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Herbaceous communities' heterogeneity in the Kalahari sandy soils environment: A case study of Kweneng, Kgatleng Districts and Mahalapye Sub-District of Botswana

Shimane W Makhabu*[1], Koketso Tshireletso[2], Mpho R Setlalekgomo[1], Ednah Kgosiesele[3], Lawrence Akanyang[2], Boipuso Legwatagwata[1], Mackenzie Nsinamwa[2], Zibanani Seletlo[4], Sipho Majaga[2]

[1]*Department of Biological Sciences, Botswana University of Agriculture and Natural Resources, Botswana*

[2]*Department of Range and Forest Resources, Botswana University of Agriculture and Natural Resources, Botswana*

[3]*Department of Wildlife and Aquatic Sciences, Botswana University of Agriculture and Natural Resources, Botswana*

[4]*Department of Animal Science and Production, Botswana University of Agriculture and Natural Resources, Botswana*

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Abstract

Biotic and abiotic factors shape most vegetation communities' structures and composition. Over the years, climatic conditions have been changing. Livestock and wild animal populations have also been dynamic in Botswana's rangelands. Rainfall, temperatures and fire occurrences have also been fluctuating. All these factors affect the diversity and community patterns of vegetation. This study aimed at determining the diversity of vascular plants, how species are associated and distributed within the districts of Kgatleng, Kweneng and the sub-district of Mahalapye in Botswana. Data collection was carried out using line transects and plots measuring 20 m by 50 m. Determination of species identity, number and percentage cover in each plot was done. Soil samples were collected to analyse for pH, EC and particle size. From the data collected and remote sensing protocols, we generated diverse vegetation communities and vegetation maps. Results showed that good species for animal grazing are present in some areas whereas other areas are degraded. *Cenchrus biflorus* Roxb. and *Pavetta harborii* harmful species to the beef industry were noticed in Kweneng and Mahalapye areas. Bush encroaching species were present in the three districts. The area is being invaded by an exotic species, *Verbesina encelioides* which need to be controlled. Measures to reduce degradation and bush encroachment need to be put in place. Thus, the Kweneng district can be classified as being in moderate to good grazing condition. Kgatleng district and Mahalapye subdistrict can be classified as being in poor to moderate grazing conditions.

***Corresponding Author:** Shimane W Makhabu ✉ smakhabu@buan.ac.bw

Introduction

The loss of biodiversity on a global scale is on the rise. The causes of these losses are thought to be both natural and anthropogenic. The anthropogenic factors include overexploitation of resources, habitat loss and pollution. The natural ones include global environmental changes such as climate change, resulting in global warming and increased wildfire incidents. The most affected species whenever areas are disturbed are rare species at high risk of going extinct (Purvis *et al.*, 2000). Rare species have small population sizes, restricted geographical ranges, or narrow habitat tolerances (Leitão *et al.*, 2016). Rare species are at greater sensitivity to natural and anthropogenic disturbances than abundant and widespread species (Davies *et al.*, 2004. Sekercioglu *et al.*, 2008, Leitão *et al.*, 2016).

Plant species diversity is a fundamental component of ecosystem diversity, contributing to the habitat structure and ecosystem function (Srivastava and Vellend 2005, Shameem *et al.*, 2017). Disturbances can alter plant species diversity. Species diversity can decline under high disturbances, while moderate disturbance can enhance or reduce it depending on the species' spatial scale and types (Chaneton and Facelli, 1991, Hamer and Hill 2000, Dumbrell, 2008, Shameem *et al.*, 2017). It has long been established that vegetation communities play a role in regulating climate, conserving biodiversity and providing people's livelihood (Shameem *et al.*, 2017). The human population worldwide has been increasing during the past decades, and Botswana is no exception. Botswana's human population had doubled from less than one million in the 1980s to above 2 million in 2020. Since rangelands provide people's livelihoods, then an increase in population exerts pressure on the rangeland resources. Some people of Botswana are farmers who need land for arable and pastoral farming. Since Botswana is a semi-arid area, farming activities used to be restricted in the eastern part of the country, which receives better rains than the western region. However, technology and affordable prices have enabled the drilling of boreholes for livestock in areas that used to be out of cattle reach. Overgrazing by cattle has now spread from big villages to the arid part of the Kalahari Desert. The floristic inventory and diversity studies in most of Botswana have little been done, if any. So, the impact of disturbances brought by natural factors and anthropogenic factors on vegetation is little known, and the baseline vegetation data is not well documented.

Naturally, Botswana is blessed with the different fauna and flora species that must be nurtured and protected to ensure sustainability. With climate change effects being felt around the globe, what can only be imagined is what would happen to the different species of plants that are both food and habitat to many species of wild animals that support wildlife-based tourism. Documentations of natural resources are in line with International Standards on Biodiversity Conservation. In Botswana, the distribution of trees, shrubs and grasses, especially at the district level, is essential as this serves as baseline information to be referred to in future. In the past, biodiversity studies in Botswana mainly focused on Botswana's northern part (Roodt, 1998; Heath and Heath, 2009), with little being done in the south. Most of the studies done have focused on the woody layer with little reference to the herbaceous layer. It is not proper to ignore the herbaceous layer as it is vital in the ecosystem function, contributing organic matter, aiding in decomposition, controlling soil erosion, and conserving nutrients (Roberts and Gilliam, 1995, Falk *et al.*, 2008). The herbaceous layer changes continuously in space and time due to various factors such as anthropogenic disturbances, livestock grazing, fire and rainfall, which vary in intensity, spatially and duration (Shameem *et al.*, 2011, Shameem *et al.*, 2017). Grazers selectively graze good grass species before they can graze the poor ones. Thus, good grasses decrease with grazing pressure while poor grasses might increase. Some herbaceous layer members, especially the forbs, are known to be toxic to cattle and can be lethal. Activities of farming might bring into the rangeland invading species that may outcompete indigenous ones (Makhabu and Marotsi, 2012).

Kgatleng, Kweneng, and the sub-district of Mahalapye in Botswana are mainly used for arable and pastoral farming. Arable fields are farmed during the rainy period and are used by cattle during the dry period. Cattle in the three districts are farmed either in communal grazing areas or in ranches, and they freely graze in both systems. The area has abundant wild animals, which are herbivores. The animals include the kudu (*Tragelaphus strepsiceros*), impala (*Aepyceros melampus)*, steenbok (*Raphicerus campestris)*, gemsbok (*Oryx gazelle)*, and carnivores such as spotted hyaena (*Crocuta Crocuta)*, brown hyaena (*Hyaena brunnea*), leopard (*Panthera pardus)* and jackals (*Canis* spp.). Recently, even African (*Loxodonta africana)* elephants have been spotted in the area. With an increasing elephant population in the country, there is a possibility that some elephants will soon be residents of the regions. Elephants are known to modify the vegetation (Makhabu, 2005) negatively. Therefore, this study aimed at determining the diversity of vascular plants, how species are associated and distributed within the districts of Kgatleng, Kweneng, and the sub-district of Mahalapye in Botswana. More emphasis is reported on grasses, whereas woody and forbs are reported elsewhere (Tshireletso *et al.*, 2018). The study also aimed at identifying rare plant species that need conservation attention. Also identified were exotic species invading the area and toxic plants lethal to livestock.

