	89	<i>Commiphora</i>	4	<i>Commiphora africana</i> , <i>Commiphora grandulosa</i> ^, <i>Commiphora marlothii</i> , <i>Commiphora merkeri</i>
Caesalpiniaceae	7	<i>Cassia</i>	1	<i>Cassia abbreviata</i>
Capparaceae	69	<i>Capparis, Maerua, Thilachium, Boscia</i>	6	<i>Capparis tomentosa</i> ^, <i>Maerua kirkii</i> ^, <i>Maerua parvifolia</i> , <i>Thilachium africanum</i> ^, <i>Boschia albitrunca</i> , <i>Boschia angustifolia</i> ^
Celastraceae	23	<i>Gymnosporia, Hippocratea</i>	3	<i>Gymnosporia maranguensis</i> ^, <i>Gymnosporia senegalensis</i> ^, <i>Hippocratea crenata</i> ^
Combretaceae	363	<i>Combretum, Terminalia</i>	10	<i>Combretum apiculatum</i> , <i>Combretum collinum</i> ^, <i>Combretum heroense</i> ^, <i>Combretum imberbe</i> , <i>Combretum microphyllum</i> , <i>Combretum mossambicense</i> , <i>Combretum racemosa</i> ^, <i>Combretum ziyheri</i> ^, <i>Terminalia plurinoides</i> , <i>Terminalia sericea</i>
Ebenaceae	17	<i>Euclea, Diospyros</i>	3	<i>Euclea divinorum</i> ^, <i>Diospyros lycioides</i> ^, <i>Diospyros mesplifomis</i>
Euphorbiaceae	229	<i>Acalypha, Croton, Euphorbia, Spirostachys</i>	7	<i>Acalypha ornata</i> ^, <i>Croton gratissimus</i> , <i>Croton megalobotrys</i> ^, <i>Croton pseudopulchellus</i> , <i>Euphorbia spinosa</i> ^, <i>Euphorbia ingens</i> , <i>Spirostachys africana</i>
Fabaceae	1910	<i>Albizia, Cordyla, Colophospermum, Dalbergia, Dichrostachys, Faidherbia, Mundulea, Senegalia, Vachellia, Xanthocersis, Xeroderris</i>	23	<i>Albizia harveyi</i> , <i>Cordyla Africana</i> ^, <i>Colophospermum mopane</i> , <i>Dalbergia melanoxylon</i> ^, <i>Dichrostachys cineria</i> , <i>Faidherbia albida</i> , <i>Mundulea sericea</i> , <i>Senegalia karro</i> , <i>Senegalia nigrescens</i> , <i>Senegalia schweinfurthii</i> , <i>Senegalia ataxantha</i> , <i>Senegalia erubescens</i> , <i>Senegalia goetzei</i> ^, <i>Senegalia welwitschii</i> , <i>Vachellia grandicornuta</i> ^, <i>Vachellia nilotica</i> , <i>Vachellia robusta</i> , <i>Vachellia tortilis</i> , <i>Vachellia xanthophloea</i> , <i>Vachellia erioloba</i> , <i>Vachellia exuvialis</i> ^, <i>Xanthocersis zambesiaca</i> , <i>Xeroderris stuhlmannii</i>
Kirkiaceae	11	<i>Kirkia</i>	1	<i>Kirkia acuminata</i>
Linaceae	1	<i>Hugonia</i>	1	<i>Hugonia orientalis</i> ^
Malvaceae	83	<i>Grewia</i>	5	<i>Grewia bicolor</i> , <i>Grewia flavascens</i> , <i>Grewia hornbyii</i> ^, <i>Grewia ina equilatera</i> , <i>Grewia epidopetala</i>
Moraceae	38	<i>Ficus, Maclura</i>	3	<i>Ficus abutilifolia</i> , <i>Ficus capensis</i> , <i>Ficus natalensis</i> , <i>Maclura africana</i>
Olacaceae	5	<i>Ximenia</i>	1	<i>Ximenia caffra</i> ^
Phyllanthaceae	43	<i>Bridelia, Flueggea, Hymenocardia, Phyllanthus</i>	6	<i>Bridelia cathartica</i> ^, <i>Bridelia mollis</i> , <i>Flueggea virosa</i> , <i>Hymenocardia ulmoides</i> ^, <i>Phyllanthus kirkii</i> , <i>Phyllanthus reticulatus</i> ^
Putranjivaceae	7	<i>Drypetes</i>	1	<i>Drypetes mossambicensis</i> ^
Rhamnaceae	43	<i>Berchemia, Ziziphus</i>	3	<i>Berchemia discolor</i> , <i>Ziziphus Mauritania</i> ^, <i>Ziziphus macronata</i>
Rubiaceae	5	<i>Coptosperma, Gardenia, Philenoptera, Psychotria</i>	5	<i>Coptosperma zygoon</i> ^, <i>Gardenia resiniflua</i> , <i>Philenoptera bussei</i> ^, <i>Philenoptera violacea</i> , <i>Psychotria capensis</i>
Salvadoraceae	15	<i>Salvadora</i>	2	<i>Salvadora australis</i> , <i>Salvadora persica</i> ^
Strychnaceae	5	<i>Strychnos</i>	2	<i>Strychnos madagascariensis</i> , <i>Strychnos potatorum</i>
Verbenaceae	9	<i>Vitex, Lantana</i> **	2	<i>Vitex amboniensis</i> ^, <i>Lantana camara</i> **
Vitaceae	10	<i>Cyphostemma, Rhoicissus</i>	2	<i>Cyphostemma currorii</i> ^, <i>Rhoicissus revoulli</i>

Notes: \*\*=Exotic woody plant species recorded, ^=Species that were not listed on MCL woody plant inventory in the context of the Mapungubwe Park Management Plan for 2013-2018

characteristic of regosols render them relatively poor in available soil nutrients despite having clay content that may be of alluvial origin. The lack of a significant soil layer formation because of very dry climatic conditions prevalent in Mapungubwe Cultural Landscape make regosols less productive.

