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Classification, description and mapping of the vegetation in Khutse Game Reserve, Botswana

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Abstract: There is currently no detailed classification and description of plant communities in Khutse Game Reserve (KGR), Botswana, using phytosociological techniques. The main aim of this study was to classify and describe plant communities in KGR. Classification and description of plant communities will help in understanding the plant ecology of KGR. Braun-Blanquet sampling method was applied in 91 stratified random relevés. Nine plant communities were identified and classified using Modified TWINSPAN which is contained in JUICE program. The results showed that there was a statistically significant difference in percentage cover of herbaceous plants between the different plant communities. *Schmidtia pappophoroides-Stipagrostis uniplumis* and *Heliotropium lineare-Enneapogon desvauxii* communities had higher cover (%) of herbaceous plants than other communities. *Catophractes alexandri-Stipagrostis uniplumis* community had the highest cover (%) of shrubs. There was no statistically significant difference in plant species diversity (Shannon-Wienner Index) and species evenness between plant communities, but there was a statistically significant difference in plant species richness between the different plant communities. *Dichrostachys cinerea-Grewia flava* community, *Senegalia mellifera* subsp. *detinens-Maytenus* species community and *Catophractes alexandri-Stipagrostis uniplumis* community had lower number of species, whereas *Vachellia luederitzii* var. *retinens-Grewia flava* community had the highest number (46) of plant species. This study will help the Department of Wildlife and National Parks (DWNP) to develop an updated and informed Management Plan for the reserve, which takes cognizance of the plant ecology of the reserve.

Introduction

Khutse Game Reserve (KGR) is a protected nature reserve situated in the northern part of the Kweneng District, Botswana. KGR is located about 220km to the north-west of Gaborone and south of the Central Kalahari Game Reserve (CKGR). According to DWNP (2003), KGR was officially declared a protected area in 1971 and was gazetted in order to protect wildlife and natural resources around fossil valleys and pans that extended from the CKGR. Even though there are no rivers in KGR, the reserve is a habitat of fossil dunes, rolling grasslands, grassed and bare pans and (Pfotenhauer 2009). It is located in a semi-arid Kalahari environment with savanna vegetation which is made up of a spatially complex and structurally heterogeneous mixture of woody and herbaceous species (Mishra and Crews 2014). Maintaining biodiversity and increasing plant species diversity is the main aim of rangeland managers in many semi-arid environments (Fulbright 1996). By their nature, savannas are found in places with dry winters and wet summers and they are located in the tropics between the arid regions and the equatorial forests (Skarpe 1996). Savannas are made up of different life forms of grasses, shrubs and trees and the reasons for the coexistence of these life forms and their importance in conservation and management have been widely documented (Furley 2007). In agreement, Skarpe (1996) states that savannas are characterised by herbaceous vegetation (more especially perennial grasses) and trees and/ or shrubs. The savanna biome is normally unstable and influenced by rainfall variability, fire and herbivory thus making the tree-grass ratio to be changeable (Huntley and Walker 1982; Scholes and Walker 1993; Furley 2010). In Africa, savannas exist due to the impact of large herbivores and fire (Skarpe 1992).

Recently, plant ecology of savannas has enabled researchers to understand species composition and functioning, as well as showing their complexity and dynamic nature (Furley 2010). Savannas seem to follow a pattern of succession before it is interrupted by disturbance (Furley 2010). In this debate, Gillson (2004) suggests that at different scales, tree abundance is dominated by various ecological processes and this leads to a concept of patch dynamics that varies spatially and temporally. Wiegand et al. (2003; 2005; 2006) and Meyer et al. (2009) also support the patch dynamics theory while Nicholas et al. (2009) favour soil-fire-vegetation feedback loops. Scholes et al. (2002) suggested that aridity and fire are the two inversely correlated factors which control shrub cover in the Kalahari savanna. When aridity increases, woody plants decrease, to the point where rainfall at below 300 mm per annum, most woody plants are below 2.5 m threshold which is used to differentiate trees from shrubs (Scholes et al. 2002). In most cases, woody shrubs found in the moister places do not reach tree height due to fire which intensifies during the dry season when there is increased grass production. Currently, patch dynamics theory appear to be the most favourable (Furley 2010).

KGR supports both resident and migratory populations of large mammalian herbivores. It experienced the same challenges that were observed in the CKGR, whereby very high mortalities of migratory wildlife species were recorded during the 1982-1986 droughts. An intervention by the Government of Botswana was to drill three boreholes between 1986 and 1990 to provide water to wildlife in the game reserve (DWNP staff, pers. comm.). This was part of the same measures that were made for CKGR, where nine boreholes were developed (Makhabu et al. 2002). Each of the three boreholes in KGR supplies an artificial water point and these water points are located at Khutse 1 Pan, Moreswe Pan and Molose Pan.

The discipline of vegetation science (plant ecology) was developed in the 20th century and most European plant ecologists were interested in phytosociology (*phyto* meaning plant and *sociology* meaning groupings of species) (Brown et al. 2013). The classification, description and mapping of vegetation in game reserves have gained a wider interest in plant ecology. Recently, the demand for data acquired from vegetation studies has increased especially in the discipline of biodiversity conservation and environmental monitoring (Chytrý et al. 2011). Due to climate change, studies on phytosociology are very crucial since vegetation data can be used to determine how plant communities respond to environmental changes over time (Brown et al. 2013). Vegetation surveys and classifications are also crucial in basic research of plant ecology and they give information for describing vegetation types and understanding various ecosystems (Chytrý et al. 2011). In a protected nature reserve, it is very important to understand plant communities in order to come up with conservation strategies (Daemane et al. 2010). Since the 1990s, vegetation studies have attracted some interest because of an increase in demand from experts in the field of nature conservation to come up with comprehensive systems of vegetation or habitat classifications which are needed for conservation planning and making well informed management decisions (Chytrý et al. 2011). Another reason for the interest is that there have been huge advances in technology which aid in the establishment and management of electronic databases that enable vegetation data collected from past decades to be converted into formats that can be accessed and analysed with ease (Schaminée et al. 2009; Chytrý et al. 2011; Dengler et al. 2011).

In South Africa, numerous phytosociological studies have been carried out in natural protected areas such as national parks and privately owned game reserves and these studies have produced many publications on vegetation of protected areas in various biomes (Brown et al. 2013). The description and mapping of vegetation has played a crucial role in classifying and interpreting various complex ecosystems and in simplifying their spatial and temporal complexity (Mucina and Rutherford 2006; Brown et al. 2013). There is a need to conserve biodiversity and it is crucial to develop wildlife management plans that are efficient, ecologically sound and scientifically based (Bezuidenhout 1994; 2009). The natural resources can be used sustainably if the vegetation of the reserve is grouped into plant communities (Bezuidenhout 2009). In natural areas, ecosystems are represented by plant communities which serve as a basis of any management plan (Brown et al. 2005). When there is information on plant communities, and their distribution is well known, it will be easy to find habitats that are suitable for herbivores since different species of animals use different plant communities for shelter, food and reproduction (Brown et al. 2005; Woldewahid et al. 2007).