Materials and methods

Study Location

The study was conducted in the district of Kweneng, Kgatleng, and Mahalapye district in Botswana (Fig. 1). These districts are in the southeast of Botswana and cover an area of about 67 538 km². Kweneng, Kgatleng, and Mahalapye district cover an area of 35 890 km², 7 960 km², and 23 688 km², respectively. Most of the region of Kweneng is covered by the deep Kalahari sandy soils. On the other hand, apart from the Kalahari sand, Kgatleng and Mahalapye have loamy clay soil sections. The area is semi-arid with an annual rainfall of between 350 to 600 mm, which falls mainly between November and April. Mean daily temperatures in summer used to vary between 25-32.6°C, but these days the Department of Meteorological Services of Botswana reports maximums of up to 39°C. In winter, the temperatures range between 15 - 30°C but at night can go below 10°C.

The study area's vegetation is savanna woodland dominated by species of the genera Grewia, Vachellia, Terminalia, and Philenoptera (Tshireletso *et al.*, 2018). Dominating grass species genera are Aristida, Tragus, Stipagrostis, Urochloa, and Melinis. Forbs include those of genera Walteria, Evolvolus, Talinum, and Hibiscus.

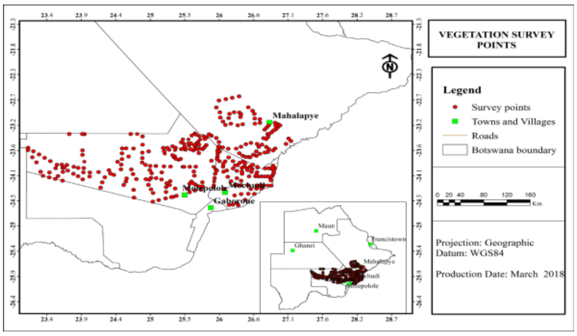

Fig. 1. Location of the study area and sample plots. The map on the bottom right shows the location of the study area in Botswana.

Data Collection

Data collection was done between November 2013 and July 2017 at Mahalapye sub-district, Kgatleng, and Kweneng districts. The research was an inventory involving the use of transects running south-north direction. Along the transects, we established sample points at distances ranging between 5-10 km. The sample points and distances were based on satellite images from Google Earth and printed before going to the field. The sample points coordinates were then entered into a geographical positioning system (GPS) receiver and used for locating the sample points in the area. Adjustments on distances were made in the field when vegetation was either homogenous or heterogenous or fell inside a property. At each sampling point, the located GPS point served as the corner of a 20 m x 50 m sample plot. Within the 20 m x 50 m plot, a smaller 10 m x 10 m plot was established to assess the herbaceous layer. A total of 345 plots were surveyed. The abundance of woody species was determined by counting individuals of each species in the 20 x 50 m plot. Abundance and cover of herbaceous species were done by counting each species' individuals in the 10 x 10 m small plot. The percentage cover of each species was estimated visually.

The plant species' usefulness and detrimental effects were obtained from residents through meetings held with them at their village's traditional gathering places (Dikgotla).

Statistical analysis

Classification of vegetation

The data used for the classification of vegetation was the percentage cover. Cover data (%) of species for all 345 vegetation plots were standardized using relativisation by the maximum in Principal Component Ordination 6 (PCORD) (McCune *et al.*, 2002). The data were then subjected to hierarchical cluster analysis (β linkage, β = -0.25, Sorensen distance) in PCORD 6 (McCune *et al.*, 2002) based on 65 species distributed in the 345 plots for both woody and grass species. Indicator species analysis (Dufrene and Legendre, 1997) was used to define meaningful vegetation communities (McCune *et al.*, 2002). Indicator values (IVS) were assessed for statistical significance using the Monte Carlo technique in PCORD 6. Sorensen distance measure was used to examine differences between vegetation communities using a multi-response permutation procedure (McCune *et al.*, 2002).

Vegetation mapping

Vegetation maps were developed to show the distribution of plant communities. Four wet season scenes of Landsat 8 Operational Land Imager of 2016 were freely downloaded from USGS GloVis (Global Visualization Viewer), at a resolution of 30m. The wet season scenes were used because this is when the vegetation is mature, and the appearance on imageries shows the real picture when foliage is at its maximal production. However, our sampling covered both the dry and wet seasons. The scenes were atmospherically corrected using FLAASH and mosaicked using seamless mosaic in ENVI 5.1. Supervised classification was performed on the Landsat images using the maximum likelihood classifier. Vegetation communities were mapped using ENVI 5.1, and the classification results were imported in ArcMap 10.3 for the finalisation of mapping the communities. The area of interest was extracted by mask, utilising the extent of the study area boundary.

Diversity and species richness

The grass species diversity was determined by calculating the Shannon Diversity Index, sometimes called the Shannon-Wiener Index (Kent and Coker, 1992). The formula used was as follows:

$$Diversity\ H' = -\sum_{i=0}^{s} \mathrm{Pi}(\ln \mathrm{Pi})$$

Where H' = Shannon Diversity Index, s = the number of species, p_i = the proportion of individuals or the abundance of the ith species expressed as a proportion of total abundance

ln = log $base_n$

Species richness was achieved by counting the number of species occurring in each plot in each community. Species richness for a community was taken as the mean number of species for plots in that community. To test whether species richness differs between communities, the data were analysed with a one-way analysis of variance. Means were considered significant at $P < 0.05$. Species richness was reported as the number of species per m^2.

Microsoft Excel and IBM SPSS statistics for windows 23 (IBM Corp., 2015) were used to analyse the data and draw some graphs. Graphs of species richness were generated from the data using SigmaPlot 14.0.

Results

Classification and mapping of woody and herbaceous vegetation species combined

Nine vegetation community classes were generated for the study area when considering herbaceous and woody plant life forms combined. These communities were *Combretum apiculatum- Grewia bicolor, Aristida congesta- Walteria indica, Dichrostachys* *cinerea- Evolvolus alsinoides, Senegalia mellifera- Cadaph, Grewia flava- Rhigozum brevispinosum, Terminalia serecia- Rhynchosia totta, Eragrostis lehmanniana- Schmidtia pappophoroides, Vachellia tortilis- Pavonia burchellii* and *Eragrostis pallens- Ochna pulchra*. The communities were named using the two species with the highest indicator values. These communities were mapped and are as shown in Fig. 2. The dominating community on the western side of the study area is *Eragrostis lehmanniana- Schmidtia pappophoroides*. The southeastern is dominated by a mixture of *Eragrostis pallens- Ochna pulchra* and *Dichrostachys cinerea- Evolvolus alsinoides* (Fig. 2). The northern east part of the study area, which is Mahalapye sub-district, was classified as mainly *Vachellia tortilis- Pavonia burchellii. Senegalia mellifera- Cadaba aphylla* is scattered to the southeast and northern part of the study area.

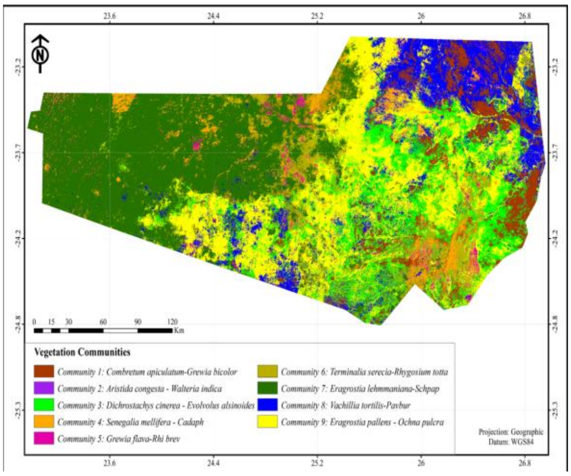

Fig. 2. Vegetation communities in the districts of Kweneng, Kgatleng, and Mahalapye sub-district. Full names of abbreviated species are Schpap- *Schmidtia pappophoroides, Pavbur- Pavonia burchelli, Cadaph- Cadaba aphylla* and *Rhibrev- Rhigozum brevispinosum.*

Dichrostacys cinerea, *Senegalia mellifera* and *Terminalia sericea* are considered as some of the species which fall in the category of species that are bush encroachers. These species' densities were in some plots as high as 150 per Ha, 54 per Ha, and 115 per Ha for *Dichrostacys cinerea*, *Senegalia mellifera* and *Terminalia sericea,* respectively. Other woody species found in high densities include the genera Grewia, Philenoptera, Euclea, Brevispermum, and Ochna. Residents of the areas reported all the woody species to be useful as browse for livestock, especially during the dry season. Leaves of *Philenoptera nelsii* were reported to be significant as livestock forage when grasses were absent in sandy areas.

