

*Full Length Research Paper*

# Diversity, stand structure and regeneration status of woody species, and spatial cover of herbaceous species in Mokolodi Nature Reserve, Southeastern Botswana

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**Diversity of woody and herbaceous species, stand structure and regeneration status of woody species, spatial cover of the herbaceous species as well as nutritional values of woody and herbaceous species were studied in Mokolodi Nature Reserve (MNR), Botswana. Ten 1 ha quadrats were used to collect data, and in each quadrat, ten 1 m<sup>2</sup> plots were used to estimate the spatial cover of herbaceous species. MNR exhibited high species, genera and family richness, but low diversity and evenness. The diversity and evenness values of woody species were 1.44 and 0.38, respectively. Density of woody species was about 4,785 ha<sup>-1</sup>. Most of the woody species demonstrated unstable population structures and hampered natural regeneration. The spatial cover of all herbaceous species was only 44.67% ha<sup>-1</sup>. The nutritional values of the species ranged between low and high while there was no information on the nutrition values for 16 and 55% of the woody species and herbaceous species, respectively. The dominance values of woody species indicate inadequate number of big-sized trees, and that MNR is still at the recovery phase. For 68% of the woody species, natural regeneration is hampered. Future research topics and recommendations on the future management of MNR are proposed.**

**Key words:** Density, dominance, evenness, frequency, importance value index, nutritional value, over grazing, population structure, soil erosion, species richness.

## INTRODUCTION

Botswana has one of the highest percentages of protected land in the world, with around 37.2% of the land

seen as either totally or partially protected areas, namely national parks, nature and forest reserves and nature

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**Figure 1.** Map of Botswana showing the location of Mokolodi where Mokolodi Nature Reserve is located (source: [http://www.safaripatrol.com/pics\\_map/botswana.gif](http://www.safaripatrol.com/pics_map/botswana.gif), accessed on 13-07-2016).

sanctuaries (World Bank, 2012). Most of these proclaimed protected areas in Botswana, are located in the central, northern and southwestern parts of the country, which are far from the main centers of the country's human population (Figure 1). Thus, the dispersal of settled areas has resulted in a large percentage of the population in Botswana growing up without having an understanding or appreciation for their natural environment (Mosothwane and Ndwapi, 2012). In 1991, the Mokolodi Wildlife Foundation (MWF), a registered non-for-profit organisation, was created with a vision of establishing a nature reserve in close proximity to Botswana's capital and largest city, Gaborone, thereby, providing a platform for environmental education (Martin and Njiru, 2006). Following a national and international fund raising drive, which resulted in securing sufficient funds, MWF embarked on a project aimed at developing the Mokolodi Nature Reserve (MNR). The land encompassed by MNR was originally a freehold cattle farm until 1986 (Schroder, 2001). During this time it appears to have been

overstocked and, therefore, overgrazed. Lower than average rainfall during the 1980's and early 1990's also had an impact on the veld condition. Although the MNR is slowly recovering, the game species concentrate on the flatter, lower lying areas of the reserve since the grasses are more palatable as the soils contain more mineral salts, which are leached from the higher lying areas. This has led to selective overgrazing, and the low amounts of rainfall experienced in the 1980's and 1990's have added to this problem.

As stated above, historically, MNR has been used for cattle ranching with no strict management principles and, hence, the intensity of cattle grazing was high. The high stocking rates lead to overgrazing and its associated effects, such as soil erosion, land degradation, reduced risk of fire and bush encroachment. Erosion has negative effects on an ecosystem, such as loss of topsoil, which prevents vegetation establishment, damage to infrastructure, that is, roads and fences, and reduction of aesthetic value of the site. Fire is an integral component

of savannah ecology. Thereof, its absence, in combination with overgrazing, allows the woody layer to become dominant (bush encroachment), with associated negative effects, such as loss of biodiversity, a reduction in carrying capacity and reduced visibility on game drives. Mesic savannas are evolutionary unstable systems that change in response to disturbances, such as fire and herbivory, and most importantly, fluctuating rainfall, on both regional- and local-scale (van Rooyen, 2010; David-Andersen, 2012). Thus, the vegetation in the reserve is expected to be in constant spatial and temporal fluctuation. This, nevertheless, does not exclude management from optimizing the condition of the veld - through sound management practice - and mitigating the negative anthropological effects that MNR has inherited from past generations (David-Andersen, 2012).

The vegetation in MNR was incapable of recovering due to long period of overgrazing, leading to widespread land degradation, which, in turn, is manifested in two main forms, that is, bush encroachment and soil erosion. Bush encroachment has removed the natural veldt of palatable grass species, whilst certain invading species, including *Dichrostachys cinerea* (L.) Wight and Arn. and *Acacia mellifera* (Vahl) Benth., provide poor browsing for game animals (Table 1). These unpalatable and naturally aggressive plant species have the ability to out-compete natural grasses for light (due to dense canopies) and water (due to extensive shallow root systems), converting the veldt into a barren, sparsely populated, rangeland (Orwa et al., 2009). With the aggressive species outcompeting the grasses, the soil surface has become vulnerable to soil erosion, which peaks, especially, during rainfall events, owing to low rates of infiltration due to the lack of vegetative cover. The exposed topsoil substrate is washed away by the surface water, removing the valuable nutrients contained within. In extreme cases, soil erosion leads to the formation of deep gullies, and there are numerous examples of this across the Reserve. Gullies that are left uncontrolled grow and spread further across the rangeland instigating further degradation. Thus, land degradation has been a serious problem in MNR, which requires appropriate attention, research, continuous monitoring and measures targeting rehabilitation/restoration of the land and natural vegetation.

After the establishment of MNR, the vegetation has been assessed annually (Schroder, 2001; Martin and Njiru, 2006; Batura et al., 2007; Njiru, 2008, 2009, 2010, 2011; David-Andersen, 2012), mainly, to determine its carrying capacity in relation to the number of wild animals it has been supporting. A long-term study has also been underway in MNR since 1997 through the the establishment of experimental area exclosures to exclude large herbivores with similar areas left open as control. Since then, different studies (Flyman, 1999; Källér, 2003; Bengtsson-Sjörs, 2006; Leife, 2010; Herrera, 2011) were carried out to investigate the fate of seedlings of woody

plants in the presence and absence of large herbivores (Flyman, 1999), growth pattern and reproduction of woody vegetation (Källér, 2003) and establishment and survival of woody seedlings (Bengtsson-Sjörs, 2006), both of which were carried out in 2001, and changes in woody vegetation (Leife, 2010) and spatial structure of woody savanna vegetation (Herrera, 2011), both of which were carried out after 11 years of the area exclosure establishment.

Based on the results of these studies, and cognizant of the past and ongoing land degradation as well as the urgent need to address the associated problems of soil erosion and bush encroachment, MNR developed a project proposal, which was submitted to the Global Environmental Fund - Small Grant Programme (GEF-SGP) of UNDP for funding. The general objective of the project was the reclamation and regeneration of land for improved grazing within MNR. The specific objectives were to: (i) stabilise the current and continuous advance of gullies to prevent further erosion; (ii) removal of invasive species; (iii) reclaim the land for grazing; and (iv) educate and inform the local communities on the benefits of correct land management (MNR undated project proposal document). Through implementation of the project, MNR aimed to: (i) restore and rehabilitate 750 ha of degraded land; (ii) involve local communities to demonstrate and educate on sustainable management practices; (iii) adjust the behaviour and harmful practices currently undertaken by stakeholders; and (iv) seek to increase the number of local communities actively practising land management through the cost-effective and innovative financial mechanisms trailed during the project.

In converting the degraded land into fertile grassland, the project was intended to bring about numerous conservation impacts. For instance, increasing the frequency and size of grassy areas was assumed to improve the conditions for the wild animals in MNR by: (i) making more food available and, thus, reducing the severity of drought conditions on the animals; (ii) decreasing competition for food resources; (iii) returning the habitat to the natural open bushveld, thus, supporting a greater biodiversity; and (iv) increasing the vegetation cover to protect the soil from surface run-off and, therefore, reducing soil erosion. The project was predicted to benefit the local communities in numerous ways, that is, through the casual labour force required in undertaking the work and carrying out workshops to increase the knowledge of local rural populations on correct land management. In addition, the school visits to Mokolodi Education Centre was believed to ensure that future generations of local children carry with them an understanding of environmental issues and the skills to combat the problems faced (MNR, undated project proposal document). The planned project activities included, among others, "clearing 10 quadrats (each with a size of one hectare), containing the

**Table 1.** List of species recorded from the study site arranged in descending order of their densities (DE, ha<sup>-1</sup>) with their scientific and family names, frequencies (FR, %), dominance (Do, m<sup>2</sup> ha<sup>-1</sup>), relative densities (RDE, %), relative frequencies (RFR, %), relative dominance (RDO, %), importance value index (IVI, %) and feed value (FV).