There is currently no detailed classification and description of plant communities in KGR using phytosociological techniques. Vegetation data collected through phytosociological methods can be

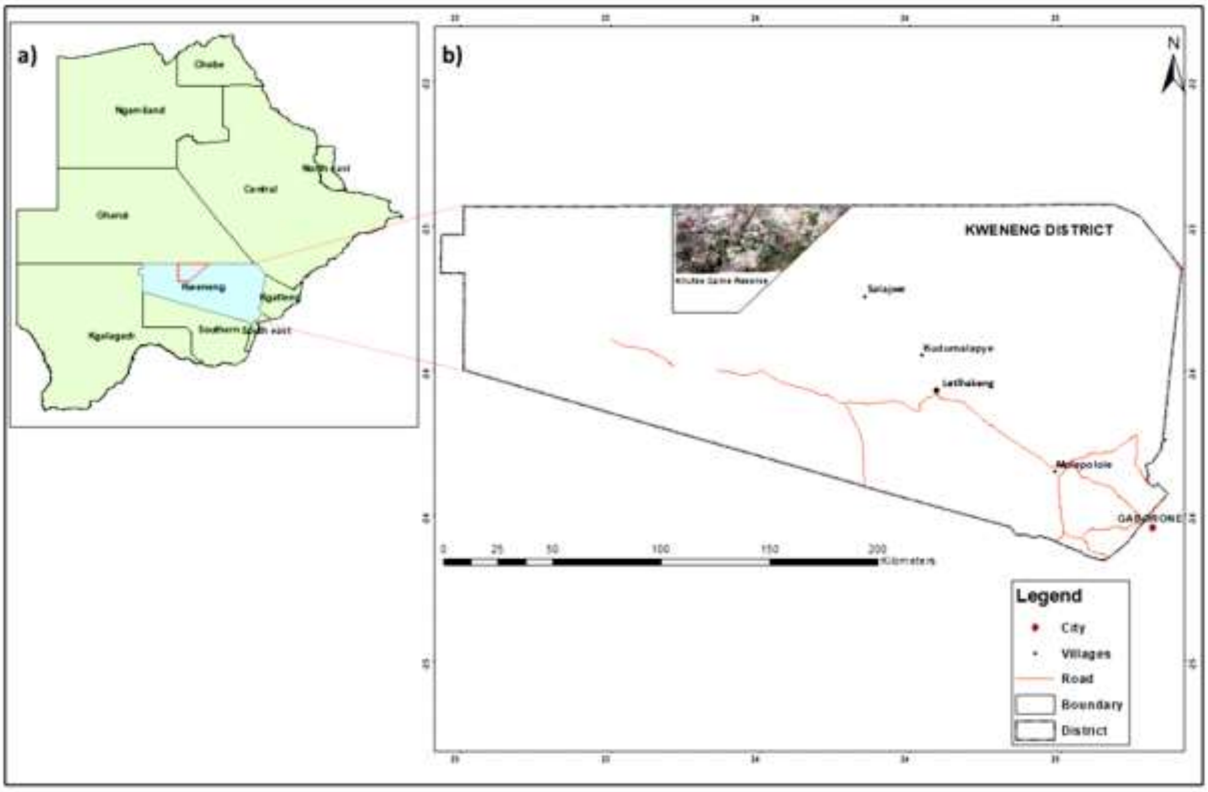

Fig. 1: a) Map of Botswana indicating the location of KGR (red square) in Kweneng District, b) Map of Kweneng District showing KGR with an overlay of Sentinel-2A natural color RGB (red, green and blue) imagery of the study area.

utilised in availing detailed information on the abundance of plant species, describing vegetation structure and determining plant species diversity, plant succession and production of different ecosystems (Brown et al. 2013). Vegetation studies also help in finding out areas that are ecologically sensitive, threatened by bush encroachment, degraded, habitats for rare or endangered plant and animal species (Zietsman and Bredenkamp 2006). The main aim of this study was to classify and describe plant communities in KGR. The study is crucial because it is the basis of ecological classification of plant communities in KGR, and will also be a long term record of the characteristics of the vegetation in each plant community.

Description of Study Site

The research was conducted in KGR which is situated in northern Kweneng District, Botswana (Fig. 1) and is about 220km north-west of Gaborone. It is on the south of the Central Kalahari Game Reserve (CKGR) and is located between latitude 23°S & 24°S and longitude 23°E & 25°E, at an average altitude of 1000m above sea level. KGR is 2600 km² in size and was officially declared a protected area in 1971 (Weilenmann et al. 2010; DWNP 2003). There has not been any detailed ecological study done on the vegetation of KGR (DWNP staff, pers. comm.).

Climate

The climate of KGR is semi-arid with very cold and dry winter (May-September) and a very hot and wet summer (October-April) (DWNP 2003; Weilenmann et al. 2010). July average temperature is 13-14°C and January average temperature is 25-26°C (Zehnder 2015). The mean annual rainfall is 321 ± 67 mm and most of the rain falls between December and April (DWNP 2003; Weilenmann et al. 2010).

Geomorphology and soils

KGR is a flat area characterized by Kalahari sandveld with sandy soils and fossil dunes outside the pans (Makhabu et al. 2002; Pfotenhauer 2009; Weilenmann et al. 2010). These sandy soils are deep, yellowish to reddish in colour and they drain quickly (de Wit & Nachtergaele 1990). There are fossil river valleys in KGR as well as some bare and grassed pans (Makhabu et al. 2002). The artificial water points in KGR are located at Khutse 1 Pan, Moreswe Pan and Molose Pan. The three major soil factors that influence the distribution of plants in all Kalahari habitat types are surface soil clay content, sub-surface hardpan layers and calcrete beds and catena position (DWNP 2003). The pans are mainly calcrete and have a high content of clay soils with high mineral content and they retain moisture very well (DHV 1980; Makhabu et al. 2002).

Animals

KGR has mammalian herbivores and these include springbok (*Antidorcas marsupialis*), kudu (*Tragelaphus strepsiceros*), gemsbok (*Oryx gazelle*) and giraffe (*Giraffa camelopardis*). Carnivores include lions (*Panthera leo*), leopards (*Panthera pardus*) and black-backed jackal (*Canis mesomelas*). The birds which are found in KGR include ostrich (*Struthio camelus*), Kori bustard (*Ardeotis kori*), eagle (*Hieraatus spilogaster*), lappet faced vulture (*Torgos tracheliotos*), and southern pied babbler (*Turdoides bicolor*) (DWNP 2003).