Classification and mapping of grass species

When considering the grass species on their own, they were classified into ten communities. These were community 1: *Aristida congesta - Tragus racemosa,* community 2: *Eragrostis lehmanniana,* community 3: *Chloris virgata - Eragrostis biflora,* community 4: *Eragrostis pallens- Digitaria eriantha,* community 5: *Eragrostis rigidior- Aristida* sp, community 6: *Stipagrostis uniplumis - Pogonarthria squarrosa,* community 7: *Megaloprochne albescens- Dactyloctenium aegyptium,* community 8: *Enneapogon desvauxii,* community 9: *Anthephora pubescens- Schmidtia pappophoroides* and community 10: *Digitaria velutina- Perotis patens* (Fig.3). The grass species diversities were significantly different ($F_{9,194}$ = 1.987, p = 0.043). The lowest diversity index was for *the Digitaria velutina- Perotis patens* community, while the highest was for *Eragrostis rigidior- Aristida* sp community (Fig 4).

Aristida congesta- Tragus racemosa grass community is not prominent on the map (Fig. 3) but is mostly found in the eastern part of the area covering the Mahalapye sub-district and Kgatleng district. This community had 21 grass species (Fig. 6) and several forbs and woody species. The grass species most abundant in this community included decreasers such as *Stipagrostis amabilis* (Schweick.) De Winter, *Brachiaria nigropedata* (Fical. & Hier) Stapf, and *Anthephora pubescens* Nees with average to very high grazing value (Table 1). The second dominating group of species (Fig. 6) was the annual increaser II, which included *Enneapogon cenchroides* (Roem. Schult.) C.E.Hubb., *Aristida congesta* Roem. & Schult and *Melinis repens* (Wild.) Zizka all being of low to average grazing values (Table 1). The least abundant species was *Cenchrus ciliaris* which is a perennial decrease of high grazing value. Species richness in this community varied from 1 to 9 per $100m^2$ plot (Fig. 5).

The forbs included *Melhania forbesii*, *Hibiscus macrantha* and others. Each species' relative abundances and cover varied from area to area, with *Cenchrus ciliaris* having the least and Stipagrostis species having the highest (Fig. 6).

Grass species communities, namely *Eragrostis lehmanniana, Chloris virgata- Eragrostis biflora, Eragrostis pallens- Digitaria eriantha* and *Eragrostis rigidior- Aristida sp* do not cover a big proportion of the study area as can be seen from the map (Fig. 3). There are, however, amongst the communities with high diversities (Fig. 4) and richness (Fig. 5). *Eragrostis lehmanniana* community had 12 species dominated by perennials *Stipagrostis uniplumis* (Licht.) De Winter and *Eragrostis lehmanniania* Nees (Fig.7) of average to high grazing value, respectively (Table1). *Chloris virgata- Eragrostis biflora* community had 16 grass species dominated by the genus Eragrostis mainly *Eragrostis trichophora* Coss. & Dur and is the only one with the rare species *Triraphis andropogonoides* (Steud.) *E. Phillips* (Fig. 8). The *Eragrostis pallens- Digitaria eriantha* community had 16 species dominated by the genera Stipagrostis and Eragrostis (Fig. 9).

The *Eragrostis rigidior- Aristida* sp community had 14 grass species (Fig. 10). It had *Enneapogon cenchroides* which was absent in most communities except this one, and *Aristida congesta- Tragus racemosa* community (Fig. 6). The *Stipagrostis uniplumis- Pogonarthria squarrosa* community had 21 grass species (Fig 11). The dominating species was the perennial, increaser II of average grazing value *Eragrostis rigidior* Pilg. The *Megaloprochne albescens - Dactyloctenium aegyptium* community had eight grass species (Fig. 12) dominated by *Megaloprotachne albescens* C.E. Hubbard, an increaser II of average grazing value. There was also abundant *Panicum maximum* L. in this community but with a negligible cover because of heavy grazing (Fig. 12). This community had *Eragrostis pallens*, but its relative abundance was very low. *Enneapogon desvauxii* community was present in small pockets of the study area (Fig. 3) mainly associated with pans and was made of 9 species (Fig. 13).

The *Anthephora pubescens- Schmidtia pappophoroides* community had 14 grass species (Fig. 14). The dominant species in terms of cover and abundance were *Anthephora pubescens* Nees and *Stipagrostis uniplumis* (Licht.) De Winter. These species are perennial decreasers, with the former being of high grazing value while the latter is of average grazing value. Other species in this community are *Aristida congesta* Roem. & Schult, *Brachiaria nigropedata* (Fical. & Hier) Stapf, *Digitaria eriantha* Steud., *Enneapogon desvauxii* Beauv., *Eragrostis biflora* Hack. ex Schinz, *Eragrostis lehmanniania* Nees, *Eragrostis nindensis* Fical. & Hiem, *Eragrostis rigidior* Pilg., *Melinis repens* (Wild.) Zizka, *Pogonarthria squarrosa* (Roem. & Schult.) Pilg., *Schmidtia pappophoroides* Steud. and *Urochloa trichorpus* (Hochst.) Stapf. These species are of varying growth form, ecological status and grazing values (Table 1).

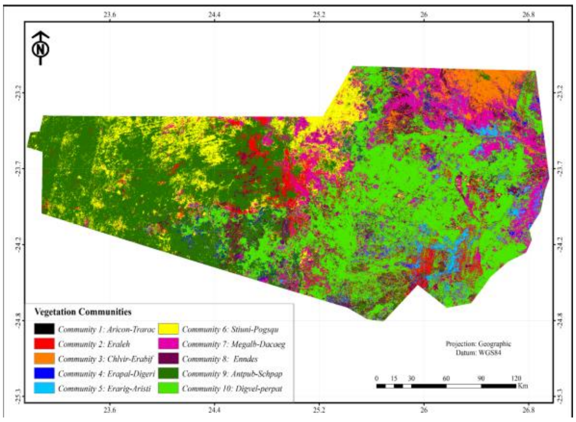

Fig. 3. Grass species communities in the districts of Kweneng, Kgatleng and Mahalapye sub-district. The full names of the grass species communities abbreviated above are *Aristida congesta- Tragus racemosa, Eragrostis lehmanniana, Chloris virgata- Eragrostis biflora, Eragrostis pallens- Digitaria eriantha, Eragrostis rigidior- Aristida* sp, *Stipagrostis uniplumis- Pogonarthria squarrosa, Megaloprochne albescens- Dactyloctenium aegyptium, Enneapogon desvauxii, Anthephora pubescens- Schmidtia pappophoroides* and *Digitaria velutina- Perotis patens.*

The *Digitaria velutina - Perotis patens* community had 13 species dominated by *Digitaria veluntina* (Fig.15).