Species	Family	DE	FR	DO	RDE	RFR	RDO*	IVI	FV**
<i>Dichrostachys cinerea</i> (L.) Wight and Arn.	Fabaceae	1119.4	100	4.040	23.66	3.79	11.89	39.33	L
<i>Euclea undulata</i> Thunb.	Ebenaceae	622.9	100	0.920	13.17	3.79	2.71	19.67	L
<i>Combretum apiculatum</i> Sond.	Combretaceae	474.6	90	6.310	10.04	3.41	18.57	32.02	M-H
<i>Grewia flavescens</i> Juss.	Tiliaceae	435.0	80	0.000	9.20	3.03	0.00	12.23	H
<i>Grewia flava</i> DC.	Tiliaceae	399.9	100	0.020	7.19	3.79	0.06	11.04	H
<i>Grewia bicolor</i> Juss.	Tiliaceae	372.1	100	0.130	7.87	3.79	0.38	12.04	H
<i>Acacia erubescens</i> Welw. ex Oliv.	Fabaceae	232.8	100	3.170	4.93	3.79	9.33	18.04	L
<i>Acacia mellifera</i> (Vahl) Benth.	Fabaceae	230.7	90	3.020	4.88	3.41	8.89	17.18	L
<i>Acacia tortilis</i> (Forssk.) Hayne	Fabaceae	201.6	100	5.600	4.27	3.79	16.48	24.54	L/H
<i>Sterculia africana</i> (Lour.) Fiori	Sterculiaceae	141.5	70	7.240	3.00	2.65	21.30	26.96	NA
<i>Grewia retinervis</i> Burret	Tiliaceae	80.7	90	0.050	1.71	3.41	0.15	5.27	H
<i>Peltophorum africanum</i> Sond.	Fabaceae	67.9	100	1.700	1.44	3.79	5.00	10.23	H
<i>Boscia foetida</i> Schinz	Capparaceae	46.7	90	0.010	0.99	3.41	0.03	4.43	H
<i>Rhus leptodictya</i> Diels	Anacardiaceae	39.7	80	0.040	0.85	3.03	0.12	3.99	H
<i>Ehretia rigida</i> (Thunb.) Druce	Bignoniaceae	39.0	90	0.070	0.82	3.41	0.21	4.44	M-H
<i>Pappea capensis</i> Eckl. and Zeyh.	Sapindaceae	36.8	100	1.000	0.78	3.79	2.94	7.51	H
<i>Combretum imberbe</i> Wawra	Combretaceae	36.0	80	0.360	0.76	3.03	1.06	4.85	M-H
<i>Gymnosporia senegalensis</i> (Lam.) Loes.	Celastraceae	33.2	100	0.280	0.70	4.55	0.83	6.1	M-H
<i>Tarchonanthus camphoratus</i> L.	Asteraceae	26.6	80	0.001	0.57	3.03	0.00	3.60	L
<i>Terminalia sericea</i> Burch. ex DC.	Combretaceae	25.7	20	0.260	0.55	0.76	0.77	2.07	M
<i>Commipora pyracanthoides</i> Engl.	Burseraceae	23.8	50	0.050	0.51	1.89	0.15	2.55	L-M
<i>Acacia nilotica</i> (L.) Willd. ex Delile	Fabaceae	20.7	70	1.000	0.44	2.65	2.94	6.04	L-H
<i>Combretum hereroense</i> Schinz	Combretaceae	14.4	50	0.180	0.30	1.89	0.53	2.72	M-H
<i>Acacia rubusta</i> Burch.	Fabaceae	13.8	70	1.000	0.30	2.65	2.94	5.89	L-M
<i>Carissa bispinosa</i> (L.) Desf. ex Brenan	Apocynaceae	12.8	40	0.160	0.27	1.52	0.47	2.26	M
<i>Ehretia amoena</i> Klotzsch	Bignoniaceae	6.7	40	0.004	0.15	1.52	0.01	1.67	NA
<i>Ximenia americana</i> L.	Olacaceae	6.6	50	0.100	0.15	1.89	0.29	2.34	M-H
<i>Ziziphus mucronata</i> Willd.	Rhamnaceae	5.5	70	0.030	0.11	2.65	0.09	2.85	M-H
<i>Ximenia caffra</i> Sond.	Olacaceae	5.1	50	0.010	0.11	1.89	0.03	2.03	M-H
<i>Acacia caffra</i> (Thunb.) Willd.	Fabaceae	3.7	40	0.290	0.08	1.52	0.85	2.45	L-M
<i>Berchemia zeyheri</i> (Sond.) Grubov	Rhamnaceae	1.6	20	0.000	0.04	0.76	0.00	0.80	NA
<i>Acacia gerrardi</i> Benth.	Fabaceae	1.3	10	0.100	0.02	0.38	0.29	0.69	L
<i>Sclerocarya birrea</i> (A.Rich.) Hochst.	Anacardiaceae	1.1	50	0.210	0.02	1.89	0.62	2.53	H
<i>Gardenia volkensii</i> K.Schum.	Rubiaceae	1.0	10	0.050	0.02	0.38	0.15	0.55	NA
<i>Acacia karroo</i> Hayne	Fabaceae	0.9	100	0.010	0.02	3.79	0.03	3.84	M-H

Table 1. Contd.

<i>Ozoroa paniculosa</i> (Sond.) R. Fern. and A. Fern.	Anacardiaceae	0.7	10	0.001	0.02	0.38	0.00	0.40	H
<i>Boscia albitrunca</i> (Burch.) Gilg and Gilg-Ben.	Capparaceae	0.6	10	0.000	0.02	0.38	0.00	0.40	M-H
<i>Rhigozum brevispinosum</i> Kuntze	Bignoniaceae	0.5	40	0.000	0.01	1.52	0.00	1.53	H
<i>Dombeya rotundifolia</i> (Hochst.) Planch.	Sterculiaceae	0.4	20	0.010	0.01	0.76	0.03	0.80	H
<i>Vangueria infausta</i> Burch.	Rubiaceae	0.3	10	0.000	0.01	0.38	0.00	0.39	NA
<i>Olea europaea</i> L.	Oleaceae	0.2	20	0.000	0.00	0.76	0.00	0.76	NA
<i>Acacia luederitzii</i> Engl.	Fabaceae	0.1	10	0.010	0.00	0.38	0.03	0.41	L
<i>Berchemia discolor</i> (Klotzsch) Hemsl.	Rhamnaceae	0.1	10	0.000	0.00	0.38	0.00	0.38	NA
<i>Combretum zeyheri</i> Sond.	Combretaceae	0.1	10	0.010	0.00	0.38	0.03	0.41	M-H
Total		4784.8	2640	33.986	100.00	100.00	100.00	300.00	

\* = All values indicated as 0 represent values very close to, but above zero; \*\* Nutritional Values: H = high, M-H = medium to high, M = medim, L-M = low to medium, L = low and NA = not available (Hendzel 1981; David-Andersen, 2012).

targeted encroaching, rapid regenerating and invasive bushy species, and treating them with herbicide that inhibits regrowth". However, apart from inclusion of the planned clearing activity in the project based on casual observation and experiences of staff members in MNR, there was no research-based empirical information on the status of woody species, including the accurate identity and nutritional/feed value of the woody species, and criteria to distinguish those woody species with aggressive/invasive biological nature from all the other woody species in the study site. Similarly, there was no systematic way of determining the identity, nutritional/feed value and spatial cover of the herbaceous species (herbaceous species). The lack of the above mentioned information on the woody species and herbaceous species would have made not only the implementation and monitoring of the project activities difficult but also the importance and applicability of the subsequent outputs from the project very limited. This necessitated the undertaking of a pre-clearing inventory of all woody species and herbaceous species to generate the above mentioned information

required to successfully implement the project activities and serve as a bench-mark for the purpose of future referencing if and when it is required.

Therefore, a pre-clearing inventory of the 10 quadrats (measuring 10 ha) mentioned above was carried out with the following specific objectives - to: (i) determine the species richness of both the woody species and herbaceous species; (ii) investigate the diversity and evenness of the woody species; (iii) assess the stand structure of the woody species through determining their densities, frequencies and dominance (basal areas), importance value indices and population structures; (iv) assess the regeneration status of woody species; and (v) determine spatial (ground) cover (hereafter referred to as spatial cover) of the herbaceous species; and (vi) determine the nutritional values of woody species and herbaceous species.

## METHODS

### Study site

Mokolodi Nature Reserve (MNR) is located in the South

East District of Botswana, about 15 km south-west of the capital city Gaborone, along the Gaborone - Lobatse road at 24° 44' 20.81" S and 25° 48' 56.79" E (MNR, 2015; Figure 1).

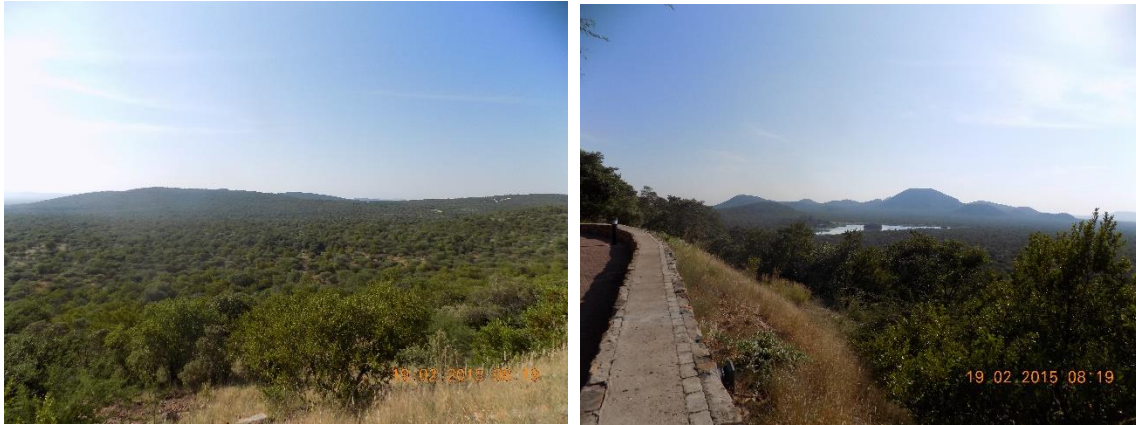
The climate of the Gaborone area is semi-arid and sub-tropical. The mean maximum daily temperature varies from 32°C from November to February to 22°C in late June to August. The mean minimum daily temperature varies from 22°C from November to February to 4°C in late June to August (Njiru, 2008; David-Andersen, 2012). The average altitude above sea level in the MNR is 1,063 m.

The red, sandy clay loam to clay soils found at the flatter areas of the reserve cover Precambrian rock. On the slopes, the soils are shallow to moderately deep, moderately to well drained, dark reddish brown to greyish brown, coarse sands to clay loams and cover acidic volcanic lava (Schroder, 2001; Njiru, 2008; David-Andersen, 2012).

The vegetation occurring in the reserve is classified as Hardveld or Eastern Mixed Tree Savanna of which the common components are *Acacia erubescens* Welw. ex Oliv. (Blue thorn), *A. mellifera* (Black thorn), *Peltophorum africanum* Sond. (Weeping wattle), *Spirostachys africanum* Sond. (Tamboti), *Terminalia sericea* Burch. ex DC. (Silver cluster tree) and many other species (Schroder, 2001; Njiru, 2008; David-Andersen, 2012) (Figure 2).

### History of the study area

Mokolodi Nature Reserve was established in 1994 on land



**Figure 2.** Partial views of the vegetation of Mokolodi Nature Reserve (Photo by Demel Teketay).



**Figure 3.** Greater Kudu (A) and Ostrich found in the Mokolodi Nature Reserve (Photos by Demel Teketay).

previously used for livestock farming. As one of the aforementioned protected areas in Botswana, MNR has two main objectives, that is, to conserve wildlife and natural resources found in Botswana for current and future generations, and promote understanding of natural systems, conservation and general environmental awareness through environmental education (Njiru, 2011; David-Andersen, 2012). The land was donated into a Trust for the children of Botswana so as to provide a natural area that would allow them to learn about nature, conservation and the environment, and to ensure that the young people in Botswana grow-up to be good custodians of their natural history, helping to conserve their common heritage for future generations (MNR, undated project proposal).