Habitat and Vegetation

DHV (1980) identified four major habitat types of the Kalahari and described them as follows: (i) Fossil river valley and pan habitat: This habitat has a high content of clay soils and this leads to predominance of grassland mixed with occasional clumps of trees called tree islands. Shrub communities predominate in areas where sands overlay pan and valley floors. (ii) Dune habitat: In dunes, there is a mixture of woodland, shrub and grassland. The upper dune slopes and crests have coarse sands for easy root penetration and they are often covered with trees, whereas the lower slopes have compacted sands and they promote growth of shrubs and grasses. (iii) Interdunal habitat: This habitat has smaller sand particles and patchy sub-surface hardpan layers that promote access to water near the soil surface by the roots of shrubs and grasses. The interdunal habitat forms a mosaic with the dune habitat. (iv) Plain habitat: The plain habitat has smaller soil particles which do not promote penetration by tree roots and it lacks compacted sub-surface soil layers which hinders the availability of moisture near the soil surface. A study by Mishra et al. (2015) broadly and physiognomically defined six vegetation morphology classes in the neighbouring CKGR as (i) woodland, (ii) dense shrubland, (iii) open shrubland, (iv) very open shrubland, (v) grassland and (vi) pan.

The plant species which are found in KGR include trees such as *Philoneptera nelsii* (Schinz) Schrire, *Senegalia erubescens* Welw. ex Oliv. *Senegalia mellifera* subsp. *detinens* (Burch.) Brenan, *Boscia albitrunca* (Burch.) Gilg & Gilg-Ben., *Ziziphus mucronata* Willd. and *Terminalia sericea* Burch. ex DC. Shrubs consist of *Greiwa flava* DC., *Gardenia volkensii* K. Schum., *Catophractes alexandri* D. Don, *Dichrostachys cinerea* (L.) Wight & Arn., *Pentzia calva* S. Moore and *Rhigozum brevispinosum* Kuntze. Grasses include *Schmidtia pappophoroides* Steud. ex J.A. Schmidt, *Stipagrostis uniplumis* (Licht.) De Winter, *Brachiaria humidicola* (Rendle) Schweick and *Enneapogon desvauxii* P. Beauv. Herbs include *Chloris virgate* Sw., *Limeum sulcatum* (Klotzsch) Hutch., *Panicum maximum* Jacq., *Chamaesyce inaequilatera* (Sond.) Soják and *Commelina diffusa* Burm.f.

Materials and Methods

A reconnaissance of the study area was done on the 13th-15th November 2015 inorder to determine homogeneous areas in the vegetation. Google earth images and driving surveys were used to stratify the area into physiognomic-physiographic units in order to identify homogenous vegetation types. The main vegetation sampling was conducted in summer from the 2nd March to the 12th May 2016 when there was optimal vegetation growth. Vegetation cover was determined by means of the Braun-Blanquet method (Braun-Blanquet 1932). The Braun-Blanquet method was selected because it needs one third to one fifth the time required for stem-counts (Wikum and Shanholtzer 1978).

Plots were arranged along transects which ran parallel to the tracks for easy access and they were randomly located within the different homogenous units. Inorder to avoid road edge effects, plots were located at a minimum distance of 50m away from the tracks. The vegetation was divided into herbaceous layer (grasses and herbaceous species), shrub layer (woody species between 0-3m) and tree layer (woody species>3m) as in Bezuidenhout (2009). Sampling plots of 10m x 10m were marked with range poles. These plots were used for recording trees and shrubs. Four 1m x 1m quadrats were randomly located inside the 10m x 10m plot for recording herbaceous vegetation. In each sampling plot, i.e., the large 10m x 10m plot and each of the four 1m x 1m smaller plots, all plant species were recorded to determine species composition. The cover and height of the vegetation were also determined.

Cover data was based on the Braun-Blanquet cover estimation classes whereby **1** is cover between 1-5%, **2** is cover between 5-25%, **3** is cover between 25-50%, **4** is cover between 50-75% and **5** is cover more than 75% (Braun-Blanquet 1932; Mueller-Dombois and Ellenberge 1974). A 5m telescopic levelling rod was used to measure the height of trees and shrubs. A handheld Global Positioning System (Garmin GPS64S) was used to mark the location of each sampling plot. Other environmental factors that were recorded included altitude, habitat type and soil colour. Munsell Soil Colour Chart was used for identifying soil colour. A NIKON D5200 digital camera was used to take pictures of the plant communities. Plant species were pressed and taken to the University of Botswana Herbarium for verification and identification. Plant species names follow Setshogo and Venter (2003), Kabelo and Mafokate (2004), Setshogo (2005) and van Oudtshoorn (2009).

Data Analysis

SPSS 24 was used for statistical analysis. Percentage cover data were arcsine transformed in order to try stretching out both the tails and compress the middle part of the distribution (Sokal and Rohlf 1969). Shapiro-Wilk test was used to test for normality of the data. Data on arcsine transformed cover were not normally distributed ($p<0.05$). Therefore, nonparametric statistics were used to analyse the data. Modified TWINSPAN (Roleček et al. 2009), which is contained in JUICE 7.0.102 program (Tichý 2002), was used to classify plant communities. The Braun-Blanquet scale (1, 2, 3, 4 and 5) was used and the scale values were converted into percentages as 3, 13, 38, 63, and 88. The values of pseudospecies cut levels were 0, 5, 25, 50 and 75 with minimum group size of 6. The type of fidelity measure used was phi coefficient. Phi coefficient was chosen because it uses presence/ absence data and does not depend on the size of the data (Chytrý et al. 2002). The size of all groups was standardized to equal size and the size of the target group was 40% of the total data set. Fisher's exact test was calculated and plant species with significance $p<0.05$ were diagnostic. Fidelity threshold was set to 40 lower and 80 higher, frequency threshold set to 60 lower and 80 higher, and cover threshold set to 50 lower and 80 higher. Species richness, Shannon-Wienner diversity index and species evenness were calculated in JUICE 7.0.102 program (Tichý 2002).

Results

Classification of Plant Communities

Nine plant communities were classified by modified TWINSPAN analysis. Table 1 lists the communities according to how modified TWINSPAN grouped them. The classification results are also presented in a synoptic table and dendrogram (Table 2 and Figure 2, respectively). Figure 3 shows plant communities of KGR and the number of relevés in which photos were taken from.

Table 1: Plant communities of KGR with their number of relevés sampled. Total number of relevés is 91.

Group	Plant community	Number of relevés	Relevé numbers
1	*Heliotropium lineare-Enneapogon desvauxii* community	**10**	82 87 67 83 76 65 91 70 90 78
2	*Senegalia mellifera-Maytenus species* community	**4**	4 15 68 86
3	*Senegalia erubescens-Philoneptera nelsii* community	**15**	6 79 34 39 60 43 49 11 19 38 47 75 31 21 32
4	*Brachiaria humidicola-Philoneptera nelsii* community	**6**	7 53 84 54 13 36
5	*Terminalia sericea- Philoneptera nelsii* community	**17**	74 72 40 41 73 77 46 64 29 62 63 56 52 30 12 33 35
6	*Dichrostachys cinerea-Grewia flava* community	**3**	16 66 69
7	*Catophractes alexandri-Stipagrostis uniplumis* community	**6**	1 2 3 14 44 57
8	*Vachellia luederitzii* var. *retinens-Grewia flava* community	**14**	24 88 81 58 25 9 17 61 55 22 23 71 80 26
9	*Schmidtia pappophoroides-Stipagrostisuniplumis* community	**16**	5 8 10 18 20 27 28 37 42 45 48 50 51 59 85 89

Table 2: Percentage synoptic table of 91 relevés of KGR plant communities. Diagnostic species have fidelity measure (phi coefficient x 100) of over 40.0 and significant fidelity (P<0.05, Fisher's exact test). Dashes represent negative fidelity. Group numbers represent plant communities and they are described in Table 1.