The dominating species in this community are annuals, namely *Digitaria velutina*, which is of low grazing value, *Perotis patens* Gand, an increaser II of low grazing value, and *Urochloa trichorpus* (Hochst.) Stapf a decreaser of high grazing value (Fig. 14 & Table 1).

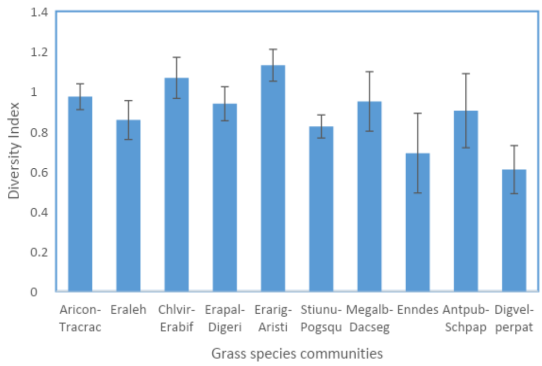

Fig. 4. Grass species diversity in 10 identified grass species communities.

The full names of the grass species communities abbreviated above are *Aristida congesta- Tragus racemosa, Eragrostis lehmanniana, Chloris virgata - Eragrostis biflora, Eragrostis pallens- Digitaria eriantha, Eragrostis rigidior- Aristida* sp, *Stipagrostis uniplumis- Pogonarthria squarrosa, Megaloprochne albescens- Dactyloctenium aegyptium, Enneapogon desvauxii, Anthephora pubescens- Schmidtia pappophoroides* and *Digitaria velutina- Perotis patens.*

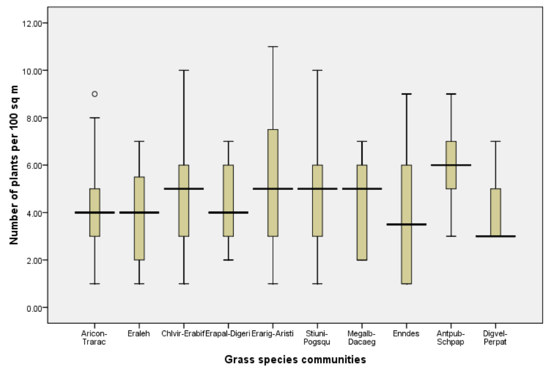

Fig. 5. Grass species richness in 10 identified grass species communities.

The full names of the grass species communities abbreviated above are *Aristida congesta- Tragus racemosa, Eragrostis lehmanniana, Chloris virgata- Eragrostis biflora, Eragrostis pallens- Digitaria eriantha, Eragrostis rigidior- Aristida* sp, *Stipagrostis uniplumis- Pogonarthria squarrosa, Megaloprochne albescens- Dactyloctenium aegyptium, Enneapogon desvauxii, Anthephora pubescens- Schmidtia pappophoroides* and *Digitaria velutina- Perotis patens.*

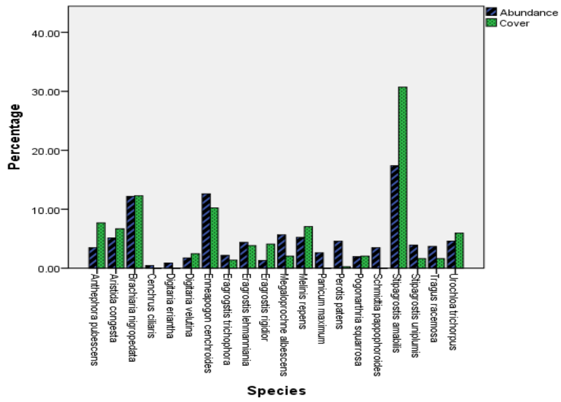

Fig. 6. Relative abundance and the cover of grass species in *Aristida congesta- Tragus racemosa* grass community.

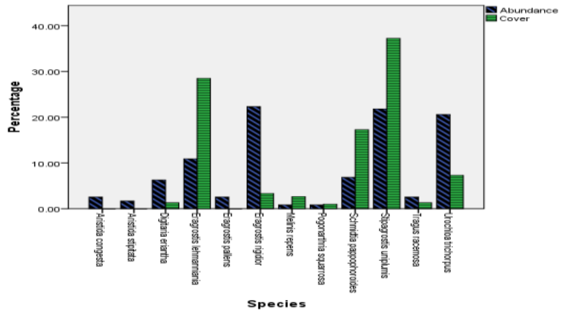

Fig. 7. Relative abundance and the cover of grass species in *Eragrostis lehmanniana* grass community.

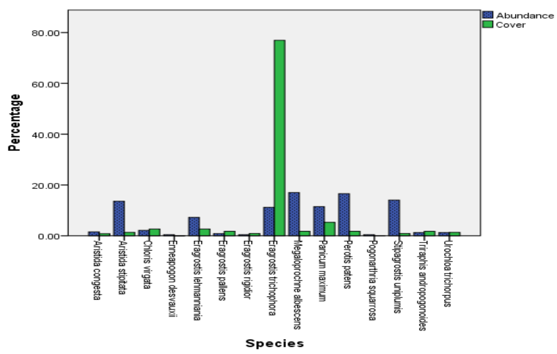

Fig. 8. Relative abundance and the cover of grass species in *Chloris virgata- Eragrostis biflora* grass community.

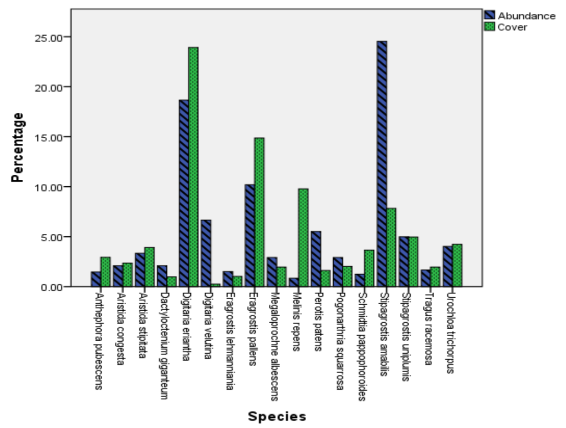

Fig. 9. Relative abundance and cover of grass species in *Eragrostis pallens- Digitaria eriantha* grass community.

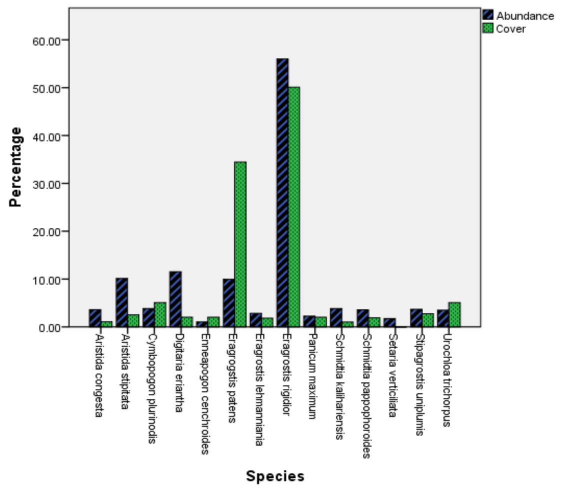

Fig. 10. Relative abundance and the cover of grass species in *Eragrostis rigidior- Aristida* sp grass community.