Initially, MNR covered an area of 3000 ha, but was later expanded by 750 ha (containing crocodile pools) to the current-day area of approximately 3,750 ha (Bengtsson-Sjörs, 2006). Following the acquisition of the land, the appropriate infrastructure was developed, including electrified fencing of the reserve, improved structure/network of roads, an education center, staff and client accommodation, and an animal sanctuary and rehabilitation center. MNR was, then, stocked with wild animals that had historically occurred in the area. The animals introduced into the reserve included Blue Wildebeest (*Connochaets taurinus*), Burchell's Zebra

(*Equus burchelli*), Hippopotamus (*Hippopotamus amphibius*) Gemsbok (*Oryx gazella*), Giraffe (*Giraffa camelopardalis*), Red Hartebeest (*Alcelaphus buselaphus*), White Rhinoceros (*Ceratotherium simum*) and many other species (Martin and Njiru, 2006).

The wild animals inhabiting MNR currently include Aardvark (*Orycteropus afer*), Aardwolf (*Proteles cristatus*) Black-Backed Jackal (*Canis mesomelas*), Blue Wildebeest (*Connochaetes taurinus*), Brown Hyena (*Hyaena brunnea*), Burchell's Zebra (*Equus burchelli*), Bushbuck (*Tragelaphus scriptus*), Bushpig (*Potamochoerus porcus*), Caracal (*Felis caracal*), Chacma Baboon (*Papio ursinus*), Common Duiker (*Sylvicapra grimmia*), Eland (*Tragelaphus oryx*), Gemsbok (*Oryx gazella*), Giraffe (*Giraffa camelopardalis*), Hippopotamus (*Hippopotamus amphibius*), Impala (*Aepyceros melampus*), Klipspringer (*Oreostragus oreostragus*), Greater Kudu (*Tragelaphus strepsiceros*) (Figure 3A), Leopard (*Panthera pardus*), Mountain Reedbuck (*Redunca fulvorufula*), Pangolin (*Manis temminckii*), Red Hartebeest (*Alcelaphus buselaphus*), Serval (*Leptailurus serval*), Steenbok (*Raphicerus campestris*), Vervet Monkey (*Cercopithecus aethiopicus*), Warthog (*Phacochoerus aethiopicus*), Waterbuck (*Kobus ellipsiprymnus*), White Rhinoceros (*Ceratotherium simum*) (Martin and Njiru, 2006) and Ostrich (*Struthio camelus*) (Figure 3B; Teketay, personal

observation). MNR is also home to a variety of other mammals, a diverse array of reptile, amphibian and bird species.

There is a 30 ha dam, Lake Gwithian (Figure 2), which acts as the main water supply for the reserve with the capacity of carrying  $\pm$  2.5 million cubic meters of water. The Chalet dam, Lake Elizabeth, Broken Dam and Bushy Farm Water Hole are seasonal water supplies (Schroder, 2001; Martin and Njiru, 2006).

### Data collection

To determine the species richness of woody species and herbaceous species as well as diversity and evenness, stand structure (density, abundance, frequency, dominance, population structure and important value index), regeneration status of the woody species, and spatial cover of herbaceous species, a total of 10 quadrats, each having an area of one ha, were laid down systematically. In each of the quadrats, the following parameters were recorded: Identity of all woody species and herbaceous species, number of all live individuals and diameter at breast height (DBH) of individuals with DBH > 2 cm of each woody species. In the case of juveniles (seedlings and coppices < 1.5 m height), the number of individuals of each woody species was counted and recorded in each quadrat. A calliper and graduated measuring stick were used to measure DBH and height, respectively, of the woody species. For the herbaceous species, in order to ensure sampling of herbaceous species across the variation observed in the spatial cover of each quadrat, 10 small quadrats (replications) measuring 1 x 1 m (1 m<sup>2</sup>) were systematically laid down in each of the 10 quadrats. In the small quadrats, a visual estimation of the proportion (percentage) of spatial cover of each herbaceous species and bare ground was made in relation to the spatial cover of other herbaceous species.

The woody species and herbaceous species were identified directly in the field by using the available literature (Timberlake, 1980; Ellery and Ellery, 1997; van Wyk and van Wyk, 1997, 2007; Heath and Heath, 2010; Roodt, 1993, 1998; Setshogo, 2002, 2005; Setshogo and Venter, 2003) and with the help of local people familiar with the flora. Plant nomenclature in this article follows that of Setshogo and Venter (2003), and Setshogo (2005).

The nutritional values of both the woody species and herbaceous species were determined using reports by Hendzel (1981) and David-Andersen (2012).

### Data analyses

*Species richness* (S) is the total number of different woody species and herbaceous species recorded in the study site, and does not take into account the proportion and distribution of each woody species and herbaceous species.

The *diversity* of woody species was analysed by using the Shannon Diversity Index (H') (also known as the Shannon-Weiner/Weaver Diversity Index in the ecological literature) (Krebs, 1989; Magurran, 2004). The index takes into account the species richness and proportion of each woody species in all sampled quadrats. The following formula was used to analyse woody species diversity:

$$H' = - \sum_{i=1}^S P_i \ln P_i$$

where, H' = Shannon index, S = species richness, P<sub>i</sub> = proportion of S made up of the <sup>i</sup>th species (relative abundance). Evenness or equitability, a measure of similarity of the abundances of the different woody species in the sampled project sites, was analysed by using *Shannon's Evenness or Equitability Index* (E) (Krebs,

1989; Magurran, 2004). Equitability assumes a value between 0 and 1 with 1 being complete evenness. The following formula was used to calculate evenness:

$$E = H' / \ln S$$

where, E = evenness and S = species richness. The mean *density* (MDE) of woody species was determined by converting the total number of individuals of each woody species encountered in all the quadrats to equivalent number per hectare.

The mean *frequency* (MF) was calculated as the proportion (%) of the number of quadrats in which each woody species was recorded from the total number of quadrats in the study site. The *dominance* of the woody species, with diameter at DBH > 2 cm, was determined from the space occupied by a species, usually its basal area (BA). The mean dominance of each woody species was computed by converting the total basal area of all individuals of each woody species to equivalent basal area per hectare (Kent and Coker, 1992).

The *important value index* (IVI) indicates the relative ecological importance of a woody species in each of the project sites (Kent and Coker, 1992). It is determined from the summation of the relative values of density, frequency and dominance of each woody species. *Relative mean density* (RMDE) was calculated as the percentage of the density of each species divided by the total stem number of all woody species ha<sup>-1</sup>. *Relative mean frequency* (RMF) of a woody species was computed as the ratio of the frequency of the species to the sum total of the frequency of all woody species. *Relative mean dominance* (RMDO) was calculated as the percentage of the total basal area of a woody species out of the total basal areas of all woody species.

Population structure of each woody species in the study sites was assessed through histograms constructed by using the density of individuals of each species (Y-axis) categorized into ten diameters classes (X-axis) (Peter, 1996), that is:

1 = < 2 cm; 2 = 2-5 cm; 3 = 5-10 cm; 4 = 10-15 cm; 5 = 15-20 cm; 6 = 20-25 cm; 7 = 25-30 cm; 8 = 30-35; 9 = 35-40; 10 = > 40 cm.

Based on the profile depicted in the population structures, the regeneration status of each woody species was determined. The average spatial cover of each herbaceous species was determined by first calculating the average spatial cover value of each herbaceous species and bare ground in each quadrat from the aggregated spatial cover values recorded in the 10 small quadrats. Then, the final spatial cover values of each herbaceous species and bare ground were calculated from the average values of the spatial cover values of each herbaceous species and bare ground recorded in all the 10 quadrats, respectively.

The nutritional values of the woody species were first categorized into high, medium to high, low to high, medium, low to medium, low and information not available, and the percentage proportion of each of the categories was calculated. For the herbaceous species, four categories were used, namely high, medium, low and information not available. Then, the percentage proportion of each of these categories was calculated.

## RESULTS

### Species richness of woody and herbaceous species

The study site had a total species richness of 113 species of woody species and herbaceous species recorded in all the ten quadrats, representing 32 families and 74 genera (Tables 1 and 2). The most diverse families were Poaceae (31 spp., about 23.3% of all spp.),

**Table 2.** List of herbaceous species recorded in the study with their scientific names and families, average proportions of spatial (ground) cover (% ha<sup>-1</sup>) and nutritional values.