Group No.	1	2	3	4	5	6	7	8	9
No. of relevés	10	4	15	6	17	3	6	14	16
Diagnostic species of Group 1									
Heliotropium lineare	87.7	—	—	—	—	—	—	—	—
Enneapogon desvauxii	79.6	—	—	—	—	—	—	—	—
Tarchnanthus camphoratus	45.2	—	—	—	—	—	—	—	—
Limeum sulcatum	43.1	—	—	—	—	—	—	—	—
Urochloa trichopus	43.1	—	—	—	—	—	—	—	—
Diagnostic species of Group 2									
Senegalia mellifera subsp. *detinens*	—	79.4	—	—	—	—	—	—	25.4
Maytenus species	—	70.7	—	—	—	—	—	—	—
Ziziphus mucronata	—	59.8	—	—	—	—	—	—	—
Commelina diffusa	—	40.8	—	—	—	—	—	—	—
Setaria verticillata	—	40.8	—	—	—	—	—	—	—
Hibiscus trionum	—	40.8	—	—	—	—	—	—	—
Chamaesyce inequilatera	—	40.8	—	—	—	—	—	—	—
Diagnostic species of Group 3									
Senegalia erubescens	—	—	80.0	—	—	—	—	—	—
Diagnostic species of Group 4									
Brachiaria humidicola	—	—	—	72.5	—	—	—	—	—
Digitaria pentzii	—	—	—	48.0	—	—	—	—	—
Commelina africana	—	—	—	41.3	—	—	—	—	—
Diagnostic species of Group 5									
Anthephora pubescens	—	—	—	—	45.1	—	—	—	—
Eragrostis pallens	—	—	—	—	44.7	—	—	—	—
Diagnostic species of Group 6									
Aptosimum procumbens	—	—	—	—	—	48.0	—	—	—
Diagnostic species of Group 7									
Catophractes alexandri	—	—	—	—	—	—	100.0	—	—
Diagnostic species of Group 8									
Vachellia luederitzii var. retinens	—	—	—	—	—	—	—	52.7	—
Diagnostic species of Group 9									
Schmidtia pappophoroides	—	—	—	—	—	—	—	—	64.7
Common diagnostic species of two or three communities									
Terminalia sericea	—	—	—	52.3	56.4	—	—	—	—
Dichrostachys cinerea	—	—	—	48.2	—	83.6	—	—	—
Gardenia volkensii	—	—	—	—	—	—	50.5	42.8	—
Rhigozum brevispinosum	—	—	—	—	—	—	—	41.9	41.9
Grewia flava	—	—	—	—	—	—	—	45.6	33.3
Philoneptera nelsii	—	—	45.3	56.2	48.7	—	—	—	—

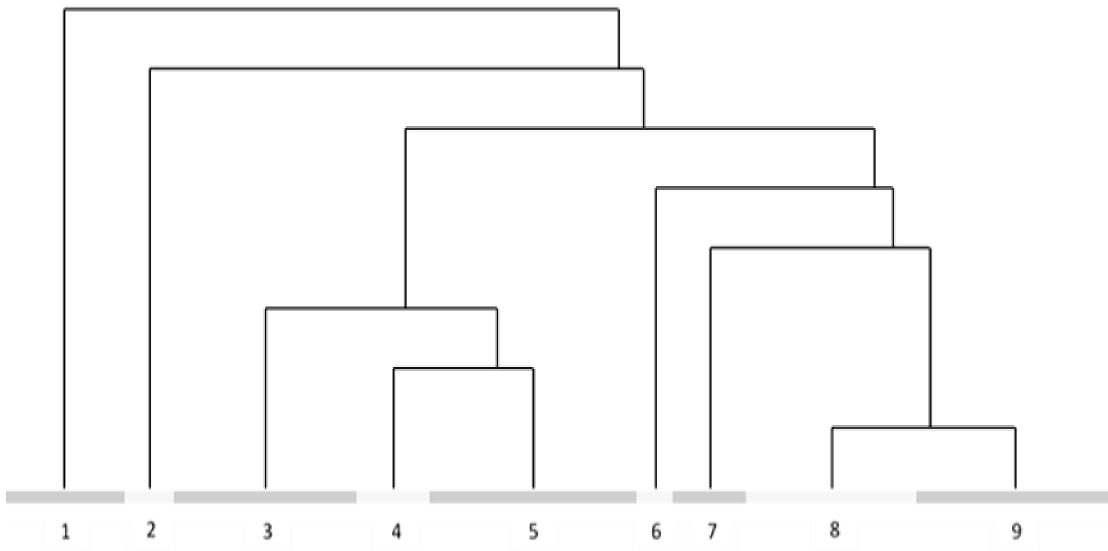

Fig. 2: Cluster analysis dendrogram of KGR plant communities. Numbers (1-9) are groups representing plant communities and they are described in Table 1.

Percentage Cover of Herbs, Shrubs and Trees in Plant Communities

Herbaceous Layer

Independent samples Kruskal-Wallis H test showed that there was a statistically significant difference in cover (%) of herbaceous plants between the different plant communities, χ^2 (8) = 18.114, p = 0.020. *Catophractes alexandri-Stipagrostis uniplumis* community had a minimum mean rank of 47.30 and *Schmidtia pappophoroides-Stipagrostis uniplumis* and *Heliotropium lineare-Enneapogon desvauxii* communities had mean ranks of 101.00 and 97.70, respectively. (Figure 4 and Table 3). This shows that the two plant communities had higher cover (%) of herbaceous plants than other communities.

Shrub Layer

The results showed that there was no statistically significant difference in cover (%) of shrubs between the different plant communities, χ^2 (8) = 9.320, p = 0.316. In plain habitat, *Catophractes alexandri-Stipagrostis uniplumis* community had a highest cover (%) of shrubs (mean rank of 262.93) and *Brachiaria humidicola-Philoneptera nelsii* community had a lowest cover (%) of shrubs (Figure 4) with minimum mean rank of 180.11 (Table 3).

Tree Layer

There was no statistically significant difference in cover (%) of trees between the different plant communities, χ^2 (5) = 8.102, p = 0.151. *Schmidtia pappophoroides-Stipagrostis uniplumis* community, with a maximum mean rank of 37.33, had the highest cover (%) of trees (Figure 4 and Table 3). *Brachiaria humidicola-Philoneptera nelsii* community had a minimum mean rank of 16.25 and this shows that this community had the lowest cover (%) of trees than other plant communities.

