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Review

Black Crowned crane (*Balearica pavonina* L.) conservation guideline in Chora Boter district of Jimma zone: The case of Ethiopia

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This guideline has been developed to provide directions for people working and interested to work on the conservation of Black Crowned cranes to save the species from loss and extinction. The conservation guideline is developed in consultations with the local communities and stakeholders in Ethiopia, Jimma zone, Chora Boter district through: field survey, focused group discussions, community and multi-stakeholders workshop from March 2015 to January 2016. Local communities and stakeholders participations are crucial in any conservation plan. This guideline present overviews of Black Crowned cranes conservation and its importance's, the role of people and social medias in conservation, the importance of pre-defined conservation strategies, and lastly, how to secure fund for Black Crowned crane conservation.

Key words: Black crowned cranes, conservation, Ethiopia, guideline, local communities.

INTRODUCTION

What is conservation?

The dictionary meaning of conservation is the act of conserving; prevention, decay, or loss; preservation. In biology context, conservation is the science of protection and management of biodiversity. Conservation as a movement focused on natural resource use, allocation and protection (Soule, 1985; McCormick, 1991). Conservation is needed in response to biodiversity threats and loss and to transferee to future generations. Conservation practitioners and environmentalist struggle to identify and mitigate species threats, declines, restore degraded ecosystems and manage natural resource sustainably (Cooke et al., 2013). We live in global wave of anthropogenic driven biodiversity loss: species and population extirpations and also, critically, declines in local abundance of species (Dirzo et al., 2014). For the sake of daily survival, human beings overexploited biodiversity (Peres, 2010). Destructions of natural habitat are the major threat that affects the life of species (IUCN, 2014). According to the IUCN estimation currently, over 22, 000 species were threatened out of which 85%

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were associated with habitat loss. It is clear that human population growth and its basic needs is increasingly affecting the life of biodiversity and enhances pressures on this natural environment. In order to overcome the increasing global and local threats to marine and costal ecosystems, worldwide plans of actions with ambitious conservation guidelines has been established by international community (Butchart et al., 2010).

Biodiversity loss is one of the global challenges that we all encounter due to over exploitation of natural resources by human beings. Human beings drive both threats to biodiversity and its conservation. Because of this fact, human beings are considered as the destructor as well as the builder of the natural environment. Conservation needs to be done by humans. Conservation today is an evidence-based problem solving science (Musengezi, 2015). Human pressure on world natural habitat is increasing from time to time which leads to reduction of space for various species. According to the Millennium Ecosystem Assessment report of 2005, human beings have changed the world ecosystems more rapidly and extensively than ever before over the past fifty years to meet rapidly growing demand for food, fresh water, timber, fiber and fuel.

Why conservation?

Conservation is important to prevent floods, fires, desertification and drought. Conservation is crucial to understand the resource we have and what we can leave for future generation. According to the United Nations Convections on Biological Diversity of 1992, conservation is crucial to conserve and sustainably use of biological diversity for the benefit of present and future generations. Article 13 of United Nations Convections on Biological Diversity, stated that ‘‘promoting and encourage understanding the importance of biological diversity conservation as well as its propagation through media, and the inclusion of these topics in educational programmes are important with respect to conservation and sustainable use of biological diversity’’. Even though science is revealing that some local successes and increasing response of biodiversity loss, no significant recent reductions rate and the pressures on biodiversity showed increased (Butchart et al., 2010). The disappearance of birds can help us in evaluating the dangers to the environment (Balasubramanian, 2010). Similar to other species conservations, bird conservation is important for both humans and environment since they played an important role in ecological, social and economic value and also scientific significance.