Species	Family	Spatial cover	Nutritional value*
<i>Eragrostis lehmanniana</i> Nees	Poaceae	7.1	High
<i>Tragus berteronianus</i> Schult.	Poaceae	3.5	Low
<i>Eragrostis rigidior</i> Pilg.	Poaceae	3.47	Low
<i>Waltheria indica</i> L.	Sterculiaceae	2.83	Not available
<i>Panicum maximum</i> Jacq.	Poaceae	2.25	High
<i>Aristida congesta</i> Roem. and Schult	Poaceae	2.14	Low
<i>Aristida stipitata</i> Hack.	Poaceae	1.95	Low
<i>Melinis repens</i> (Wild.) Zizka	Poaceae	1.8	Low
<i>Urochloa mosambicensis</i> (Hack.) Dandy	Poaceae	1.55	Medium
<i>Schmidtia pappophoroides</i> Steud. ex J. A. Schmidt	Poaceae	1.38	Good
<i>Melhania prostrata</i> DC.	Sterculiaceae	1.2	Not available
<i>Kyphocarpa angustifolia</i> (Moq.) Lopr.	Amaranthaceae	1.01	Not available
<i>Pogonarthria squarrosa</i> (Roem. and Schult.) Pilg.	Poaceae	0.95	Low
<i>Chloris gayaa</i> Kunth	Poaceae	0.90	High
<i>Chrysopogon serrulatus</i> Trin.	Poaceae	0.85	High
<i>Chloris virgata</i> Sw.	Poaceae	0.82	High
<i>Evolvulus alsinoides</i> (L.) L.	Convolvulaceae	0.82	Not available
<i>Enneapogon cenchroides</i> (Roem. and Schult.) C.E.Hubb.	Poaceae	0.80	L
<i>Justicia betonica</i> L.	Acanthaceae	0.80	Not available
<i>Cenchrus ciliaris</i> L.	Poaceae	0.70	High
<i>Indigofera melanadenia</i> Benth. ex Harv.	Fabaceae	0.67	Not available
<i>Panicum coloratum</i> L.	Poaceae	0.65	High
<i>Indigofera daleoides</i> Benth. ex Harv.	Fabaceae	0.61	Not available
<i>Eragrostis biflora</i> Hack. ex Schinz	Poaceae	0.40	Low
<i>Heteropogon contortus</i> (L.) Roem. and Schult.	Poaceae	0.35	High
<i>Pennisetum</i> sp. <i>setaceum</i> (incorrect ident.!)	Poaceae	0.30	Low
<i>Urochloa trichopus</i> (Hochst.) Stapf	Poaceae	0.30	High
<i>Eragrostis trichophora</i> Coss. and Durieu, ( <i>E. atherstonii</i> )	Poaceae	0.27	Medium
<i>Aristida adscensionis</i> L.	Poaceae	0.25	Low
<i>Aristida meridionalis</i> Henrard	Poaceae	0.25	Low
<i>Hermannia modesta</i> (Ehrenb.) Mast.	Sterculiaceae	0.25	Not available
<i>Aristida scabrivalvis</i> Hack.	Poaceae	0.20	Low
<i>Solanum lichtensteinii</i> Willd.	Solanaceae	0.20	Not available
<i>Vernonia poskeana</i> Vatke and Hildebr.	Asteraceae	0.20	Not available
<i>Boerhavia coccinea</i> Mill.	Nyctaginaceae	0.15	Not available
<i>Dicoma tomentosa</i> Cass.	Asteraceae	0.15	Not available
<i>Hemizygia elliotii</i> (Baker) M.Ashby	Lamiaceae	0.15	Not available
<i>Hibiscus micranthus</i> L. f.	Malvaceae	0.15	Not available
<i>Monsonia angustifolia</i> E.Mey. ex A.Rich.	Geraniaceae	0.15	Not available
<i>Otoptera burchellii</i> DC.	Fabaceae	0.15	Not available
<i>Perotis patens</i> Gand.	Poaceae	0.15	Low
<i>Tephrosia rhodesica</i> Baker f.	Fabaceae	0.15	Not available
<i>Dactyloctenium aegyptium</i> (L.) Willd.	Poaceae	0.10	High
<i>Dichanthium annulatum</i> (Forssk.) Stapf	Poaceae	0.10	High
<i>Eragrostis gummiflua</i> Nees	Poaceae	0.10	Low
<i>Hibiscus. engleri</i> K. Schum.	Malvaceae	0.10	Not available
<i>Indigofera cryptantha</i> Benth. ex Harv.	Fabaceae	0.10	Not available
<i>Indigofera filipes</i> Benth. ex Harv.	Fabaceae	0.10	Not available
<i>Indigofera oxytropis</i> Benth. ex Harv.	Fabaceae	0.10	Not available
<i>Melhania acuminata</i> Mast.	Sterculiaceae	0.10	Not available



Table 2. Contd.

<i>Acrotome inflata</i> Benth.	Lamiaceae	0.05	Not available
<i>Aptosimum lineare</i> Marloth and Engl.	Scrophulariaceae	0.05	Not available
<i>Ceratotheca triloba</i> (Bernh.) Hook. f.	Pedaliaceae	0.05	Not available
<i>Chamaesyce inaequilatera</i> (Sond.) Soják	Euphorbiaceae	0.05	Not available
<i>Crotalaria lotoides</i> Benth.	Fabaceae	0.05	Not available
<i>Digitaria eriantha</i> Steud.	Poaceae	0.05	Very High
<i>Eragrostis pallens</i> Hack.	Poaceae	0.05	Poor
<i>Hibiscus cannabinus</i> L.	Malvaceae	0.05	Not available
<i>Indigofera holubii</i> N. E. Br.	Fabaceae	0.05	Not available
<i>Kyllinga alba</i> Nees	Cyperaceae	0.05	Not available
<i>Lippia javanica</i> (Burm.f.) Spreng.	Verbenaceae	0.05	Not available
<i>Macrotyloma axillare</i> (E.Mey.) Verdc.	Fabaceae	0.05	Not available
<i>Portulaca oleracea</i> L.	Portulacaceae	0.05	Not available
<i>Sansevieria aethiopica</i> Thunb.	Dracaenaceae	0.05	Not available
<i>Senna italica</i> Mill.	Fabaceae	0.05	Not available
<i>Setaria verticillata</i> (L.) P.Beauv.	Poaceae	0.05	Fairly Good
<i>Solanum delagoense</i> Dunal	Solanaceae	0.05	Not available
<i>Striga asiatica</i> (L.) Kuntze	Scrophulariaceae	0.05	Not available
<i>Tephrosia lupinifolia</i> DC.	Fabaceae	0.05	Not available
Bare Ground		55.33	
<b>Total</b>		100.0	

\* Sources: Hendzel (1981) and David-Andersen (2012).

Fabaceae (23 spp., about 17.3% of all spp.), Combretaceae (five spp.) and Tiliaceae (four spp.) while five families had three species each (Tables 1 and 2). The most diverse genera were *Acacia* (nine spp.), *Eragrostis* (six spp.), *Indigofera* (six spp.), *Aristida* (five spp.), *Combretum* (four spp.), *Grewia* (four woody species) and *Hibiscus* (three spp.). The numbers of families and genera that were represented by only one species were 16 and 56, respectively.

The species richness of the woody species alone was 44, representing 17 and 26 families and genera, respectively (Table 1). The most diverse families were Fabaceae, Combretaceae and Tiliaceae with 11, five and four woody species, respectively. The most diverse genera were *Acacia* (nine woody species), *Combretum* (four woody species) and *Grewia* (four woody species). The numbers of families and genera, which were represented by only one species were six and 19, respectively.

A total of 69 different herbaceous species were recorded, representing 19 families and 48 genera (Table 2). Of these, about 45% were different species of grasses while the rest included different species of forbs and sedges. The families with the highest number of herbaceous species were Poaceae (31 spp., 44.9% of all herbaceous spp.), Fabaceae (12 spp., 17.4% of all herbaceous spp.), Sterculiaceae (four spp.) and Malvaceae (three spp.). The genera with the highest number of herbaceous species were *Eragrostis* (six spp.),

*Indigofera* (six spp.), *Aristida* (five spp.) and *Hibiscus* (three spp.) (Table 2).

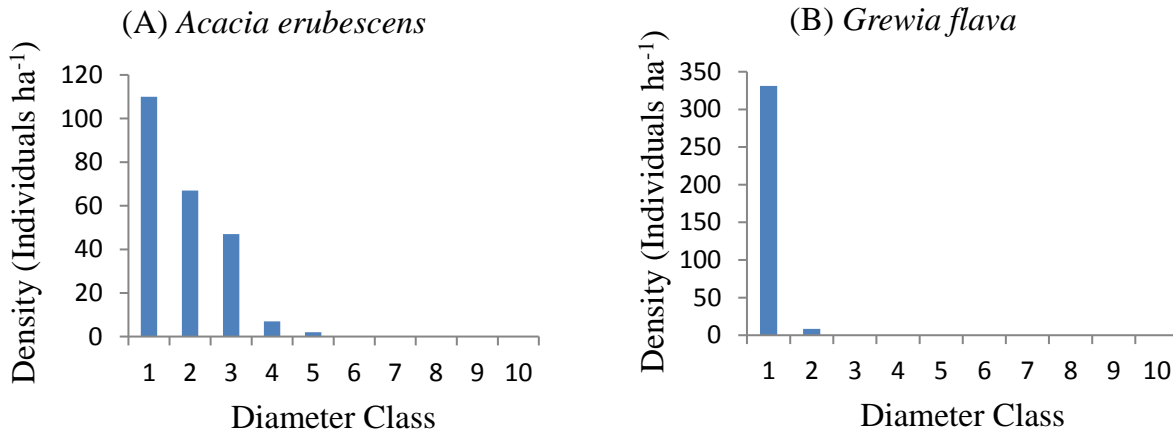
### Diversity and evenness of woody species

The diversity (H') and evenness (E) values of woody species encountered in the study site were 1.44 and 0.38, respectively.

### Density, frequency and dominance

A total of 47,848 stems of all the woody species (abundance) were recorded in all the ten quadrats, translating into a total density of 4,784.8 ha<sup>-1</sup> with a range of 0.1 and 1,119 stems ha<sup>-1</sup> (Table 1). The five densest woody species in the study site were *Dichrostachys cinerea* (L.) Wight and Arn. (1,119 stems ha<sup>-1</sup>), *Euclea undulata* Thunb. (623 stems ha<sup>-1</sup>), *Combretum apiculatum* Sond. (475 stems ha<sup>-1</sup>), *Grewia flavescens* Juss. (435 stems ha<sup>-1</sup>) and *Grewia bicolor* Juss. (372 stems ha<sup>-1</sup>). In contrast, *Vangueria infausta* Burch. (0.3 stems ha<sup>-1</sup>), *Olea europaea* L. (0.2 stems ha<sup>-1</sup>), *Combretum zeyheri* Sond. (0.1 stems ha<sup>-1</sup>), *Berchemia discolor* (Klotzsch) Hemsl. (0.1 stems ha<sup>-1</sup>) and *Acacia luederitzii* Engl. (0.1 stems ha<sup>-1</sup>) exhibited the five lowest densities (Table 1).

The frequencies of the woody species ranged between 10 (eight woody species) and 100% (10 woody species).



**Figure 4.** Population structure of woody species recorded at Mokolodi Nature Reserve [diameter class (DBH): 1 = < 2 cm; 2 = 2-5 cm; 3 = 5-10 cm; 4 = 10-15 cm; 5 = 15-20 cm; 6 = 20-25 cm; 7 = 25-30 cm; 8 = 30-35; 9 = 35-40; 10 = > 40 cm].

The most frequently found woody species in the study site, that is, with frequencies of 100%, were *D. cinerea*, *E. undulata*, *G. bicolor*., *Grewia flava* DC., *Acacia erubescens* Welw. ex Oliv., *Acacia tortilis* (Forssk.) Hayne, *Peltophorum africanum* Sond., *Pappea capensis* Eckl. and Zeyh., *Gymnosporia senegalensis* (Lam.) Loes. and *Acacia karroo* Hayne (Table 1). About 41% of all the woody species recorded in the study site had frequency values of more than 50%. In contrast, the least frequent woody species, with frequency value of 10% each, were *Boscia albitrunca* (Burch.) Gilg and Gilg-Ben., *Ozoroa paniculosa* (Sond.) R. Fern. and A. Fern., *Gardenia volkensii* K.Schum., *Acacia gerrardi* Benth., *Vangueria infausta* Burch., *C. zeyheri*, *B. discolor*. and *A. luederitzii* (Table 1).