Plant Species Richness, Diversity and Evenness of Plant Communities

One-way ANOVA results showed no statistically significant differences in species diversity (Shannon-Weiner Index) between plant communities ($F_{[8, 82]}$ = 1.975, p = 0.060). Independent samples Kruskal-Wallis H test showed that there was a statistically significant difference in species richness between the different plant communities, χ^2 (8) = 15.733, p = 0.046. *Dichrostachys cinerea-Grewia flava* community, *Senegalia mellifera* subsp. *detinens-Maytenus species* community and *Catophractes alexandri-Stipagrostis uniplumis* community had lower species richness of 11, 14 and 16, respectively. *Vachellia luederitzii* var. *retinens-Grewia flava* community had a highest number of species richness (Table 4). This plant community also had the highest Euclidean distance, Jaccard and Simpson Beta-diversity (Table 5).

The results indicated no statistically significant difference in species evenness between the different plant communities, χ^2 (8) = 7.364, p = 0.498. *Brachiaria humidicola-Philoneptera nelsii* community had the highest species evenness (Table 4).

Table 3: Mean ranks of herbaceous, shrubs and trees in KGR plant communities located in pans and plain habitats. Group numbers represent plant communities which are described in Table 1. There were no data for trees in groups 1, 6 and 7.

	Herbaceous		**Shrubs**		**Trees**	
Group	N	Mean Rank	N	Mean Rank	N	Mean Rank
1	23	97.70	33	198.80		
2	5	87.90	13	205.54	5	27.5
3	27	76.30	64	198.28	19	23.05
4	12	68.46	32	180.11	4	16.25
5	30	79.67	82	199.13	11	22.73
6	2	81.75	9	216.89		
7	10	47.30	22	262.93		
8	22	67.16	94	194.68	8	34.06
9	31	101.00	54	210.27	3	37.33
Total	162		403		50	

Table 4: Plant communities of KGR with their number of relevés, number of species, species diversity and evenness. Group numbers represent plant communities which are described in Table 1.

Group	**Number of relevés**	**Species richness**	**Mean no. of Species/ Plot**	**Mean Species Diversity (H')**	**Mean Species evenness**
1	10	26	5.60	1.18	0.71
2	4	14	5.00	1.09	0.68
3	15	35	6.53	1.48	0.79
4	6	23	7.50	1.62	0.83
5	17	39	6.59	1.39	0.77
6	3	11	5.00	1.06	0.69
7	6	16	5.33	1.25	0.78
8	14	46	8.50	1.63	0.78
9	16	26	5.38	1.21	0.74

Table 5: Average Total inertia, Euclidean distance, Whittaker (overall**)** and Beta-diversity dissimilarity indices within relevés groups. Group numbers represent plant communities which are described in Table 1.

Data variability				**Beta-diversity (only presence absence-pair comp.)**				
Group	**Total inertia**	**Euclidean distance**	**Whittaker**	**Jaccard**	**Sorensen**	**Harrison**	**Williams**	**Simpson**
1	2.97	2.644	3.643	0.767	0.641	0.275	0.203	0.486
2	1.525	2.484	1.800	0.763	0.641	0.208	0.171	0.458
3	3.83	2.863	4.357	0.770	0.641	0.412	0.278	0.555
4	1.925	3.074	2.067	0.779	0.648	0.416	0.276	0.547
5	4.485	2.938	4.920	0.798	0.679	0.386	0.267	0.591
6	1.153	2.562	1.200	0.800	0.677	0.292	0.215	0.528
7	1.955	2.530	2.000	0.752	0.615	0.353	0.249	0.507
8	3.946	3.431	4.412	0.821	0.708	0.414	0.282	0.618
9	3.012	2.416	3.837	0.709	0.563	0.316	0.224	0.429

Naming and Description of Plant Communities

Diagnostic species (the first name), constant species and dominant species (the second name) obtained from vegetation data analysed in JUICE 7.0.102 program (Tichý 2002) were used to name plant communities. According to Chytrý and Tichý (2003), diagnostic species have a distinct concentration of occurrence or abundance in a particular plant community. Constant species are species of high frequency and dominant species are species of high cover-abundance (Chytrý and Tichý 2003).

1. Heliotropium lineare-Enneanpogon desvauxii community

Heliotropium lineare-Enneapogon desvauxii community is associated with reddish gray soil and it was found in pans of the study area (Figure 3a). The diagnostic species of this community were herbaceous *Heliotropium lineare* (87.7% fidelity), grass *Enneapogon desvauxii*, herbaceous species *Limeum sulcatum*, shrub *Tarchonanthus camphoratus* Linnaeus and grass *Urochloa trichopus* (Hochst.) Stapf (Table 2). The dominant species with each species having 30% cover were *Heliotropium lineare* and *Enneapogon desvauxii*. The other dominant herbaceous species *Chloris virgata*, *Limeum sulcatum*, *Panicum maximum*, shrubs *Pentzia calva* and *Solanum* species (smaller fuits) had 10% cover each. The constant species were *Heliotropium lineare* and *Enneapogon desvauxii* with frequency of 90% and 80%, respectively. The average height of *Heliotropium lineare* is 0.3m. The average canopy cover of herbaceous and shrub layers was 36.7% and 17.2%, respectively (Figure 4). *Heliotropium lineare-Enneapogon desvauxii* community does not have tree species.

2. Senegalia mellifera subsp. *detinens-Maytenus* species community

Senegalia mellifera subsp. *detinens-Maytenus* species community was a tree island situated in pans (Figure 3b). The diagnostic species were shrubs and trees of *Senegalia mellifera* subsp. *detinens* (79.4% fidelity), shrub *Maytenus* species, shrubs and trees *Zizipus mucrunata*, herbaceous species *Chamaesyce inaequilatera*, herbaceous *Commelina diffusa*, shrub *Hibiscus trionum* L., and grass *Setaria verticillata* (L.) P.Beauv. (Table 2). *Senegalia mellifera* subsp. *detinens* was dominant with 50% cover, whereas *Chamaesyce inequilatera*, *Maytenus* species and *Setaria verticillata* had a cover of 25% each. The constant species *Senegalia mellifera* subsp. *detinens* and *Maytenus* species had frequency of 100% and 75%, respectively. The average canopy cover of herbaceous and shrub layers was 31.0% and 19.9%, respectively (Figure 4).

3. Senegalia erubescens-Philoneptera nelsii community

Senegalia erubescens-Philoneptera nelsii community was a woodland community located in plain habitat (Figure 3c). It was associated with dark brown soil. The diagnostic species were shrubs and trees of *Senegalia erubescens* (80% fidelity) and *Philoneptera nelsii* (Table 2). The dominant species were *Senegalia erubescens* (33% cover) and grass *Stipagrostis uniplumis* (27% cover). Shrub *Philoneptera nelsii*, herbs *Pollichia campestris* Aiton and *Sansevieria aethiopica* Thunb. were also dominant with 7% cover each. *Senegalia erubescens* (80% frequency) and *Philoneptera nelsii* (73% frequency) are constant species. The average canopy cover of shrub and tree strata was 15.9% and 26.2%, respectively (Figure 4).