BLACK CROWNED CRANE

The Black Crowned crane is one of the six crane species in Africa (Harris and Mirande, 2013). Black Crowned crane is a bird in the crane family of Gruidae with black legs, dark plumage and its head is topped with graced with crown of stiff golden feathers (Figure 1). The species is categorized as vulnerable (IUCN, 2012). Geographically, its home range extends from Senegal and Gambia on the Atlantic coast to the upper Nile River basin in Sudan and the Ethiopia highlands (Boere et al., 2006). Its population is declining and even in some countries disappearing (Meine and Archibeld, 1996; Beilfuss et al., 2007; IUCN, 2012; Harris and Mirande, 2013). It is predicted that the population decline will continuous in the future due to habitat loss (IUCN, 2012). In the population range countries, wetland degradation and lose is become serious threat for the species survival. Birds are extinct from one region probably due to environmental disturbances that occurs due to nature and anthropogenic induce. Habitat loss due to lack of clear wetland protection and weak rules and regulations are the major factors that affect the Black Crowned cranes in Ethiopia (Aynalem et al., 2012). Destruction of breeding and feeding habitats and killing of chicks by children are also other factors that affect the life of Black Crowned Crane in Ethiopia (Aynalem et al., 2010).

Threats to Black Crowned crane conservation in Chora Boter district

Based on our field survey, household interview, focused group discussions, community and stakeholders workshop, we conclude that the Black crowned cranes are under threat in Jimma zone. Gemeda et al. (2016) conclude that the local communities are converting wetlands to agricultural fields that threatens the breeding and nesting sites of Black Crowned cranes in Chora boter district of Jimma zone. If wetland degradation and loss is continued in the future without conservation intervention, the Black crowned cranes should be either extinct or migrated to other areas for searching of feeding and breeding. The local communities described that habitat loss and degradation, depletion of water resources, wetland draining for irrigation purpose, siltation of wetlands because environmental degradation, over-grazing in wetlands buffer zone, human disturbance and lack of awareness about the socio-ecological values of wetlands from the community are the major threats of Black Crowned cranes in Chora boter distric.

Enhancing Black Crowned Crane Conservation along the communities

The community living nearby the wetlands (the breeding, nesting ground, feeding ecology and potential habitat) of Black Crowned Crane will be involved in conservation. It is crucial to involve the local people and stakeholders in

Figure 1: Pair of Black Crowned crane

Black Crowned Crane conservation plans (Figure 2). Involving the local people and stakeholders in any conservation project will increase the accountability and belongingness of the people on the desired project. It is clear that any conservation initiative without local people acceptance will likely not be successful while conservation plan that have been developed and agreed upon with the local communities, in many cases, survive over the long term and also successful (IWMI, 2014). The success of any conservation plan is based on active participation of the local community and stakeholder's. For the implementation of conservation campaign all sectors and individuals will contribute their own capacity as much as possible since all of us share the same finite resources in this world. It is better if different experts are involved and contributes their own roles and capacity without restricting their specializations. Conservation is not the task of biologist only but also social scientist will contribute in many ways through changing the perception of people towards conservations. The process of developing a conservation approaches jointly with the local communities will be essentials to make the designed conservation successful and sustainable.

Economic importance's of birds' conservation

Bird- watchers are the source of tourist attraction in several countries. Diversity of birds and calls of birds constituted a major component of visitor satisfaction (Tisdell and Wilson, 2004). About 40% of American birders are willing to travel to discover new bird-watching opportunities (Birdlife International, 2015). Bird-watching tourism world-wide appears to be growing rapidly amongst Western travelers which substantially enhance local economies (Jones and Buckley, 2001). Many countries across the world are happy to introduce their countries by using birds. For instance, about 43 airlines bears birds on airlines and many countries used as stamp designers and postal services to feature the birds as national messengers to be sent around the globe. From bird species, six airlines bear the crane, in different designs, on their tail unit of their planes: Lufthansa, German; Shanghai airlines, China Eastern Airlines; Xiamen airlines, China Southern airlines; Japans' airlines; Polish airlines and Uganda airlines.

Objectives

The aim of this guideline is to reduce the threats of the Black Crowned cranes in Chora boter district of Jimma zone of Ethiopia. In order to do so, the guideline describes various activities that will ensure its conservation through communities and stakeholders participations.