The total dominance of all the woody species recorded in the study site was about 34 m<sup>2</sup> ha<sup>-1</sup> and ranged between very close to zero and 7.24 m<sup>2</sup> ha<sup>-1</sup> (Table 1). The five dominant woody species in the study site were *Sterculia africana* (Lour.) Fiori (7.24 m<sup>2</sup> ha<sup>-1</sup>), *C. apiculatum* (6.31 m<sup>2</sup> ha<sup>-1</sup>), *A. tortilis* (5.6 m<sup>2</sup> ha<sup>-1</sup>), *D. cinerea* (4.04 m<sup>2</sup> ha<sup>-1</sup>) and *A. erubescens* (3.17 m<sup>2</sup> ha<sup>-1</sup>). More than 77% of all the woody species exhibited dominance values of less than one m<sup>2</sup> ha<sup>-1</sup> (Table 1).

### Important value index (IVI)

The five woody species that exhibited the highest IVI values were *D. cinerea* (about 39%), *C. apiculatum* (about 32%), *S. africana* (about 27%), *A. tortilis* (about 25%) and *E. undulata* (about 20%). In contrast, the lowest IVI values (< 1%) were recorded for 11 of the woody species (Table 1). It is interesting to see that both *D. cinerea* and *C. apiculatum* exhibited higher values of density, frequency, dominance and, hence, IVI than the other woody species.

### Population structure and regeneration status

The woody species recorded from the study site demonstrated different patterns of population structures, which can be broadly categorized into three major groups, that is: Group I - represents woody species that exhibited stable or more or less population structures composed of the highest density of individuals at the lowest DBH class followed by gradually declining densities of individuals with increasing DBH classes (Figure 4A). The following 14 woody species (31.8% of all woody species) were categorized under this group: *A. erubescens* Welw. ex Oliv., *A. mellifera* (Vahl) Benth., *A. nilotica* (L.) Willd. ex Delile, *Carissa bispinosa* (L.) Desf. ex Brenan, *Combretum imberebe* Wawra, *D. cinerea* (L.) Wight and Arn., *Ehretia amoena* Klotzsch, *Euclea undulata* Thunb., *Gymnosporia senegalensis* (Lam.) Loes., *Pappea capensis* Eckl. and Zeyh., *Peltophorum africanum* Sond., *Tarchonanthus camphoratus* L., *Sterculia africana* (Lour.) Fiori and *Ziziphus mucronata* Willd.

Group II - represents woody species that exhibited unstable population structures resulting from occurrence of individuals only in the lowest DBH classes (seedlings), only individuals in the first few DBH classes and seedlings and/or individuals missing in most of the DBH classes (Figure 4B). The following 15 woody species (34.1% of all woody species) were categorized under this group: *Acacia rubusta* Burch., *Acacia tortilis* (Forssk.) Hayne, *Boscia foetida* Schinz, *Combretum apiculatum* Sond., *Combretum hereroense* Schinz, *Commipora pyracanthoides* Engl., *Ehretia rigida* (Thunb.) Druce, *Grewia bicolor* Juss., *Grewia flava* DC., *Grewia flavescens* Juss., *Grewia retinervis* Burret, *Rhus leptodictya* Diels, *Terminalia sericea* Burch. ex DC., *Ximenia americana* L. and *Ximenia caffra* Sond.

Group III – represents woody species that had

densities of less than five, which did not allow meaningful assessment of their population structure using histograms. The following 15 woody species (34.1% of all woody species) were categorized under this group: *Acacia caffra* (Thunb.) Willd., *Acacia gerrardi* Benth., *Acacia karroo* Hayne, *Acacia luederitzii* Engl., *Berchemia discolor* (Klotzsch) Hemsl., *Berchemia zeyheri* (Sond.) Grubov, *Boscia albitrunca* (Burch.) Gilg and Gilg-Ben., *Combretum zeyheri* Sond., *Dombeya rotundifolia* (Hochst.) Planch., *Gardenia volkensii* K.Schum., *Olea europaea* L., *Ozoroa paniculosa* (Sond.) R. Fern. and A. Fern., *Rhigozum brevispinosum* Kuntze, *Sclerocarya birrea* (A.Rich.) Hochst. and *Vangueria infausta* Burch.

### Spatial (ground) cover of herbaceous species

The total average proportion of spatial (ground) cover of all the herbaceous species in the study site was 44.67% ha<sup>-1</sup> and ranged between 0.05 (19 spp.) and 7.1 (*Eragrostis lehmannia* Nees) percent ha<sup>-1</sup> while that of the bare ground represented 55.33% ha<sup>-1</sup> (Table 2). The herbaceous species, which exhibited average proportions of spatial cover above 2% ha<sup>-1</sup> were *Eragrostis lehmannia* Nees (7.1% ha<sup>-1</sup>), *Tragus berteronianus* Schult. (3.5% ha<sup>-1</sup>), *Eragrostis rigidior* Pilg. (3.47% ha<sup>-1</sup>), *Waltheria indica* L. (2.83% ha<sup>-1</sup>), *Panicum maximum* Jacq. (2.25% ha<sup>-1</sup>) and *Aristida congesta* Roem. and Schult (2.14% ha<sup>-1</sup>) (Table 2). The average proportions of spatial cover of 57 of the herbaceous species (about 83%) were less than 1% ha<sup>-1</sup>.

### Nutritional values of the woody and herbaceous species

The nutritional values of 27, 25, 16, 6, 5 and 5% of the woody species were high, medium to high, low, low to medium, medium and low to high, respectively. For 16% of the woody species, their nutrition values could not be established for lack of information (Table 1). Similarly, the nutritional values of 22, 20, and 3% of the herbaceous species were low, high and medium, respectively, and those for 55% of the herbaceous species could not be established for lack of information (Table 2).

### DISCUSSION

The species, family and genera richness values of woody species (44 spp., 17 families and 26 genera) recorded in this study were higher than those reported from studies in Shorobe (41 spp., 15 families and 23 genera), Maun (area enclosure in Island Safari Lodge, 33 spp., 13 families and 20 genera) and Xobe (27 spp., 10 families and 24 genera) villages (Neelo et al., 2013; Neelo et al., 2015) as well as in an area enclosure of more than 10

years (32 spp., 12 families and 19 genera) and open area adjacent the area enclosure (24 spp., 10 families and 15 genera) in Maun (Teketay et al., 2016) in northern Botswana, and in Shekole (18 spp.) and Guba (23 spp.) in western Ethiopia (28 spp. and 22 genera) (Yilma et al., 2015). However, the study area in MNR exhibited lower species richness of woody species compared with reports from studies in the Sudanian savanna in Burkina Faso (Savadogo et al., 2007), dryland forests and woodlands in Ethiopia (Woldemariam et al., 2000; Senbeta and Teketay, 2003; Zegeye et al., 2006, 2011; Alelign et al., 2007; Worku et al., 2012) as well as woodlands and forests in South Africa (Dovie et al., 2008), Tanzania (Louga et al., 2000; Banda et al., 2008), and Uganda (Nangedo et al., 2006; Kalema, 2010). When all the species (woody species and herbaceous species) are considered, the species composition in MNR is lower than those reported from Ethiopia (Senbeta and Teketay, 2003; Zegeye et al., 2006).

The diversity and evenness values of the woody species in MNR (1.44 and 0.38, respectively) are much lower than those reported for Shorobe (2.18 and 0.6, respectively), Maun (area enclosure in Island Safari Lodge, 2.15 and 0.6, respectively), Xobe (1.5 and 0.5, respectively) villages (Neelo et al., 2013; Neelo et al., 2015) as well as in an area enclosure of more than 10 years (3.14 and 1.6, respectively) in Maun (Teketay et al., 2016), northern Botswana, and other dry land forests (Senbeta and Teketay, 2003; Alelign et al., 2007; Zegeye et al., 2006).

The low woody species evenness value recorded in MNR indicates that there is unbalanced representation of individuals of the different woody species.

The total density of woody species recorded in MNR is higher than those reported for Shorobe, Island Safari Lodge and Xobe in Northern Botswana (Neelo et al., 2013; Neelo et al., 2015) as well as a nature reserve forest (Senbeta and Teketay, 2003) and dryland forests and woodlands (Zegeye et al., 2006, 2011; Alelign et al., 2007; Worku et al., 2012; Yilma et al., 2015) in Ethiopia. However, it was much lower than a dry Afromontane forest (Woldemariam et al., 2000) in Ethiopia. The relatively high density of woody species in MNR compared with other woodlands in Botswana might be attributed to the protection provided to the reserve from livestock grazing since its establishment in 1994, though wild animals still graze freely in the reserve.

The highest density of woody species in MNR (about 24% of the total woody species density) was exhibited by *D. cinerea* (Table 1). This species has both advantages and disadvantages. It has a number of land and environmental uses, that is, in agroforestry, soil improvement, revegetation, land reclamation, soil conservation, erosion control, hedging and live fencing. It has been used for the stabilization of sand dunes and in soil conservation. It is also used to improve soils, e.g. along the riverbanks in the Sahel (World Agroforestry

Centre, 2005). Another use, a reason for its introduction, has been its perceived value as an ornamental hedging plant with its attractive pink and yellow flowers. The wood is considered as termite resistant and has been used for a wide range of purposes, including round wood, posts, exterior fittings, fences, though its utilization is limited by the scarcity of suitable dimensions and is more commonly used for walking sticks, tool handles, spears, etc. (von Maydell, 1986). The wood is most commonly used as fuel or for making charcoal. It has a high calorific value, burns slowly and is sought after as a preferred source of fuel. Non-wood uses include gums, lac, fodder, dyestuffs, bark products, fibres, honey and medicinal products. Debarked roots are used for strong weaving work, such as baskets and racks, and bark fibres for various applications (von Maydell, 1986). Leaves and seeds are edible but are commonly sought after by livestock and are considered very nutritious. The bark, roots and leaves are all used for a number of medicinal purposes for example to treat headaches, toothaches, stings, sore eyes, leprosy, epilepsy and as a diuretic (World Agroforestry Centre, 2005), and to treat snakebites, elephantitis and other internal parasitic worms, syphilis and gonorrhoea (von Maydell, 1986).