4. Brachiaria humidicola-Philoneptera nelsii community

Brachiaria humidicola-Philoneptera nelsii community was a shrubland community occuring in plain habitat with reddish brown soil (Figure 3d). The diagnostic species were grass *Brachiaria humidicola* (72.5% fidelity), shrubs and trees *Philoneptera nelsii*, *Terminalia sericea*, *Dichrostachys cinerea*, grass *Digitaria pentzii* and herb *Commelina africana* L. (Table 2). The dominant species were *Philoneptera nelsii* and grass *Eragrostis tef* (Zucc.) Trotter with each species having cover of 17%. *Philoneptera nelsii* (83% frequency) was a constant species together with *Brachiaria humidicola*, shrub *Dichrostachys cinerea*, shrub *Grewia flava* and shrub *Terminalia sericea* which have 67% frequency each. The average canopy cover of herbaceous and tree strata was 18.8% and 10.5%, respectively (Figure 4).

5. Terminalia sericea-Philoneptera nelsii community

Terminalia sericea- Philoneptera nelsii community was a shrubland community found in plain habitat with light brown well drained soil (Figure 3e). The diagnostic species were shrub *Terminalia sericea* (56.4% fidelity), shrub *Philoneptera nelsii*, grass *Anthephora pubescens* Nees and grass *Eragrostis pallens* Hack. (Table 2). The dominant species were *Philoneptera nelsii*, grass *Stipagrostis uniplumis* and shrub *Terminalia sericea* with 12% cover each. *Anthephora pubescens*, shrub *Dichrostachys cinerea*, shrub *Grewia flava* and shrub *Vachellia luederitzii* var. *retinens* are also dominant with each species having cover of 6%. The constant species *Philoneptera nelsii*, *Terminalia sericea* and *Stipagrostis uniplumis* had frequency of 76%, 71% and 65%, respectively. The average canopy cover of herbaceous, shrub and tree strata was 24.3%, 16.0% and 23.9%, respectively (Figure 4).

6. Dichrostachys cinerea-Grewia flava community

Dichrostachys cinerea-Grewia flava community was a shrubland community located in plain habitat with reddish brown soil (Figure 3f). The diagnostic species were shrub *Dichrostachys cinerea* (83.6% fidelity) and herb *Aptosimum procumbens* (Lehm.) Steud. (Table 4.2). The dominant species were *Dichrostachys cinerea* and herb *Talinum* species (Thunb.) Eckl. & Zeyh. and each species has 67% cover. The constant species were *Dichrostachys cinerea* (100% frequency), shrub *Grewia flava* (67% frequency), and *Talinum* species (67% frequency). The estimated average cover of herbaceous and shrub strata was 33.0% and 22.4%, respectively (Figure 4). *Dichrostachys cinerea-Grewia flava* community did not have a tree stratum.

7. Catophractes alexandri-Stipagrostis uniplumis community

Catophractes alexandri-Stipagrostis uniplumis community was a closed shrubland community found around pans (Figure 3g). The soil was reddish gray in colour. The diagnostic species were shrub *Catophractes alexandri* (100% fidelity) and shrub *Gardenia volkensii* (Table 2). The dominant species were *Catophractes alexandri* and shrub *Rhigozum trichotomum* with a cover of 50% and 17%, respectively. The constant species are *Catophractes alexandri* (100% frequency) and grass *Stipagrostis uniplumis* (67% frequency). The average canopy cover of herbaceous and shrub strata was 10.5% and 30.7%, respectively (Figure 4). This plant community did not have a tree layer.

8. Vachellia luederitzii var. *retinens-Grewia flava* community

Vachellia luederitzii var. *retinens-Grewia flava* community was a woodland community situaed in plain habitat (Figure 3h). It was associated with dark reddish gray soil. The diagnostic species were shrubs and trees of *Vachellia luederitzii* var. *retinens* (52.7% fidelity), shrub *Grewia flava,* shrub *Gardenia volkensii* and shrub *Rhigozum brevispinosum* (Table 2). *Vachellia luederitzii* var. *retinens* (29% cover) was dominant, as well as shrub *Paveta* species, *Rhigozum brevispinosum*, tree *Senegalia mellifera* subsp. *detinens* and grass *Stipagrostis uniplumis* which have 7% cover each. The constant species was *Grewia flava* (86% frequency). The average canopy cover of shrub and tree strata was 14.3%, and 44.3%, respectively (Figure 4).

9. Schmidtia pappophoroides-Stipagrostis uniplumis community

Schmidtia pappophoroides-Stipagrostis uniplumis community was a grassland mixed with shrubs and trees occuring in plain habitat (Figure 3i). It was found in dark yellowish brown soil. The diagnostic species are grass *Schmidtia pappophoroides* (64.7% fidelity) and shrub *Rhigozum brevispinosum* (Table 2). The dominant species were grass *Stipagrostis uniplumis* (50% cover), grass *Schmidtia pappophoroides* (25% cover), *Rhigozum brevispinosum* (6% cover) and tree *Senegalia mellifera* subsp. *detinens* (6% cover). *Schmidtia pappophoroides* and *Stipagrostis uniplumis* grasses were also constant species together with shrub *Grewia flava* and they have frequency of 75% each. The average canopy cover of herbaceous, shrub and tree strata was 37.5%, 15.3% and 46.3%, respectively (Figure 4).

Discussion

Heliotropium lineare-Enneapogon desvauxii community was found in pans. The main pans in KGR are Khutse, Moloswe, Moreswe, Kujwe, Sutswane and Motailane. Artificial boreholes have been constructed by DWNP at Khutse 1, Moloswe and Moreswe pans, whereas Motailane pan has a seasonal watering hole. In the pans and dry river valleys of central Kalahari soils are mainly clay (Shaw and Thomas 1996; Deacon and Lancaster 1988). The pans indicate concentric bands of vegetation related to various flooding and soils (van Rooyen and van Rooyen 1998). Scholes et al. (2002) reported that salty pans such as Makgadikgadi pan are associated with halophytic shrubs and grasses or are sometimes bare, whereas non-saline areas such as Nxai pan, support sedge and grasslands. In KGR, animals drink water in the pans and mammalian herbivores graze grass *Enneapogon desvauxii* found in *Heliotropium lineare-Enneapogon desvauxii* community. According to van Oudtshoorn (2009), grass *Enneanpogon desvauxii* grows on overgrazed areas and it sprouts rapidly after the first rains (eight day grass). It is also good in protecting soil from erosion (van Oudtshoorn 2009). Springboks (*Antidorcas marsupialis*) prefer to inhabit this community so that they can easily see predators. Valeix et al. (2009) found that habitat selection by mammalian herbivores was influenced by short-term predation risk and grazers prefer to use grasslands and areas nearby waterholes in Hwange National Park (Zimbabwe). Habitats with dense vegetation cover are risky for the prey because they decrease the ability to detect a predator (Gorini et al. 2012). The plant species in *Heliotropium lineare-Enneapogon desvauxii* community are trampled by animals and the