Since vegetation is a key driver of large herbivore biomass, African savannahs are known to host high diversity of large herbivores (Valeix *et al.*, 2011). The high herbivore diversity in such systems have been attributed to spatio-temporal dynamics on forage quantity and quality (Sensenig *et al.*, 2010). On that note, large herbivore populations are expected to be higher in habitats characterised by fertile soils than habitats with nutrient poor soils (Scholes and Walker, 1993, Scholes, 1990, Vanlauwe and Giller, 2006). The Mapungubwe Cultural Landscape is experiencing an increase in the population of elephants and other large herbivores (Selier *et al.*, 2014, O'Connor, 2010a, Selier *et al.*, 2015) and inevitably having consequences for the Mapungubwe vegetation (O'Connor, 2010a) and this has been recorded elsewhere (Bakker *et al.*, 2015, Gaugris *et al.*, 2014, Scholtz *et al.*, 2014). Effective management of protected areas require knowledge of vegetation types as they constitute the habitats for wildlife (Clegg and O'Connor, 2012). The inventory of woody vegetation species produced in this study is important for documentation of the biodiversity assets in terms of plant diversity and terrestrial habitat character of Mapungubwe Cultural Landscape. This is important where unique and valuable biodiversity in the sub-tropical savanna vegetation is being lost continuously (Coetzer, 2012, Coetzer *et al.*, 2013). Vegetation, like soil, is a product of the same group of independent variables since the same environmental factors responsible for soil formation are also responsible for the vegetation that is produced (Major, 1951)

The low density of vegetation in the central Mapungubwe Cultural Landscape resonates well with previous occupation of this area in archeological history (Huffman, 2005) as human beings are likely to settle where there is less probability of conflict with wildlife whilst the more fertile soils were used for cultivation and grazing by the agro-pastoral community that once thrived in the area (Huffman, 2009). Soil nutrient availability is known to influence the vegetation community structure (Bell, 1982) and consequently human settlement patterns (Drechsel *et*

*al.*, 2001). The past agro-pastoral society that thrived in the Limpopo river valley utilized the Limpopo floodplain (Huffman, 2000) and since droughts are a norm in the area (O'Connor and Kiker, 2004) the settlement patterns in the ancient kingdom of Mapungubwe could have also influenced both structural and compositional attributes of vegetation dynamics in the area. Whilst the societal developments that occurred in the Shashe-Limpopo basin (Huffman, 2009) and associated past landuse activities in Mapungubwe Cultural Landscape (Huffman, 2000) could have shaped the contemporary vegetation communities. The anthropogenic advancement (Miller, 2001, Caton-Thompson, 1939) and changing lifestyle in the iron-age community of Mapungubwe (Huffman, 2005) and use of different tools (Fagan, 1964, Kuman *et al.*, 2005) resulted in the development of a more sophisticated society (Prinsloo and Colomban, 2008) and associated population dynamics from Henneberg and Steyn, 1994's palaeo-demography study could have shaped the vegetation at various disturbance thresholds (Henneberg and Steyn, 1994).

Humans are known to influence vegetation through burning, agricultural activities (Adams, 2007) and even positively through establishment of protected areas whereby resource extraction (including purposeful removal of woody vegetation) is either limited or completely stopped (depending on level of protection). Authors attribute the variable woody vegetation (trees and shrubs) structure and composition amongst the soil strata predominantly to the influence of soil composition (Scholes and Archer, 1997) among other key factors that are characteristic to sub-tropical savannas. Understanding local-scale vegetation dynamics and species mix is therefore important for protected area management as that informs decision-making processes involved for effective conservation programs contained the Mapungubwe Park Plan developed for the period 2013 – 2018 and the Environmental Management Framework (SANParks, 2010). Implementation of such plans are also important in line with Sections 39 and 41 of the South African National Environmental Management: Protected Areas Act (NEMPA) (Act 57 of 2003) and chapter 4 of the World Heritage Convention Act (Act 49 of 1999), whilst appreciating factors that have shaped present-day vegetation status, with insights on how these ecosystems have evolved over time. This makes understanding vegetation structure and composition

very important and combining with palaeo-data (Gillson, 2015; Bakker *et al.*, 2015) becomes even more important for a site like the Mapungubwe Cultural Landscape as that is also in line with the Convention on Biological Diversity Strategic Plan for Biodiversity 2011 to 2020, including a set of twenty headline targets known as Aichi Biodiversity Targets (Drechsel *et al.*, 2001; Bertzky *et al.*, 2012). Information gathered in this study is an important reference baseline for monitoring programmes in the Greater Mapungubwe Transfrontier Conservation Area and advancing palaeoecological research in the Mapungubwe Cultural Landscape as the authors provide a spatially-explicit record of woody vegetation family/species assemblage of the area.

## CONCLUSION

Present and future initiatives for conserving the biodiversity endowment of Mapungubwe Cultural Landscape should consider the influence of soil type and its interaction with other key environmental variables, including human activities and their effect on woody plant diversity to guide effective and meaningful restoration programs aimed at preserving ecological integrity of protected area. Ecosystems are in constant flux and updating woody plant species inventory of a protected area system as achieved in this study is invaluable. Conservation programs are tailor-made to the known biodiversity assets of an area and baseline information on plant species found in an area, including the structural attributes is important for establishing informed ecological monitoring systems beyond the boundaries of a protected area.

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## CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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