Such uses are, however, limited because of its disadvantages. *Dichrostachys cinerea* is a long-lived and fast growing tree that has become an undesirable weed and is particularly a problem in areas where there has been overgrazing. In the areas where it becomes an invader, the species forms very dense thickets, especially at its younger stage, making areas impenetrable. In some countries, such as Cuba, West Indies, Hawaii and South America (SANBI, 2011), the species is considered as an invasive species. In the West Indies, *D. cinerea* has been responsible for the invasion of rangelands and has caused significant agricultural production losses (SANBI, 2011), notably through bush encroachment, the ecological process in which a grass-dominated community is changed into a woody community.

Encroachment is the result of overgrazing and is attributed to the ability of *D. cinerea* to regenerate profusely owing to its biological characteristics that foster its aggressiveness. These include regeneration of *D. cinerea* from seeds, smallest amount of root or through its root suckers. Large numbers of seeds, about 39,000 seeds  $\text{kg}^{-1}$ , are produced almost all year long, and seeds can be produced even by young trees (Fournet, 2004; World Agroforestry Centre, 2005). The seeds can survive for long periods of time in the soil (Fournet, 2004) by forming persistent soil seed banks (Leck et al., 1989; Teketay, 2005). Seeds may be dispersed by wind and water. Seeds may also be carried in the hooves of cattle (PIER, 1999). The indehiscent pods, exhibiting animal dispersal syndrome, are eaten by a number of animals including cattle, camels and game (e.g. giraffe, buffalo, kudu, impala and Nyala) (Cooke, 1998; World Agroforestry Centre, 2005), which distribute its processed

seeds that are ready to germinate along with their droppings widely (Teketay, 1996a, b, 2005; Kalema, 2010; Neelo et al., 2013; Neelo et al., 2015). The species has prolific root suckers and can regenerate from very small root cuttings. It can produce 130 new stems from root suckers within a 15 m radius from the main trunk over 10 years (World Agroforestry Centre, 2005). It is fire resistant and found in a variety of habitats, e.g. dry deciduous forests, in areas with strong seasonal climates, saline, infertile, lateritic and poor soils, and is widely distributed in the seasonally dry tropics of Africa, Asia and Australia (von Maydell, 1986; World Agroforestry Centre, 2005; PIER, 1999). Mean annual temperatures where *D. cinerea* grows are 15 to 27°C, but it also tolerates mean monthly temperatures as high as 38°C and an absolute minimum temperature of 0°C. The mean annual rainfall where *D. cinerea* grows range from 200 to 1400 mm, with dry season durations of 4 to 10 months. It is known to occur from sea level in coastal areas up to 2000 m altitude in Ethiopia (von Maydell, 1986; Hunde and Thulin, 1989).

In general, the impact mechanisms of *D. cinerea* include competition by monopolizing resources and production of spines, thorns or burrs while its impact outcomes include negative impacts on agriculture and tourism as well as reduced amenity values and native biodiversity. In terms of invasiveness, *D. cinerea* has high reproductive potential, is highly mobile locally and invasive in its native range, has proved invasive outside its native range, and tolerates or benefits from cultivation, browsing pressure, mutilation and fire. *D. cinerea* has been reported to have displaced native plant communities (Moyroud, 2000). It can cause losses in agricultural production (Fournet, 2004). Due to its thorns it can make areas inaccessible for both humans and livestock, and it is also expensive to control, which was estimated at USD 100 to 150  $\text{ha}^{-1}$  as it involves frequent management (Hernández, 2002).

The second densest woody species, *E. undulata* (about 13.5% of the total woody species density), is one of the most common small trees across the vast subtropical and central interior regions of southern Africa. It is one of the most variable species due to its adaptability to different climatic and habitat conditions. Several individuals of the species commonly grow closely together, forming impenetrable thickets, as is often the case in their southern to coastal distribution range. Although not very palatable, the leaves are browsed by a number of wild animals, and the fruits are eaten by birds and other mammals, including humans (although not tasty), which disperse the seeds over large areas quite successfully. *Euclea undulata* reproduces through both seeds and resprouting, and recovers easily from grazing or other forms of physical damage, which confirms its ability to regenerate in large number in MNR.

The third densest species, *C. apiculatum* (about 10% of the total woody species density), is a valuable fodder tree

for browsing animals, and mature green leaves are eaten by kudu, bushbuck, eland, giraffe and elephant. Elands are so attracted to the tree that they can do damage to it with their feeding. Cattle like the leaves when they are about to fall or have fallen, especially when they are least nutritious. It is considered as an indicator of mixed veld, good for spring and summer grazing by most farmers but needs careful management. Its fruit pose a threat to livestock, especially the seeds which are poisonous but eaten by brown-headed parrots. Seed of all populations of *C. apiculata* studied showed the ability to acquire thermotolerance, but recovery from heat shock as assessed by germination and growth was higher with the lower altitude populations, which also exhibited a greater ability to withstand the 50°C heat stress (Chickono and Choinski, 1992). Based on these characteristics, it was proposed that acquisition of thermotolerance by *C. apiculatum* may be of survival advantage to the seeds in the lower altitude areas of its range, particularly when the early rains are erratic and the seeds likely to be subjected to periods of post-imbibitional heat stress (Chickono and Choinski, 1992), also commonly observed in MNR. The species also responds well to coppicing, growing back with plentiful foliage (mean leaf dry mass production = 875 g tree<sup>-1</sup>) (Smith, 2003). These characteristics of *C. apiculata* explain its high density recorded in MNR.

Three species of *Grewia* have also exhibited high stem densities, representing about 27% of the total woody species density in MNR. This could be attributed to wild animals, especially frugivorous birds, and livestock, which eat the fruits and disperse seeds of the species widely (Tews et al., 2004; Mothogoane, 2012a and b). The seeds that have passed through the stomach of animals germinate rapidly, presumably due to the stomach acids that help to dissolve the tough seed coat. Also it has been demonstrated that cattle may facilitate shrub encroachment of *Grewia*, and the severity of shrub encroachment is governed by the intensity of seed dispersal (Tews et al., 2004). In addition, the species, e.g. *G. flava*, which is heavily browsed, especially during the dry season, are known to coppice profusely (Oppelt, 2003).

The three species of *Acacia*, namely *A. erubescens*, *A. mellifera* and *A. tortilis* have also exhibited relatively high stem densities (about 14% of the total woody species density). This might suggest signs of bush encroachment due to overgrazing and over-exploitation of woody species (DEA, 2008; Neelo et al., 2013; Neelo et al., 2015). *Acacia mellifera* is known to form impenetrable patches of thickets as well as encroach eroded sites (Ellery and Ellery, 1997; Neelo et al., 2015) and heavily grazed areas (El-Sheikh, 2013; Neelo et al., 2015). The relatively high density of *Acacia* species, which are indicative of heavy grazing and encroachment, is consistent with the fact that MNR, as alluded in the introduction, has been used as an open grazing area in the past. Also, it may be associated with their seed

dispersal, which is known to be facilitated by ruminants that usually browse them, and the subsequent conducive environment for seed germination and seedling development within the accompanying organic manure from animal droppings (Teketay, 1996a, b, 2005; Kalema, 2010; Neelo et al., 2013, 2015).

The 10 woody species, which had the highest stem densities also exhibited high frequency of occurrence (present in 80 to 100% of the quadrats) and dominance, that is, ground covered by the cross section of their stems (for six of the spp.). As a result, they also represented the highest IVI value, suggesting that they are ecologically the most important species than the other woody species in MNR (Kent and Coker, 1992; Zegeye et al., 2006, 2011; Senbeta and Teketay, 2003; Worku et al., 2012; Neelo et al., 2013, 2015). The IVI values are also used in conservation programmes, where species with low IVI values are prioritized for conservation (Shibru, 2002; Shibru and Balcha, 2004) and those with high IVI values need monitoring management (Gurmessa et al., 2012).

Tree size class distribution is an important indicator of changes in population structure and species composition of a forest ecosystem (Condit et al., 1998; Neelo et al., 2015). Population structure of woody species yields information on the history of past disturbance of the species and their environment (Teketay, 1997b; Wale et al., 2012; Neelo et al., 2015), which can be used to predict the future trend of the population of a particular species (Teketay, 1997b; Wilson and Witkowski, 2003; Kalema, 2010; Neelo et al., 2015). The assessment of diameter class distributions of woody species in MNR resulted in the recognition of three different patterns of the population structures. In the first group, to which only about 32% of the woody species belong, the number of individuals decreased with the increasing diameter class, resulting in an inverted J-shaped population, an indication of stable population structure or healthy regeneration status (Teketay, 1997a; Alelign et al., 2007; Tesfaye et al., 2010; Zegeye et al., 2011; Helm and Witkowski, 2012; El-Sheikh, 2013; Neelo et al., 2015). The woody species (about 68% of the woody species), which were categorized in the two other groups of population structure exhibited hampered regeneration, suggesting that the vegetation in MNR has been highly degraded as a result of a long period of open grazing/overgrazing and cutting of individuals of usable stem size. Human disturbance, particularly grazing, has been reported as the major reason for hampered or poor regeneration (Zegeye et al., 2011; Neelo et al., 2013, 2015). High browsing pressure can lead to the absence of seedlings or juveniles as a result of high seedling mortality (Tremblay et al., 2007; Negussie et al., 2008; Neelo et al., 2013, 2015).

Retaining and increasing spatial ground cover is important factor in reducing run-off and, thus, erosion (Murphy and Lodge, 2002). Additionally, widespread

vegetative ground cover reduces the impact of rainfall through energy absorption, decreases run-off, leads to elevated levels of soil infiltration and lowers siltation, levels (AGFACTS, 2005). The assessment revealed coverage of the plant matter on the ground surface at MNR of an estimated 45%, indicating that at current vegetative coverage levels, soil erosion and top soil loss will be high. The likely cause of the observed low levels of spatial ground cover is permanent grazing and overstocking, leading to further reduction in total ground cover (through grazing pressure and soil compaction) and decline in the rates of retention and infiltration (Jacobs et al., 2000). Although stocking rates at MNR have been decreasing, at current capacity, the land requirement of fauna in the reserve stands at 130% of land available (Geeves, 2015).