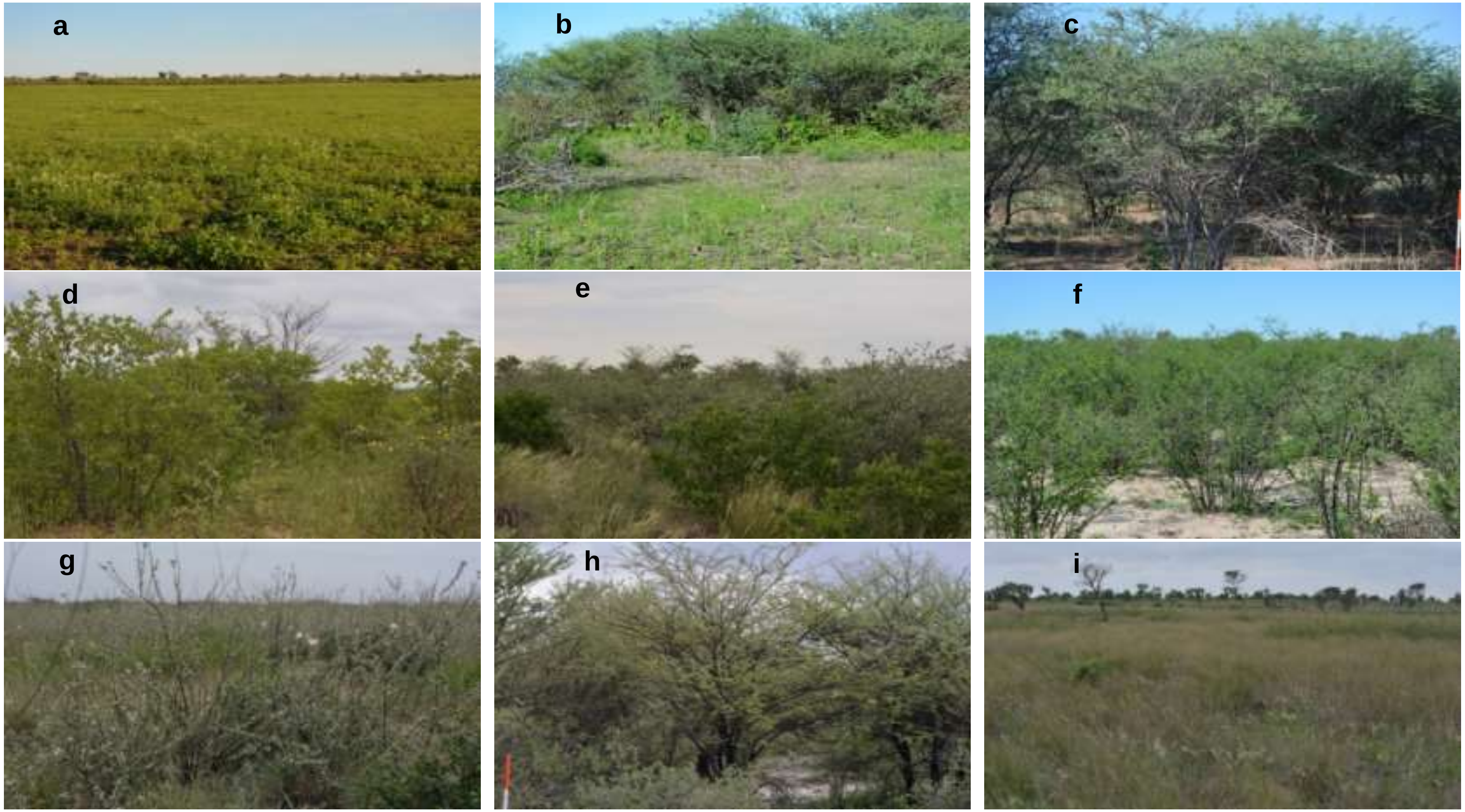

Fig. 3: Plant communities of Khutse Game Reserve and the number of relevés in which photos were taken from: a) *Heliotropium lineare-Enneapogon desvauxii* community(relevé 67), b) *Senegalia mellifera* subsp. *detinens-Maytenus* species community (relevé 68), c) *Senegalia erubescens-Philoneptera nelsii* community (relevé 38), d) *Brachiaria humidicola-Philoneptera nelsii* community (relevé 53) e) *Terminalia sericea-Philoneptera nelsii* community (relevé 56), f) *Dichrostachys cinerea-Grewia flava* community (relevé 69), g) *Catophractes alexandri-Stipagrostis uniplumis* community (relevé 44), h) *Vachellia luederitzii* var.*retinens-Grewia flava* community (relevé 22) and i) *Schmidtia pappophoroides-Stipagrostis uniplumis* community (relevé 50). Photos taken by Lori, 2016.

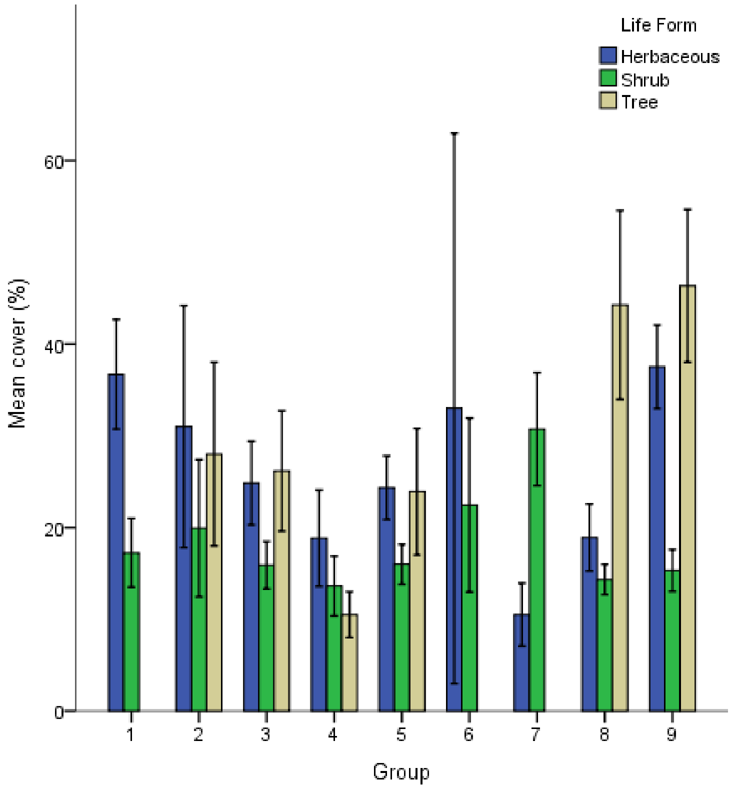

Fig. 4: Mean cover (%) of herbaceous, shrubs and trees in Khutse Game Reserve plant communities. There are no data for trees in groups 1, 6 and 7. Group numbers represent plant communities which are described in Table 1. Error bars are ± 1 SE.

pans become bare during dry season because of concentration of animals. Classification of plant communities helps in making ecologically sound decisions on the available habitat for wildlife (Brown et al. 2013).