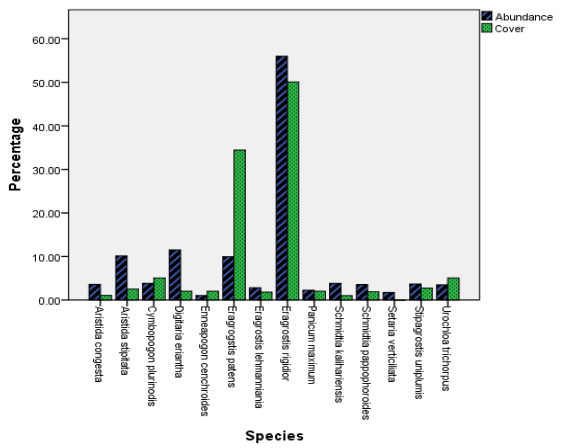

Fig. 11. Relative abundance and cover of grass species in *Stipagrostis uniplumis- Pogonarthria squarrosa* grass community.

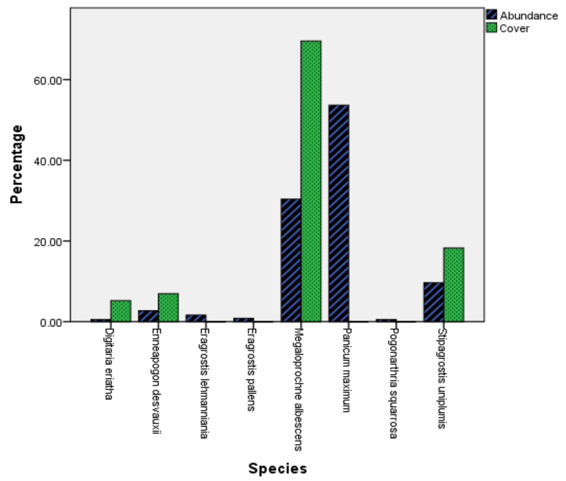

Fig. 12. Relative abundance and the cover of grass species in *Megaloprochne albescens- Dactyloctenium aegyptium* grass community.

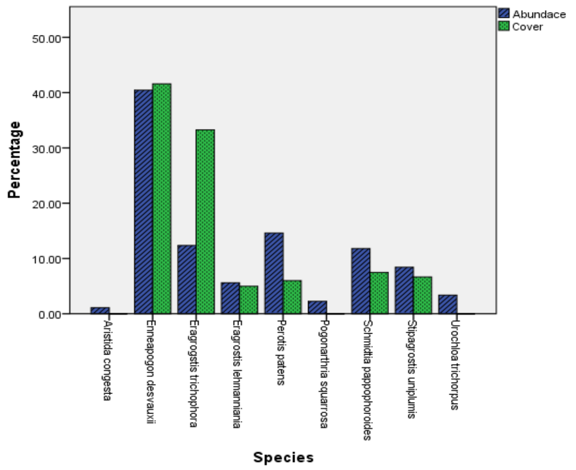

Fig. 13. Relative abundance and the cover of grass species in *Enneapogon desvauxii* grass community.

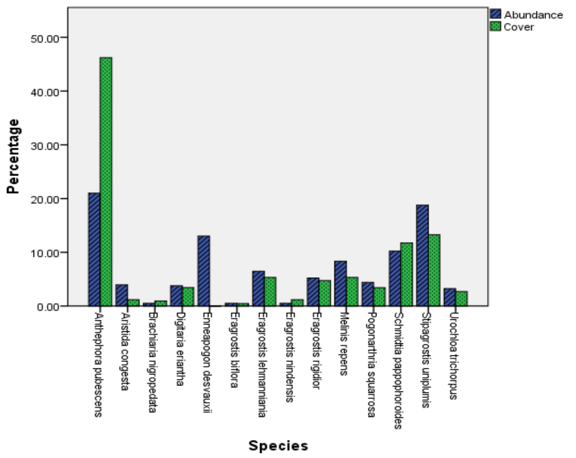

Fig. 14. Relative abundance and the cover of grass species in *Anthephora pubescens- Schmidtia pappophoroides* grass community.

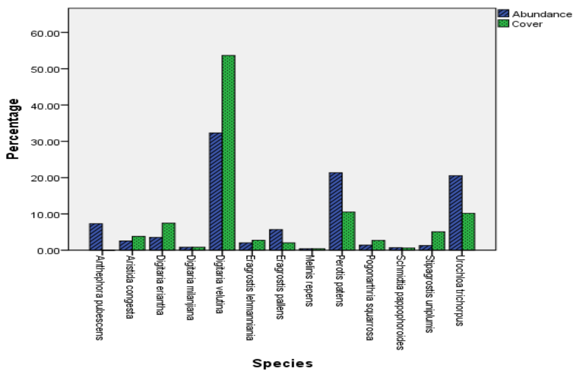

Fig. 15. Relative abundance and the cover of grass species in *Digitaria velutina - Perotis patens* grass community.

Spatial distribution of grass communities

The grass species communities are not evenly distributed within the study area. Four broad blocks were identified within the area based on the community map produced (Fig. 3). These four blocks were; Block A - western Kweneng, B - north-central Kweneng, C - eastern Kweneng, and some portion of Kgatleng while D - mostly Mahalapye sub-district and some portion of Kgatleng (Fig. 16).

The major grass communities that make Block A are community 9: *Anthephora pubescens- Schmidtia pappophoroides* and community 6: *Stipagrostis uniplumis - Pogonarthria squarrosa* (Fig. 16). The major grass species in these communities are perennials that might be decreasers or Increasers II of average to high grazing value. The area had less encroaching woody species (Fig. 2). Block A can be classified as being in good condition. Block B is mostly composed of 3 communities which are community 6: *Stipagrostis uniplumis- Pogonarthria squarrosa,* community 7: *Megaloprochne albescens- Dactyloctenium aegyptium* and community 2: *Eragrostis lehmanniana* (Fig. 16). Grass species in these communities are both perennial and annual increaser II of average grazing value. The area could be described as being in a moderate condition. Block C is made of community 10: *Digitaria velutina - Perotis patens* grass species community (Fig. 16). The dominating grasses in it are annual, increaser II and being of low grazing value. The woody species found in the area include bush encroachment species *Dichrostacys cinereal* and *Senegalia mellifera* (Fig.2). These are the characteristics of rangeland in poor condition. Block D consist of community 3: *Chloris virgata- Eragrostis biflora* and community 7: *Megaloprochne albescens- Dactyloctenium aegyptium*. It's a block with perennial/annual increaser II species of average grazing value. The dominating woody species include those in genus Vachellia that are bush encroaching species. The area is in poor condition.