Hence, the MNR has implemented an ongoing strategy to reduce fauna levels. The highest density of *E. lehmanniana* at MNR, representing 7.1% ha<sup>-1</sup> of the total density of herbaceous species, is an indicator of mild overgrazing (van Oudtshoorn, 2012) that spreads well naturally in semi-arid grasslands and rapidly offers cover for exposed soils (Skerman and Riveros, 1990). Its occurrence in MNR could indicate that grazing pressure in recent years has been reduced from the previously high levels during intensive cattle grazing and initial game overstocking. Due to the plants ability to protect soils and good palatability (van Oudtshoorn, 2012), its presence in MNR is positive. Although most of the grass species present are tolerant of grazing pressure (Geeves, 2015), native grasses are known to be negatively affected by the pressures of cattle grazing (Kimball and Schiffman, 2003). Grass species represent 33.7% ha<sup>-1</sup> of the land cover at MNR (comprising of 75.5% of herbaceous species coverage), significantly below the 50% coverage expected from an Arid Savanna Biome (Mares, 1999). It is interesting to note that despite their difference in their levels of importance, 84 and 45% of the woody species and herbaceous species, respectively, represent useful sources of feed for the wild animals. On the other hand, the results also revealed that for a considerable number of species, that is, 16 and 55% of the woody species and herbaceous species, respectively, no published information could be found on their nutritional values, indicating a major gap in terms of sustainable management of MNR as a source of relatively high nutrition for the various wild animals.

## CONCLUSIONS

The results revealed that MNR contains a relatively high species, genera and family richness of both woody and herbaceous species. However, the diversity and evenness values of MNR were relatively low suggesting that individuals of a few species dominate the reserve. The density of woody species is high, though dominated by individuals of a few species, notably *D. cinerea*. Also, ten

of the species were encountered in all of the quadrats studied, and more than 50 and 61% of the woody species exhibited frequencies of 70 and 50%. The basal areas (dominance) of almost all of the woody species were negligible, which indicates the absence or inadequate number of big-sized trees, which, in turn, suggests that MNR is still at the building or recovery phase after its exposure to heavy anthropogenic impacts, especially over-stocking with its associated over-grazing. The woody species with the highest IVI values in MNR, which are indicative of high ecological importance, include *D. cinerea*, *C. apiculatum*, *S. africana*, *A. tortilis* and *E. undulata*. Out of the 44 woody species, 14 (about 32%) exhibited stable population structures, which is also indicative of good regeneration status while the rest (30 woody species = 68%) showed unstable population structures, which could be attributed to their hampered regeneration. Therefore, there is a need to investigate the factors responsible for the unstable population structures and hampered regeneration of these woody species. The study also revealed that due to exposure of MNR to past permanent grazing and overstocking, the spatial ground coverage of the herbaceous species at MNR is less than 50%, indicating that potential of the reserve as source of herbaceous feed for the wild animals is compromised while the soil is exposed to the various agents of erosion.

For the species that information is available (84 and 45% of woody species and herbaceous species, respectively), the nutritional values ranged from low to high. The proportion of woody species and herbaceous species with no information on their nutritional values is considerable (16%) and relatively high (55%), respectively. This suggests the need for embarking on research to find out how important the two groups of species are as sources of feed for animals.

The woody vegetation of MNR should be managed and regulated properly through giving due attention to the enhancement of regeneration of the woody species with the highest nutritional values and reduction of populations of aggressive species, such as *D. cinerea* and *E. undulata*. MNR should also be stocked with native herbaceous plants with the ability to protect soils from erosion and having good palatability without affecting, rather enhancing, plant diversity in the reserve.

## Conflict of Interests

The authors have not declared any conflict of interests.

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## REFERENCES

- AGFACTS (2005). Maintaining ground cover to reduce erosion and sustain production. NSW Department of Primary Industries. P2.1.14. AGDEX 340/572.
- Alelign A, Teketay D, Yemshaw Y, Edwards S (2007). Diversity and Status of Regeneration of Woody Plants on the Peninsula of Zegie, Northwestern Ethiopia. *Trop. Ecol.* 48:37-49.
- Banda T, Mwangulango N, Meyer B, Schwartz M K, Mbago F, Sungula M, Caro T (2008). The woodland vegetation of Katavi- Rukwa ecosystem in western Tanzania. *Forest Ecol. Manag.* 255:3382-3395.
- Batura A, LeSeach E, Martin E (2007). Mokolodi Nature Reserve Vegetation Assessment 2007 Report. Mokolodi Nature Reserve Conservation Department.
- Bengtsson-Sjörs K (2006). Establishment and survival of woody seedlings in a semi-arid savanna in southern Botswana. *Minor Field Study* 123, Uppsala University, Uppsala, Sweden.
- Chickono C, Choinski JS (1992). Thermotolerance characteristics of seeds from geographically isolated populations of the African tree *Combretum apiculatum* Sonder. *Afri. J. Ecol.* 30:65-73.
- Condit R, Sukumar R, Hubbell SP, Foster RB (1998). Predicting Population Trends from Size Distributions: A Direct Test in a Tropical Tree Community. *Am. Nat.* 152:495-509.
- Cooke G (1998). The Tree Species of Djuma Game Reserve. Kruger National Park, South Africa.
- David-Andersen R (2012). Mokolodi Nature Reserve Vegetation Assessment 2012 Report. Mokolodi Nature Reserve Conservation Department, Mokolodi, Botswana.
- DEA (Department of Environmental Affairs) (2008). Okavango Delta Management Plan. DEA, Gaborone, Botswana.
- Dovie DBK, Witkowski ETF, Shackleton CM (2008). Knowledge of plant resource use based on location, gender and generation. *Appl. Geogr.* 28:311-322.
- Ellery K, Ellery W (1997). *Plants of the Okavango Delta: A Field Guide*. Tsaro Publisher, Durban, South Africa.
- EI-Sheikh MA (2013). Population structure of woody plants in the arid cloud forests of Dhofar, southern Oman. *Acta Bot. Croat.* 72:97-111.
- Flyman MV (1999). The fate of woody plant seedlings in the presence and absence of large herbivores in a semi-arid savanna. Master of Philosophy Thesis, University of Botswana, Gaborone, Botswana.
- Fournet J (2004). *Dichrostachys cinerea*. Global Invasive Species Database. University of Auckland, New Zealand.
- Geeves G (2015). Mokolodi Vegetation and Carry Capacity Report 2015. Mokolodi Nature Reserve Conservation Department, Mokolodi, Botswana.
- Gurmessa F, Soromessa T, Kelbessa E (2012). Structure and Regeneration Status of Komoto Afromontane Moist Forest, East Wollega Zone, West Ethiopia. *J. Forest. Res.* 23:205-216.
- Heath A, Heath R (2010). *Field Guide to the Plants of Northern Botswana: Including the Okavango Delta*. Kew: Kew Publishing, Royal Botanic Gardens.
- Helm CV, Witkowski ETF (2012). Characterising Wide Spatial Variation. *Forest Ecol. Manag.* 263:175-188.
- Hendzel L (1981). Range management handbook for Botswana. Division of Land Utilization, Ministry of Agriculture, Gaborone, Botswana.
- Herrera A (2011). Changes in spatial structure of woody savanna vegetation after 11 years of exclusion of large herbivores. *Minor Field Study* 162, Uppsala University, Uppsala, Sweden.
- Hernández G (2002). Invasive bush in Cuba: the case of marabú. Invasive in Mesoamerica and the Caribbean. IUCN, Costa Rica ([http://www.iucn.org/places/orma/publica\\_gnl/especies.pdf](http://www.iucn.org/places/orma/publica_gnl/especies.pdf), accessed on 16-01-2016).
- Hunde A, Thulin M (1989). *Mimosoideae*. In: Hedberg I. and Edwards (eds.) *Flora of Ethiopia and Eritrea, Vol. 3*. Addis Ababa University, the National Herbarium, Addis Ababa, Ethiopia and Department of Systematic Biology, Uppsala University, Sweden.
- Jacobs SWL, Wilson KL, Morrison DA (2000). *Grasses: Systematic and Evolution*. CSIRO Publishing, Collingwood, Australia
- Kalema VN (2010). Diversity, Use and Resilience of Woody Plants in a Multiple Land-Use Equatorial African Savanna, Uganda. Ph.D. Thesis, University of the Witwatersrand, Johannesburg, South Africa.
- Kent M, Coker, P (1992). *Vegetation Description and Analysis: A Practical Approach*. John Wiley and Sons Ltd., England.
- Kimball S, Schiffman PM (2003). Differing Effects of Cattle Grazing on Native and Alien Plants. *Conserv. Biol.* 17:1681-1693.
- Krebs CJ (1989). *Ecological Methodology*. Harper Collins Publishers, New York, USA.
- Källér A (2003). Growth pattern and reproduction of woody vegetation in a semi-arid savanna in southern Botswana. *Minor Field Study* 86, Uppsala University, Uppsala, Sweden.
- Leck MA, Parker VT, Simpson RL (Eds.) (1989). *Ecology of Soil Seed Banks*. Academic Press, San Diego, USA.
- Leife H (2010). Has woody vegetation in a semi-arid savanna changed after 11 years exclusion of large herbivores? *Minor Field Study* 153, Uppsala University, Uppsala, Sweden.
- Louga EJ, Witkowski ETF, Balkwill K (2000). Differential utilisation and ethnobotany of trees in Kitulungalo Forest Reserve and surrounding communal lands, eastern Tanzania. *Econ. Bot.* 54:328-343.
- Magurran AE (2004). *Measuring Biological Diversity*. Blackwell Publishing, Malden and Oxford, UK.
- Mares MA (1999). *Encyclopedia of Deserts*. University of Oklahoma Press, Oklahoma, USA.
- Martin E, Njiru LM (2006). Mokolodi Nature Reserve Vegetation Assessment 2006 Report. Mokolodi Nature Reserve Conservation Department, Mokolodi, Botswana.
- MNR (Mokolodi Nature Reserve) (2015). Encounters with Nature – Discoveries of Nature, Mokolodi, Botswana (<http://www.mokolodi.com/index.php?sec=101>; accessed on 13-07-2015).
- Mosothwane M, Ndwapi G (2012). Training Pre-service Teachers in Environmental Education: The Case of Colleges of Education in Botswana. *Int. J. Sci. Res. Educ.* 5:26-37.
- Mothogoane MS (2012a). *Grewia bicolor* Juss. (<http://www.plantzafrica.com/plantefg/grewiabicolor.htm>, accessed on 18-01-2016).
- Mothogoane MS (2012b). *Grewia flavescens* Juss. (<http://www.plantzafrica.com/plantefg/grewiaflavescens.htm>, accessed on 18-01-2016).
- Moyroud R (2000). Exotic weeds threaten, a brief overview and early alarm call. *Wildland Weeds* 3(2):4-8.
- Murphy SR, Lodge GM (2002). Ground cover in temperate native perennial grass pastures. 1. A comparison of four estimation methods. *Rangeland J.* 24:288-300.
- Nangedo G, Steege HT, Bongers F (2006). Composition of woody species in a dynamic forest-woodland-savannah mosaic in Uganda: implications for conservation and management. *Biodiversity and Conservation* 15:1467-1495.
- Neelo J, Teketay D, Kashe K, Masamba W (2015). Stand structure, diversity and regeneration status of woody species in open and enclosed dry woodland sites around molapo farming areas in the Okavango Delta, northeastern Botswana. *Open J. Forest.* 5:313-328.
- Neelo J, Teketay D, Masamba W, Kashe K (2013). Diversity, Population Structure and Regeneration Status of Woody Species in Dry Woodlands Adjacent to Molapo Farms in Northern Botswana. *Open J. Forest.* 3:138-151.
- Negussie A, Aerts R, Gebrehiwot K, Muys B (2008). Seedling Mortality Causes Recruitment Limitation of *Boswellia papyrifera* in Northern Ethiopia. *J. Arid Environ.* 72:378-383.