Figure 2: The local community participations on Black Crowned crane conservation issues

Geographical descriptions of Chora Boter District

The guideline is developed for Chora Boter district in Jimma zone. Chora Boter is located in Jimma zone in Oromia Regional state in Ethiopia. Jimma zone has a total population of 2,607,115 out of which 1,311,351 (50.30%) were males and 1,295,764 (49.70%) were females. Similar to other regions in Ethiopia more than 80% of the population lives in rural areas. Chora boter is found in Jimma Zone in Oromia Regional States in Southwestern Ethiopia. The total land area of the district is 1478 km^2 (Oromia Economic and Finance Bureau, 2012). Chora boter shares boundaries with four districts and one zone namely Limu Kosa and Tiro Afeta in the south, Sokoru in south west, Limu Seka in the north east and South west shewa zone in the north east. The altitude of the district varies from 650 to 2320 mas. Chora boter is splited from Limu district in November 2005. The total population of Limu district is 91,738, of whom 46,454 were men and 45,284 were women; 90,695 (98.86%) of the population were rulal and 1,043 (1.14%) of the population were urban dwellers (Central Statics Authority (CSA), 2007). According to the CSA report of 2007 the district has 20,604 households out of which 20,322 (98.63%) were rural and 285 (1.37%) were urban. In Chora Boter district two crane species namely: Black Crowned cranes and Wattled cranes are residents throughout the year.

BOTTOM-UP AND TOP-DOWN CONSERVATION APPROACH

Developing strategy is essential to choosing the best methodology to reach the researcher's final targets or destinations. Designing strategy helps anybody who works on conservation. The researcher needs to involve all key stakeholders, to agree on his objective, and to also have a time and cost budget for the implementation of any project. Conservation campaign is not a simple task that accomplished over a couple of months or years, but it takes a long time and you have to be tolerant to overcome the strong challenges from the communities sides since they are dependent on natural resources. To overcome such challenges, it is important to investigate the best strategy to save the biodiversity from threats. No single strategy is sufficient to address the issue of conservation. The combination of bottom-up and top-down approach should be considered to established effective and acceptable conservation plan. The bottom-up approach refers to changing the attitude and perceptions of local communities towards conservation at

the grassroots level; enhancing the capacity of the local communities to change their understanding on the use of conservation practices where as the top-down approaches which involves conservation interventions with the support of governmental organization that have the capacity to mobilize and change the society on a large scale (Musengezi, 2015). Developing priority setting and planning at much finer scales is necessary to allow implementation on the ground (Brooks et al., 2006). Clear guidelines and policies should be designed through a joint approach which involves all relevant stakeholders: the local communities, local administration unit head, district and zonal officials, universities and research institutes and Civil Society Organizations and relevant NGOs should contribute their experiences and practices to prevent the loss of species.

Use of social media and publisher

Enhancing the issue of conservations and scaling up communication with stakeholders, friends, colleagues and local communities at large through social media: face books, Twitter, and YouTube to share the best practices on conservation success that will make your conservation project grateful. Similar to success, sharing constraints might be also important because your friends or other concerned organs forward their comments and suggestions for improvement and also they link to others experts for advice. In addition to social medias the conservationist can publish their best practices of conservation on peer reviewed international journals and share the published documents and upload on research gates to avail your article for any users across the world. Project verifications documents: photos during field work, group discussions, stakeholder's and community workshop, public presentation at local, regional, national and international levels should be documented. Sell your findings at every stage you get the opportunities like national and international conference proceedings and workshop. Enhance strong relationships with other experts who work on your thematic areas. Progress report will be compiled and documented for evaluation of the project.

Conservation of Black Crowned Cranes needs a collaboration and team efforts from various sectors: local governmental structures like agricultural office, land and environmental protection office, forest and wildlife enterprise office, culture and tourism; private sectors; civil society organization mainly community based organization, research institutes, universities and schools will be involved in conservation. Similar to internal stakeholders and organizations, international donors and organization also played an important role both in consultancy and advice services as well as in providing seed money. Any conservation plan needs money to implement on the ground. To secure fund for conservation, any motivated conservationist can develop project proposals and apply to various organizations for support.