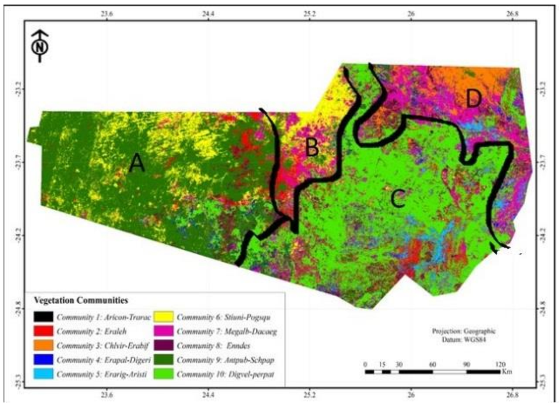

Fig. 16. Broad blocks which combine grass species communities. Block A is western Kweneng, B is north central Kweneng, C is eastern Kweneng, and some portion of Kgatleng while D is most Mahalapye sub-district and some portion of Kgatleng. The full names of the grass species communities abbreviated above are *Aristida congesta- Tragus racemosa, Eragrostis lehmanniana, Chloris virgata- Eragrostis biflora, Eragrostis pallens- Digitaria eriantha, Eragrostis rigidior- Aristida* sp, *Stipagrostis uniplumis- Pogonarthria squarrosa, Megaloprochne albescens- Dactyloctenium aegyptium, Enneapogon desvauxii, Anthephora pubescens- Schmidtia pappophoroides* and *Digitaria velutina- Perotis patens.*

Uses of some grass species

During meetings held with residents of Sojwe, Hatsalatadi, and their surroundings, grazing by livestock was reported to be the major use of most of the grass species. Livestock in the area is free-ranging. Some species were reported to be used for thatching huts. These species were *Aristida congesta, Aristida meridionalis, Aristida adscensionis, Cymbopogon* spp., *Eragrostis pallens, Pogonarthria* *squarrosa, Stipagrostis uniplumis* and *Stipagrostis amabilis*. Species used for thatching are also used for making brooms. Some grass species are used for medication, such as *Eragrostis rigidior* whose roots are boiled to heal stomach pains. *Melinis repens* is used to relieve headaches. Grass species are considered weeds when they grow on arable fields. *Noxious and exotic herbaceous species*. The Kweneng district and parts of Mahalapye had *Pavetta harborii* S.Moore, which was seen in some areas but was never spotted in any sampled plots. *Pavetta harborii* belong to the family Rubiaceae or coffee family, subfamily Ixoroideaea and tribe Pavetteae (Verstraete *et al.*, 2011).

Exotic grass species *Cenchrus biflorus* Roxb. was spotted along roads between farms of Western sandveld in the Mahalapye sub-district. It is a member of the Poaceae family, and its common English name is 'Indian sandbur'.

An exotic forbs *Verbesina encelioides* (Cav.) Benth. & Hook. f. ex A. Gray was seen in Koodibeleng in Mahalapye subdistrict and Ngware in Kweneng District. *Verbesina encelioides* is in the Asteraceae family, and its common name is 'golden crownbeard'. It is an erect annual native to north and south America.

Table 1. List of grass species identified in different communities of the study area. The numbers under community present represent the followings: 1= *Aristida congesta- Tragus racemosa,* 2 = *Eragrostis lehmanniana,* 3 = *Chloris virgata- Eragrostis biflora,* 4 = *Eragrostis pallens- Digitaria eriantha,* 5 = *Eragrostis rigidior- Aristida* sp, 6= *Stipagrostis uniplumis- Pogonarthria squarrosa,* 7 = *Megaloprochne albescens-Dactyloctenium aegyptium,* 8 = *Enneapogon desvauxii,* 9 = *Anthephora pubescens- Schmidtia pappophoroides* and 10 = *Digitaria velutina- Perotis patens.*

Scientific Name	Common name	Growth Form	Ecological status	Grazing value	Community Present
Anthephora pubescens Nees	Wool grass	Perennial	Decreaser	High	1, 4,6,9,10
Aristida congesta Roem. & Schult	Tassel three-awn	Annual /perennial	Increaser II	Fair/Low	1,2,3,4,5,6,8,9,10
Aristida stipitata Hack.	Long-awned three awn	Perennial	Increaser II	Low	2,3,4,5,6
Brachiaria nigropedata (Fical. & Hier) Stapf	Spotted signal grass	Perennial	Decreaser	Very high	1,6,9
Cenchrus ciliaris L.	Blue buffalo	Perennial	Decreaser	High	1, 6
Chloris virgata Schwarz	Feather-top chloris / old land grass	Annual	Increaser II	High	3
Cymbopogon plurinodis (Stapf.) Stapf ex Burtt Davy	Bitter turpentine	Perennial	Climax	High	5
Dactyloctenium giganteum Fischer & Schweick	Giant crowfoot	Annual	Pioneer	Fair	4
Digitaria eriantha Steud.	Common finger grass	Annual	Decreaser	Very high	1,2,4,5,6,7,9,10
Digitaria milanjiana	Makarikari finger grass	Perennial	Decreaser	Very high	10
Digitaria velutina	Velvet/long-plumed finger grass	Annual		Low	1,4,6,10
Enneapogon cenchroides (Roem. Schult.) C.E.Hubb.	Common nine-awned grass	Annual	Increaser II	Average	1,5
Enneapogon desvauxii Beauv.	Eight-day grass	Perennial	Increaser II	Average	3,7,8,9
Eragrostis patens Oliv.	Foot path love grass	Annual			5
Eragrostis rigidior Pilg.	Broad curly leaf	Perennial	Increaser II	Average	1,2,3,5
Eragrostis trichophora Coss. & Dur.	Hairy love grass	Perennial	Increaser II	Average	1,3,6,8
Eragrostis biflora Hack. ex Schinz	Shade eragrostis	Annual	Increaser II	Low	9
Eragrostis lehmannniania Nees	Lehmann's love grass	Perennial	Increaser II	High	1,2,3,4,5,6,7,8,10
Eragrostis nindensis Fical. & Hiem	Wether love grass	Perennial	Increaser II	Average	6
Eragrostis pallens Hack.	Broom love grass	Perennial	Increaser II	Low	2,3,4,6,7,10
Megaloprotachne albescens C.E. Hubbard		Annual	Increaser II	Average	1,3,4,6,7
Melinis repens (Wild.) Zizka	Natal red top	Annual/ perennial	Increaser II	Low	1,2,4,6,9,10

Scientific Name	Common name	Growth Form	Ecological status	Grazing value	Community Present
Panicum maximum L.	Small/white buffalo grass	Perennial	Decreaser	Very high	1,3,5,6,7
Perotis patens Gand.	Cat's tail grass/bottlebrush	Annual	Increaser II	Very low	1,3,46,8,10
Pogonarthria squarrosa (Roem. & Schult.) Pilg.	Herringbone grass	Perennial	Increaser II	Very low	1,2,3,4,6,7,8,9,10
Schmidtia kalahariensis Stent	Kalahari sour grass	Annual	Increaser II	Low	5
Schmidtia pappophoroides Steud.	Kalahari sand quick	Perennial	Decreaser/Increaser II	High	1,2,4,5,6,8,9,10
Setaria verticiliata (L.) Beauv.	Bur bristle grass	Annual	Increaser II	Low	5
Stipagrostis amabilis (Schweick.) De Winter	-	Perennial	Decreaser		1,4,6
Stipagrostis uniplumis (Licht.) De Winter	Silky bushman grass	Perennial	Decreaser	Average	1,2,3,4,5,6,7,8,9,10
Tragus racemosa L.		Annual	Increaser II	Low	1,2,4,6
Triraphis andropogonoides (Steud.) E. Phillips.		Perennial			3
Urochloa trichorpus (Hochst.) Stapf	Hairy signal grass	Annual	Decreaser	High	1,2,3,4,5,6,8,9,10