- Njiru LM (2008). Mokolodi Nature Reserve Vegetation Assessment 2008 Report. Mokolodi Nature Reserve Conservation Department, Mokolodi, Botswana.
- Njiru LM (2009). Mokolodi Nature Reserve Vegetation Assessment 2009 Report. Mokolodi Nature Reserve Conservation Department, Mokolodi, Botswana.
- Njiru LM (2010). Mokolodi Nature Reserve Vegetation Assessment 2010 Report. Mokolodi Nature Reserve Conservation Department, Mokolodi, Botswana.
- Njiru LM (2011). Mokolodi Nature Reserve Vegetation Assessment 2011 Report. Mokolodi Nature Reserve Conservation Department, Mokolodi, Botswana.
- Oppelt AL (2003). Root morphology of co-occurring African fruit tree species with contrasting strategies of exploration and exploitation. Doctoral Thesis, Georg-August-Universität Göttingen, Göttingen, Germany.
- Orwa C, Mutua A, Kindt R, Jamnadass R, Anthony S (2009). Agroforestry Database: a tree reference and selection guide version 4.0. World Agroforestry Centre, Nairobi, Kenya.
- Peters CM (1996). The Ecology and Management of Non-Timber Forest Resources. World Bank Technical Paper 322, World Bank, Washington, USA.
- PIER (Pacific Island Ecosystems at Risk) (1999). *Dichrostachys cinerea*. PIER, Hawaii, USA ([http://www.hear.org/pier/species/dichrostachys\\_cinerea.htm](http://www.hear.org/pier/species/dichrostachys_cinerea.htm), accessed on 16-01-2016).
- Roodt V (1993). The Shell Field Guide to the Common Trees of the Okavango Delta and Moremi Game Reserve. Shell Oil (Pty) Ltd., Gaborone, Botswana.
- Roodt V (1998). Trees and Shrubs of the Okavango Delta. Shell Oil Botswana (Pty) Ltd., Gaborone, Botswana.
- Savadogo P, Tigabu M, Sawadogo L, Odén P-C (2007). Woody species composition, structure and diversity of vegetation patches of a Sudanian savanna in Burkina Faso. *Bois et Forêts des Tropiques* 294:7-20.
- Schroder B (2001). Mokolodi Nature Reserve Vegetation Assessment 2001 Report. Mokolodi Nature Reserve Conservation Department, Mokolodi, Botswana.
- Senbeta F, Teketay D (2003). Diversity, Community Types and Population Structure of Woody Plants in Kimphee Forest, a Unique Nature Reserve in Southern Ethiopia. *Ethiop. J. Biol. Sci.* 2:169-187.
- Setshogo MP (2002). Common Names of Some Flowering Plants of Botswana. FAO, Rome, Italy.
- Setshogo MP (2005). Preliminary Checklist of the Plants of Botswana. Southern African Botanical Diversity Network (SABONET), Pretoria, South Africa.
- Setshogo MP, Venter F (2003). Trees of Botswana: Names and Distribution. Southern African Botanical Diversity Network (SABONET), Pretoria, South Africa.
- Shibru S (2002). Inventory of Woody Species in Dindin Forest. Technical Report No. 01, IBCR/GTZ/FGRC, Addis Ababa, Ethiopia.
- Shibru S, Balcha G (2004). Composition, Structure and Regeneration Status of Woody Species in Dindin Natural Forest. *Ethiop. J. Biol. Sci.* 3:15-35.
- Skerman PJ, Riveros F (1990). Tropical grasses. FAO Plant Production and Protection Series No. 23, FAO, Rome, Italy.
- Smith GN (2003). The coppicing ability of *Acacia erubescens* and *Combretum apiculatum* subsp. *apiculatum* in response to cutting. *Afric. J. Range Forage Sci.* 20:21-27.
- SANBI (South African National Biodiversity Institute) (2011). *Dichrostachys cinerea*. SANBI, Pretoria, South Africa.
- Teketay D (1996a). Seed Ecology and Regeneration in Dry Afromontane Forests of Ethiopia. Ph.D. Thesis, Swedish University of Agricultural Sciences, Umeå, Sweden. Eight Exotic Multipurpose Leguminous Species from Ethiopia.
- Teketay D (1996b). Germination Ecology of Twelve Indigenous and Ecology and Management 80:209-223.
- Teketay D (1997a). Germination Ecology of *Acacia negrii*, an Endemic Multipurpose Tree from Ethiopia. *Tropical Ecology* 38:39-46.
- Teketay D (1997b). Seedling Populations and Regeneration of Woody Species in Dry Afromontane Forests of Ethiopia. *Forest Ecol. Manag.* 98:149-165.
- Teketay D (2005). Seed and Regeneration Ecology in Dry Afromontane Forests of Ethiopia: I. Seed Production-Population Structures. *Trop. J. Ecol.* 46:29-44.
- Teketay D, Kashe K, Madome J, Kabelo M, Neelo J, Mmusi M, Masamba W (2016). Enhancement of diversity, stand structure and regeneration of woody species through area exclosures: the case of a mopane woodland in northern Botswana. In: Birhane E, Tewoldebirhan S, Samuel G, Girmay G (Eds.) Restoration of degraded lands through exclosures (accepted).
- Tesfaye G, Teketay D, Fetene M, Beck E (2010) Regeneration of Seven Indigenous Tree Species in a Dry Afromontane Forest, Southern Ethiopia. *Flora* 205:135-143.
- Tews J, Moloney K, Jeltsch F (2004). Modelling seed dispersal in a variable environment: a case study of the fleshy-fruited savanna shrub *Grewia flava*. *Ecol. Modelling* 175:65-76.
- Tews J, Schurr F, Jeltsch F (2004). Seed dispersal by cattle may cause shrub encroachment of *Grewia flava* on southern Kalahari rangelands. *Appl. Veg. Sci.* 7:89-102.
- Timberlake J (1980). Handbook of Botswana Acacias. Ministry of Agriculture, Gaborone, Botswana.
- Tremblay JP, Huot J, Potvin F (2007). Density-Related Effects of Deer Browsing on the Regeneration Dynamics of Boreal Forests. *J. Appl. Ecol.* 44:552-562.
- van Oudtshoorn F (2012). Guide to Grasses of Southern Africa. Briza Publications, Pretoria, South Africa.
- van Rooyen N (2010). Veld management principles and procedures. In: Bothma JduP, Toit JGdu (eds). Game ranch management, 5<sup>th</sup> edition, Van Schaik, Pretoria, South Africa, pp. 778-831.
- van Wyk B, van Wyk P (1997). Field Guide to Trees of Southern Africa. Struik Nature, Cape Town, South Africa.
- van Wyk B, van Wyk P (2007). How to Identify Trees in Southern Africa. Struik Nature, Cape Town, South Africa.
- Venter SM, Witkowski ETF (2010). Baobab (*Adansonia digitata* L.) Density, Size-Class Distribution and Population Trends between Four Land-Use Types in Northern Venda, South Africa. *Forest Ecol. Manag.* 259:294-300.
- von Maydell H-J (1986). Trees and Shrubs of the Sahel: Their Characteristics and Uses. GTZ, Eschborn, Germany.
- Wale HA, Bekele T, Dalle G (2012). Floristic Diversity, Regeneration Status and Vegetation Structure of Woodlands in Metema Area, Amhara National Regional State, Northwestern Ethiopia. *J. Forest. Res.* 23:391-398.
- Wilson BG, Witkowski ETF (2003). Seed banks, bark thickness and change in age and size structure (1997-1999) of the African savanna tree. *Burkea africana*. *Plant Ecol.* 167:151-162.
- Woldemariam T, Teketay D, Edwards S, Olsson M (2000). Woody plant and avian species diversity in a dry Afromontane forest on the central plateau of Ethiopia: Biological indicators for conservation. *Ethiop. J. Nat. Res.* 2:255-293.
- Worku A, Teketay D, Lemenih M, Fetene M (2012). Diversity Regeneration Status and Population Structure of Gum and Resin Producing Woody Species in Borana, Southern Ethiopia. *Forests, Trees and Livelihoods* 21(2):85-96.
- World Agroforestry Centre (2005). Agroforestry Database. ICRAF, Nairobi, Kenya.
- World Bank (2012) Terrestrial protected areas (% of total land area) (<http://data.worldbank.org>, accessed on 08-12-2015).
- Yilma Z, Worku A, Mohammed O, Girma A, Dejene T, Eshete A, Teketay D, Teshome M, Tadesse W (2015). Status of populations of gum and resin bearing and associated woody species in Benishangul-Gumuz National Regional State, western Ethiopia: Implications for their sustainable management. *Forests, Trees Livelihoods* 25(1):1-15.
- Zegeye H, Teketay D, Kelbessa E (2006). Diversity, Regeneration Status and Socio-Economic Importance of the Vegetation in the Islands of Lake Ziway, South-Central Ethiopia. *Flora* 201:483-498.
- Zegeye H, Teketay D, Kelbessa E (2011). Diversity and Regeneration Status of Woody Species in Tara Gedam and Abeyaye Forests, Northwestern Ethiopia. *J. Forest. Res.* 22:315-328.