Fund raising mechanisms for Black Crowned crane conservation

Searching fund opportunity on internet is easy, but the difficult thing is getting suitable call for proposal that is relevant to your project. If somebody is not familiar with securing funds from donors, it is good to consult someone who has a good experience, enhancing their capacity through training and workshop on proposal writing and fundraising workshop when they have a chance to get such circumstances and opportunities. We can also visit and check the announcements of funding organizations like www.terraviva, grants.org, www.fundsforngos.org, and other organizations. Before starting proposal writing for project fund, you should check the following points:

1. Ensure eligibility of your project for the donors.
2. Check priorities areas of the donors.
3. Check geographical restrictions of the donors (if any).
4. Check deadline for applications.
5. Check maximum amounts of money that the donors will support.
6. Read strictly the guidelines of the application format and word and pages limits and act accordingly.
7. Take sufficient times to prepare a sound research and conservation project.
8. Increasing the possibilities of financing for conservation activities.
9. Requesting your friends and experts for comments and edit before you send your applications to the donor.
10. Incorporate the comments and suggestion you received and upload your application.
11. Make sure that the budget and timeline of your project is realistic and justified.
12. Search other co-funding including in-kind contributions for your project.
13. Be patient to heard the final decisions of the donors by considering 50% pass and fail.
14. Do not fear regret message from the donors if your project is not successful.
15. Minimize confidence on one donors because the probability of pass and fail is equal.
16. If your proposals if rejected do not throw away since you can revise and re-sent again either to the same donors or others based on your eligibility.
17. Share your success stories to your donors and others potential organization for future work and plan.
18. Sell your findings and performance you did so far at any chance you get.

Other sources of funding for conservation project

1. Local and national governmental organizations

2. University and research institutes
3. Civil society organizations
4. Think tank organizations
5. Private investors
6. Individual donors

To implement the conservation plan of Black Crowned cranes and ensure its sustainability, the following key points will be addressed:
1. Using research based-evidence to launch and start mass mobilization towards Black Crowned crane conservation.
2. Developing a common consensus with stakeholders on Black Crowned cranes conservation.
3. Identifications of key organization that works on conservation areas.
4. Working with multi-stakeholders.
5. Ensure that all stakeholders are communicated in advance before starting any project.
6. Bringing different experts together to develop the way forward for conservation.
7. Empowering the local communities and stakeholders on conservation activities.
8. Educating the local communities to minimize overgrazing around wetlands buffer zone.
9. Conducting population monitoring of the Black Crowned cranes to check their dynamics.
10. Talk to people and motivate them to participate in conservation.
11. Respecting the opinion of the local communities and add your own.
12. Engaging young people; the future generation on conservation campaign.
13. Training the communities on the socio-ecological importance of wetlands.
14. Training the community and the stakeholders on Ecosystem services: provisioning services, regulating services, cultural services and supporting services of wetlands.
15. Conducting community and stakeholders workshop on Black Crowned cranes at village, district, zonal level and beyond based on resource you secured already.
16. Raise awareness on environmental protection and wetland conservations.
17. Promotion of the beautifulness and attractiveness of the Black Crowned cranes on social medias like face books. and Twitter by publishing high resolution pictures and developing documentary film on crane dancing, walking and flying
18. Conducting monitoring and evaluation of Black Crowned cranes conservation project.

Through the implementation of the above listed key activities, Black Crowned cranes will face fewer threats; the local communities will understand the values of ecosystem services. After confirming the positive attitudes of the community towards Black Crowned Cranes and its habitat conservation through outreach activities in the form of workshop, training, individuals and focus group discussions we can excel our conservation action to other districts in Jimma zone and later we can cascade to other areas in Oromia Regional State and beyond.