Discussion

The study has shown that the area has varied species of herbaceous and woody species whose composition differs from one area to another. Four major vegetation blocks of vegetation categories were generated, but there were no sharp lines separating them. This was expected since the area is in the savannah ecosystem, which is characterised by the dominance of trees and grasses (Wiegand *et al.*, 2006). The differences in species might be attributed to varying microhabitats. Rapid microclimatic and edaphic variations overlap each other due to a number of environmental and anthropogenic activities (Khan *et al.*, 2011). The soil type varies spatially, while rainfall varies spatially and temporally. This condition, coupled with hot summer temperatures the area receives, creates microhabitats, thereby affecting the structure and composition of vegetation. Soil types in most areas of Kgatleng and Mahalapye on the eastern side of the study area are loam to clay with some sections with deep Kalahari sandy soils, whereas in Kweneng, the bulk of the area is covered with Kalahari sandy soils with pockets of clay to loam soils. Plant species growth is correlated to soil types, with some preferring sandy soils while others prefer other soil types. In sub-tropical savannas, water limits the growth of plants due to low rainfall received and hot temperatures. The co-existence of tree and shrub can be explained by Walter's two-layer hypothesis (Walter, 1971; Walker *et al.*, 1981), which states that water is the limiting factor for both woody and grass growth. According to the hypothesis, grasses use moisture on the topsoil while woody species use sub-soil moisture. When the area is devoid of grasses due to factors such as overgrazing, then more water becomes available to woody species leading to bush encroachment (Walter, 1971; Walker *et al.*, 1981). The southeastern part of the study area was dominated by a mixture of *Eragrostis pallens- Ochna pulchra* and *Dichrostachys cinerea- Evolvolus alsinoides*, and this agrees with Tshireletso *et al.* (2018) finding that the eastern part of the Kgatleng district was dominated by *Dichrostachys cinerea*. *Dichrostachys cinerea* is considered an encroaching species (Moleele and Perkins, 1998; Moleele, 2002; Makhabu, 2011) and might be encroaching due to overgrazing in the area. Encroaching species compete with the grass species but are important to browsing goats and might sustain cattle during the dry season when grasses are absent, and cattle resort to browsing (Mphinyane *et al.*, 2015).

As for the grass community, the same southeastern part of the study area was dominated by *the Digitaria velutina - Perotis patens* community. The soil type in the area is mainly loam to clay soils with pockets of sandy areas and is usually referred to as the hardveld. This differs from the sandveld, which is mostly with deep Kalahari sandy soils found in the north and west parts of the study area. *Dichrostachys cinerea* is a woody species that grow on a variety of soil types but is mostly associated with impoverished soils; hence it usually indicates that the area is disturbed (Coates Palgrave, 2000). Similarly, grass species *Digitaria velutina* is an annual species that usually grows on disturbed soils (Van Oudtshoorn, 2014) as well as the forb *Evolvolus alsinoides* (Roodt, 2011). The disturbance could be by overgrazing or when cultivated fields are left unploughed for some time or when the ground is bare due to drought. In the study area, the eastern part of it was overgrazed and had experienced low rainfalls. The area needs to be monitored so that bushes should not encroach the area that might lead to the area with less grass cover dominated by those of poor grazing value, such as *D. velutina*. Woody plant encroachment reduces the carrying capacity for domestic livestock in savannas (Wiegand *et al*., 2006). Another part of the study area with species that usually grow in disturbed areas in the northeast, which is dominated by grass species such as *Megaloprochne albescens, Dactyloctenium aegyptium* and *Chloris virgata* and woody species such as *Vachellia tortilis*. So, woody and herbaceous species that are usually found in disturbed areas were found living side by side. The dominance of the area with poor grass species might be due to that cattle prefer good grass and will graze poor grasses when desperate during the absence of good grasses (Mphinyane *et al*., 2015). The Kgatleng district and Mahalapye subdistrict part of the study area can be described as being poor to moderate grazing condition. Thus, pastoral farmers of the area should brace themselves to stock at low levels and to supply their livestock with supplementary feed during drought years. They should also anticipate high livestock mortalities due to lack of grazing during drought years.

The west and northwest of the study area, which was predominantly on sandy soils, had the dominating species being those which are generally associated with undisturbed areas such as *Anthephora pubescens*. It also had perennial grass species such as *Stipagrostis uniplumis* and *Schmidtia pappophoroides*. This agrees with Lori *et al*. (2019), who found out that one of the communities was *Schmidtia pappophoroides - Stipagrostis uniplumis* in Khutse Game Reserve also in the Kweneng district.

The study area had *Pavetta harborii*, which is lethal to cattle when they eat it and then drink water. It is reported to cause a disease called gousiekte (literally "quick disease"), a fatal cardiotoxicosis of ruminants characterised by acute heart failure four to eight weeks after ingestion (Verstraete *et al*., 2011). *Pavetta harborii* contains pavettamine, the compound suspected to be the cause of the cardiotoxicosis (Ellis *et al*., 2010; Verstraete *et al*., 2011). This plant species has distinct bacterial nodules in its leaves. Available evidence suggests that the bacteria in nodules of *P. harborii* is Burkholderia (Verstraete *et al*., 2011). The disease gousiekte, which affects cattle after they have eaten *P. harborii*, may be due to a combination of bacteria and pavettamine chemical compound. Cattle normally eat *P. harborii* when the area is without grasses due to overgrazing or drought. Farmers in the study area reported that when cattle suspected of having eaten *P. harborii* are denied water, they may recover and not die. The disease kills cattle so fast that some cattle are just found dead without having shown signs of sickness. Therefore, avoidance of overgrazing is important to avoid cattle mortalities due to *P. harborii*.

Two exotic species, *Verbesina encelioides* and *Cenchrus biflorus,* were recorded in the study area. The ideal habitats for *V. encelioides* are open areas and disturbed habitats (PIER, 2013). In the study area it was noticed along roads, arable fields and overgrazed areas within villages. In northern India, *V. encelioides* is a common weed in fields of maise, barley, rice, peanut and millet. The plant species contains a toxic component called galegine, which poison livestock, especially sheep. However, this was not reported in the study area. *Verbesina encelioides* can harbour pests. *Verbesina encelioidesdis* has allelopathic effects inhibiting native plants growth. It can dominate in an area out-competing native species that are grazed by animals. Control of *V. encelioides* includes mechanical and chemical methods.

The noxious *C. biflorus* is believed to originate from India. It is mostly found in disturbed areas. It is regarded as noxious because of its objectionable burs, which adhere to skins of animals, clothes, shoes and machinery (Makhabu, 2012). The burs might also cause ulcers on the mouths of livestock that graze them. It also makes it difficult in working on fields it has invaded and is costly to weed it out. Mechanical and chemical means are sometimes used to control it. It is therefore important for residents of the study area to be aware of problems it can bring and control it before it invades the whole area.

Environmental and anthropogenic factors appear to determine the vegetation species composition. One of the anthropogenic factors that need to be put under control is overgrazing. The bulk of the study area is under a communal grazing system where stocking rates are not controlled. Also, as the human population increases, more land is converted into farms and arable fields for food production and economic benefits. However, this puts stress on natural resources such as grasses altering vegetation diversity. This is not good for the health of the ecosystem. Allocation of land for farming and other activities need to consider the fragility of the Kalahari ecosystem. The livestock carrying capacity of the land need to be considered whenever land is allocated so that the land resources should be used sustainably.

Conclusion

It is evident that the study area is rich in species diversity, but the activities of man, his livestock, and drought harm it. Unwanted species are also found in the area. Western Kweneng district is still in a better grazing condition than Kgatleng district and Mahalapye sub-district. Urgent management measures such as the control of livestock stocking rates need to be put in place for the sustainable use of the vegetation resources of the area. There is a need to curb the invasion of the area by exotic species such as *Verbesina encelioides* and *Cenchrus biflorus*. Where exotic species are noticed, they should be eliminated by either mechanical or chemical methods. To avoid livestock mortalities due to *Pavetta harborii*, there is a need to limit the number of livestock in the area to be in the conservative carrying capacities. *Pavetta harborii* can also be controlled by mechanical or chemical means to reduce their encounter with livestock.