Senegalia mellifera subsp. *detinens-Maytenus* species community was a tree island located in pans. This community was very crucial because animals use *Senegalia mellifera* subsp. *detinens* trees for shade during hot summer days. Good management of vegetation benefits the wildlife in the reserve and is very crucial to conservation of biodiversity that will influence policies and management practices (West 1993).

The other seven plant communities occured in plain habitat of the reserve. The plain habitat and pans found in KGR are in agreement with DHV (1980). *Senegalia erubescens-Philoneptera nelsii* community, *Brachiaria humidicola-Philoneptera nelsii* community and *Terminalia sericea-Philoneptera nelsii* community had *Philoneptera nelsii* as their diagnostic species. *Philoneptera nelsii* was the most common plant species occuring as both shrub and tree and was found in plain habitat. Dominance of the woody plants agrees with the pattern which has been suggested for savannas in southern Africa (Scholes *et al.* 2002). Neelo et al. (2013) reported that *P. nelsii* was found in deep sand. *Dichrostachys cinerea-Grewia flava* community had *Dichrostachys cinerea* as both diagnostic and dominant plant species. This community was threatened by bush encroachment of shrub *Dichrostachys cinerea.* An increase in woody plant density leads to thickets that are not penetrable by herbivores thus surpressing palatable grasses and herbs (Wiegand et al. 2006). *Catophractes alexandri-Stipagrostis uniplumis* community was found around pans. The shrub *Catophractes alexandri* was dominant and so dense that it was not easy to penetrate through. An increase in woody plant density leads to thickets that are not penetrable by herbivores thus surpressing palatable grasses and herbs (Wiegand et al. 2006).

Vachellia luederitzii var. *retinens-Grewia flava* community has *Vachellia luederitzii* var. *retinens* as the most common plant species. *Vachellia luederitzii* var. *retinens* occured as both trees and shrubs in this community. *Schmidtia pappophoroides-Stipagrostis uniplumis* community was a grassland mixed with shrubs and trees. Similarly, Wiegand et al. (2006) also reported about grass-dominated areas with interspersed trees, i.e. tree-grass co-existence, in an arid savanna of Namibia. When trees are within the grassland, they influence growth under the tree canopy (Furley 2010). During the wet season, trees aid growth of grass by improving nutrient up take and they delay wilting of grass in the dry season (Treydte et al. 2008). *Schmidtia pappophoroides-Stipagrostis uniplumis* community was characterised by grass *Stipagrostis uniplumis* which occurs throughout the reserve and it is one of the most crucial grazing grasses in sandy semi-arid environments (van Oudtshoorn 2009).

Percentage Cover of Herbaceous, Shrubs and Trees in Plant Communities

The results showed that there was a statistically significant difference in cover (%) of herbaceous plants between the different plant communities in plain habitat. This difference was found between Group 9 (*Schmidtia pappophoroides-Stipagrostis uniplumis*) and Group 3 (*Senegalia erubescens-Philoneptera nelsii*), Group 4 (*Brachiaria humidicola-Philoneptera nelsii*), Group 7 (*Catophractes alexandri-Stipagrostis uniplumis*) and Group 8 (*Vachellia luederitzii* var. *retinens-Grewia flava*). The cover (%) of herbaceous plants in Group 9 differs with other plant communities because this plant community was a grassland with herbaceous layer comprising mainly of the grasses *Schmidtia pappophoroides* and *Stipagrostis uniplumis* which were less in cover in other plant communities. The difference in cover (%) of herbaceous plants between Group 7 (*Catophractes alexandri-Stipagrostis uniplumis*) and Group 5 (*Terminalia sericea-Philoneptera nelsii*) could be due to the fact that Group 7 was dominated by shrub *Catophractes alexandri* whereas Group 5 was dominated by shrubs and trees of *Terminalia sericea* and *Philoneptera nelsii* and the plant species in these two plant communities differered in the way they suppressed herbaceous plants.

According to the results, there was no statistically significant difference in cover (%) of trees and shrubs between the different plant communities. This could be explained by the fact that in the shrub and tree layers, especially in Groups 3, 4 and 8, the dissimilarities between plant communities are associated with changes in plant species dominance rather than existence of different plant species (DWNP 2003; Mishra & Crews 2014). *Catophractes alexandri-Stipagrostis uniplumis* community (Group 7) had the highest cover (%) of shrubs followed by *Dichrostachys cinerea-Grewia flava* community because these two plant communities are mainly made up of the shrubs *Catophractes alexandri* and *Dichrostachys cinerea*, respectively.

Plant Species Richness, Diversity and Evenness of Plant Communities

The results of this study showed no statistically significant difference in plant species diversity (Shannon-Weiner Index) between plant communities. H' ranges from 1.06 to 1.68. In Ngamiland district, Neelo et al. (2013) found that the diversity of woody plants was 2.18 and 1.5 in Shorobe and Xobe, respectively. There was a statistically significant difference in plant species richness between the different plant communities. *Dichrostachys cinerea* community, *Senegalia mellifera* subsp. *detinens-Maytenus species* community and *Catophractes alexandri-Stipagrostis uniplumis* community had lower species richness of 11, 14 and 16, respectively. *Vachellia luederitzii* var. *retinens-Grewia flava* community had a highest number (46) of plant species. This plant community also had the highest average Jaccard and Sorensen distances, as well as Simpson Beta-diversity (Table 5). Jaccard and Sorensen similarity indices are used to study the co-existence of species or similarity of sampling sites (Raimundo and Vargas 1996). Higher dissimilarity index implies higher dissimilarity of sampling sites. The results indicated that there was no statistically significant difference in plant species evenness between the different plant communities. *Brachiaria humidicola-Philoneptera nelsii* community had the highest plant species evenness even though there was no statistically significant difference in plant species evenness between the different plant communities. The evenness values obtained in this study were higher than what Neelo *et al.* (2013) obtained in Ngamiland District.

Conclusion and Recommendations

This study presents a first attempt in using phytosociological approach of classifying and describing plant communities in KGR. It classified and described nine plant communities in KGR. Two plant communities *Heliotropium lineare-Enneapogon desvauxii* and *Senegalia mellifera-Maytenus* species were located in the pans. The other seven communities were located in the plain habitat. The different plant communities suggest that KGR is rich in plant diversity despite being in a semi-arid area, with *Vachellia luederitzii* var. *retinens-Grewia flava* community having the highest number of plant species. The results from this study will help DWNP to develop an updated and well informed management plan with regards to the different plant communities of the reserve. The research will also be a long term record of the characteristics of the plant species in each plant community. It is recommended that surveys of plant communities in KGR should be performed periodically in order to monitor short and long-term changes in plant species composition over time using the results of this study as a baseline.

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