MONITORING AND EVALUATION

Project monitoring is crucial to check whether the designed project addressed the formulated objectives or not. Similar to monitoring, project evaluation is also important due to the fact that, we can evaluate ourselves concerning what has been successful so far and what has unsuccessful because of various factors. If your project is failed in the middle you can develop best strategies for future projects to overcome the potential challenges and obstacles during project implementations.

Conflict of Interests

The authors have not declared any conflict of interest.

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REFERENCES

Aynalem S, Nowald G, Schroder W (2010). Biology and Ecology of Cranes; Wattled Cranes (*GrusCaruncucatus*), Black Crowned Cranes (*Balearicapavonina*), and Eurasian Cranes (*GrusGrus*) at Lake Tana, Ethiopia. (Eds) Nowald G, Weber A, Fanke J, Weinhardt E, Donner N (Eds) 2013. Proceedings of the 7th European Crane Conference-Breeding, resting, migration and biology, Crane Conservation German. GroßMohrdorf.

Aynalem S, Archibald GW, Branch J, Geiler D (2012). Survey of Wattled Cranes, Black Crowned cranes and Eurasian cranes in Ethiopia. (Eds) Mabhachi O (2012). Community Project Coordinator African Crane Conservation Program ICF/EWT Partnership, South Africa.African Cranes, Wetlands and Communities Newsletter 12.

Balasubramanian, S (2010). Why save birds? https://wildlifemusings.wordpress.com/2010/05/24/why-save-birds

Beilfuss RD, Dodman T, and Urban EK (2007). The Status of Cranes in Africa in 2005. Ostrich: J. Afr. Ornithol. 78(2):175-184.

Birdlife International (2007). Conserving Biodiversity in Africa:Guidelines for Applying the Site Support Group Approach. ICIPE Science Press, Nairobi, Kenya.

Birdlife International (2012). Balearicapavonina. The IUCN Red List of Threatened Species 2012.http://www.iucnredlist.org/details/22692039/0 (Assessed on November 8, 2015).

Birdlife International (2015). http://migratorysoaringbirds.undp.birdlife.org/en/sectors/tourism.

Boere GC, Galbraith CA, Stroud DA, Eds. (2006). Waterbirds around

the World. The Stationary office, Edinburgh, UK, P 960.
Brooks TM, Mittermeier RA, da Fonseca GA, Gerlach J, Hoffmann M, Lamoreux JF, Rodrigues AS (2006). Global biodiversity conservation priorities. Sci. 313:58-61.
Butchart SHM, Walpole M, Collen B, Van Strien A, Scharlemann JP, Almond RE, Baillie JE, Bomhard B, Brown C, Bruno J, Carpenter KE (2010). Global biodiversity: indicators of recent declines. Sci. 328:1164-1168.
Central Statics Authority (2007). Ethiopian Population and Housing Census Results.
Cooke SJ, Sack L, Franklin CE, Farrell AP, Beardall J, Wikelski M, Chown SL (2013). What is conservation Physiology? Perspectives on an increasingly integrated and essential science. Conserv. Physiol. 1 (1).
Dirzo R, Young HS, Galetti M, Ceballos G, Isaac NJB, Collen B (2014). Defaunation in the Anthropocene. Sci. 345(6195):401-406. http://nora.nerc.ac.uk/508443 (Assessed on January 10, 2016).
Gemeda DO, Minstro AA, Feyssa DH, Sima DS, Gutema TM (2016). Community Knowledge, attitude and practice towards black crowned crane (*Balearica pavonina* L.) Conservation in Chora boter district of Jimma zone, Ethiopia. J. Ecol. Nat. Environ. 8(4):40-48.
Harris J, Mirarande C (2013). A global overview of Cranes: Status, threats and conservation priorities, International Crane Foundation, Baraboo, USA, Chinese Birds 4(3):189-209.
International Union for the Conservation of Nature (IUCN) (2014). http://www.iucnredlist.org.
International Water Management Institute (IWMI). 2014. Wetlands and People. Colombo, Sri Lanka. P 32.
Jones DN, Buckley R (2001). Bird-Watching tourism in Australia, Wildlife Tourism Research Report Series No. 7, Status Assessment of Wildlife Tourism in Australia Series, CRC for Sustainable Tourism.
McCormick J (1991). Reclaming Paradise: The Global Environmental Movement, vol 660. Indian University Press, Bloomington.
Meine CD, Archibald GW (1996). The Cranes: Status Survey and Conservation Action plan. IUCN, Gland, Switzerland, and Cambridge, UK, P 294.
Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington, DC. http://www.millenniumassessment.org/documents/document.356.aspx.pdf (Assessed on January 10, 2016).
Musengezi J (2015). Contemporary Conservation: Introducing conservation, United for wildlife. https://learn.unitedforwildlife.org/mod/lesson/view.php?id=648 (Assessed on January 18, 2016).
Oromia Economic and Finance Bureau (2012). The National Regional Government of Ethiopia, Bureau of Finance and Economic Development.http://www.oromiabofed.org/index.php?option=com_content&view=category&id=46&layout=blog&Itemid=63 (Assessed on January 20, 2016).
Peres CA (2010). Overexploitation. Conservation biology for all. 107-130. Oxford University Press. http://conbio.org/images/content publications/chapter6.pdf
Soulé ME (1985). What is conservation biololgy? Biosci. 35:727-734.
Tisdell C, Wilson C (2004). Economics, Wildlife tourism and conservation ecology and the environment, working paper No. 112, School of Economics, The University of Queensland.
United Nations (1992). Convention on Biological Diversity. https://www.cbd.int/doc/legal/cbd-en.pdf