Declaration of Competing Interest

The authors have no conflict of interest.

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References

Chaneton EJ, Facelli JM. 1991. Disturbance effects on plant community diversity: Spatial scales and dominance hierarchies. Plant Ecology **93(2),** 143-155.

Coates Palgrave KC. 2002. Trees of Southern Africa 3rd ed. Struik Publishers, South Africa.

Davies KF, Margules CR, Lawrence JF. 2004. A synergistic effect puts rare, specialised species at greater risk of extinction. Ecology **85,** 265-271.

Dufrene M, Legendre P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological monographs **67,** 345-366.

Dumbrell AJ, Clark EJ, Frost GA, Randell TE, Pitchford JW, Hill JK. 2008. Changes in species diversity following habitat disturbance are dependent on spatial scale: theoretical and empirical evidence. Journal of Applied Ecology **45(5),** 1531-1539.

Ellis CE, Naicker D, Basson KM, Botha CJ, Meintjes RA, Schultz, RA. 2010. A fluorescent investigation of subcellular damage in H9c2 cells caused by pavetamine, a novel polyamine. Toxicology in Vitro **24,** 1258-1265.

Falk KJ, Burke DM, Elliott KA, Holmes SB. 2008. Effects of single-tree and group selection harvesting on the diversity and abundance of spring forest herbs in deciduous forests in south western Ontario. Forest Ecology and Management **255,** 2486-2494.

Field D. 1976. A Handbook of Common Grasses in Botswana. Ministry of Agriculture, Gaborone, Botswana.

Hamer KC, Hill JK. 2000. Scale-dependent effects of habitat disturbance on species richness in tropical forests. Conservation Biology **14(5),** 1435-1440.

Heath A, Heath R. 2009. Field guide to the plants of Northern Botswana including the Okavango. KEW publishing, UK.

IBM Corp. 2015. IBM SPSS Statistics for Windows, Version 23.0. IBM Corp, Armonk, NY.

Leitão RP, Zuanon J, Villéger S, Williams SE, Baraloto C, Fortunel C, Mendonc¸a FP, Mouillot D. 2016. Rare species contribute disproportionately to the functional structure of species assemblages. Proc. R. Soc. B 283, 20160084. http://dx.doi.org/10.1098/rspb.2016.0084

Lori T, Ditlhogo MK, Setshogo MP, Koosaletse-Mswela P. 2019. Classification, description and mapping of the vegetation in Khutse Game Reserve, Botswana. Botswana Journal of Agriculture and Applied Science **13(2),** 8-23.

Makhabu SW, Marotsi B. 2012. Changes in herbaceous species composition in the absence of disturbance in a *Cenchrus biflorus* Roxb. Invaded area in central Kalahari Game Reserve, Botswana. International Journal of Ecology 2012*, 6 pages.* http://www.hindawi.com/journals/ijeco/2012/174813/

Makhabu SW. 2005. Interactions between woody plants, elephants and other browsers in the Chobe Riverfront, Botswana. PhD Thesis, Norwegian University of Science and Technology, Trondheim, Norway. https://ntnuopen.ntnu.no/ntnu-xmlui/bitstream/handle/11250/244593/124364_FULLTEXT01.pdf?sequence=1&isAllowed=y

Makhabu SW. 2011. Advantages and disadvantages of various encroachment methods: A Riview. UNISWA Journal of Agriculture **15,** 117 - 124.

McCune B, Grace JB, Urban DL. 2002. Analysis of ecological communities. MiM Software design, Gleneden Beach, OR, USA.

Moleele N, Perkins J. 1998. Encroaching woody plants species and boreholes: is cattle density the main driving factor in the Olifants Drift communal grazing lands, Botswana? Journal of Arid Environments **40,** 425 - 253

Moleele NM. 2002. Encroacher woody plant browse as feed for cattle. Cattle diet composition for three seasons at Olifants Drift, southeast Botswana. Journal of Arid Environments **40,** 255 - 268.

Mphinyane WN, Tacheba G, Makore J. 2015. Seasonal diet preference of cattle, sheep and goats grazing on the communal grazing rangeland in the Central District of Botswana. African Journal of Agricultural Research **10,** 2791-2803.

PIER. 2013. Pacific Islands Ecosystems at Risk. Honolulu, Hawaii, USA: HEAR, University of Hawaii. http://www.hear.org/pier/index.html.

Purvis A, Agapow PM, Gittleman JC, Mace GM. 2000. Non-random extinction and the loss of evolutionary history. Science **288,** 328-330.

Roberts MR, Gilliam FS. 1995. Patterns and mechanisms of plant diversity in forested ecosystems: Implications for forest management. Ecological Applications **5,** 969-977.

Roodt V. 1998. Trees and Shrubs of the Okavango Delta. Shell oil Botswana, Gaborone, Botswana.

Roodt V. 2011. Wild flowers, waterplants and grasses of the Okavango delta and Kalahari. Veronica Roodt publications, Hartebeespoort.

Sekercioglu CH, Schneider SH, Fay JP, Loarie SR. 2008. Climate change, elevational range shifts, and bird extinctions. Conserv. Biol **22,** 140-150. (doi:10.1111/j.1523-1739.2007.00852.x).

Shameem SA, Kangroo IN, Bhat GA. 2011. Comparative assessment of edaphic features and herbaceous diversity in lower Dachigam national park, Kashmir, Himalaya. Journal of Ecology and the Natural Environment **3(6),** 196-204.

Shameem SA, Mushtaq H, Wani AA, Ahmad N, Hai A. 2017. Phytodiversity of herbaceous vegetation in disturbed and undisturbed forest ecosystems of Pahalgam Valley, Kashmir Himalaya, India. British Journal of Environment & Climate Change **7,** 148-167.

Srivastava DS, Vellend M. 2005. Biodiversity-ecosystem function research: Is it relevant to conservation? Annual Review of Ecology, Evolution and Systematics **36,** 267-294.

Tshireletso K, Makhabu SW, Nsinamwa M, Kgosiesele E, Setlalekgomo MR, Seletlo Z, Majaga S, Legwatagwata B. 2018. Diversity patterns of woody vegetation of Kgatleng District, Botswana. In: *Climate change and adaptive land management in southern Africa - assessments, changes, challenges, and solutions* (ed. by Revermann, R., Krewenka, K.M., Schmiedel, U.,Olwoch, J.M., Helmschrot, J. & Jürgens, N.), pp. 416-423, *Biodiversity & Ecology* 6, Klaus Hess Publishers, Göttingen & Windhoek. doi:10.7809/b-e.00353.

Van Oudtshoorn F. 20144. *Guide to Grasses of Southern Africa*, Briza Publications, Pretoria, South Africa, 4th edition.

Verstraete B, Van Elst D, Steyn H, Van Wyk B, Lemaire B, Smets E, Dessein S. 2011. Endophytic bacteria in toxic South African plants: identification, phylogeny and possible involvement in gousikte. PLoS One **6(4),** 1-13. (doi: 10.1371/journal. pone.0019265).

Walker BH, Ludwig D, Holling CS, Peterman RM. 1981. Stability of semi-arid savannah grazing systems. Journal of Ecology **69,** 473 - 498.

Walter H. 1971. Ecology of Tropical and Subtropical vegetation. Oliver & Boyd, Edinburgh.

Wiegand K, Saltz D, Ward D. 2006. A patch-dynamics approach to savannah dynamics and woody plant encroachment - Insights from an arid savanna. Perspectives in Plant Ecology, Evolution and Systematics **7,** 229 - 242.