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Full Length Research Paper

On-farm diversity of sorghum [*Sorghum bicolor* (L.) Moench] and risks of varietal erosion in four regions of Burkina Faso

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Local sorghum varieties managed and cultivated by farmers contribute in a large part in crop production of Burkina Faso. The loss of local sorghum varieties were reported, but very few investigations have been made on it. This study was conducted to assess the status of 739 local sorghum varieties collected in four regions of Burkina Faso and to identify the threats factors of sorghum diversity. A sample of 159 varieties identified as "rare" and described by the cycle length, the uses and disadvantageous characteristics has been submitted to a Multiple Correspondence Analysis (MCA) to determine sorghums groups and characterize them. The results showed a higher varietal richness in the North, East and Centre-East regions compared to the South-West region, with respectively 13.0; 11.7; 10.9 and 6.1 varieties per village. The MCA underlined four main groups of sorghum: custom sorghums, lain period sorghums and tincture sorghums, pharmacopeia sorghums and sweet-stem sorghums; they are characterized by lateness associated to the low grain productivity, earliness associated to the low grain quality, drought sensitivity. For these sorghums groups it appears that the climatic and socio-cultural changes are the main threats factors of sorghum diversity loss. Farmers' associations at regional level and research structures should in common develop suitable initiatives to follow-up and conserve sorghum diversity.

Key words: Sorghum, local varieties, lateness, decline of uses, erosion.

INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is a subsistence crop for many farmers in the semi-arid tropics in Africa. The cropping systems based on sorghum used manly local varieties which are part of their strategy to reduce the risks in the constraining areas. Teshome et al. (1999b) have defined the local varieties as "variable plant populations adapted to local agro-climatic conditions which are named, selected and maintained by the

traditional farmers to meet their social, economic, cultural and ecological needs".

The grain sorghum is the first food crop in Burkina Faso, with an annual average production of 1.7 million ton, which ranks the country in the fourth highest African producer behind Nigeria, Ethiopia and Sudan (FAOSTAT, 2015). Sorghum is cultivated for human consumption. The production is mainly ensured by local varieties (98%) (MASA, 2014) which are diversified and belong mostly (93%) to the botanical race guinea (Sapin, 1984; Zongo, 1991; Barro-Kondombo et al., 2008). The guinea varieties are rustic, well adapted to low agronomic conditions and climatic uncertainties (Vaksmann et al., 1996; Clerget et al., 2004; Kouressy et al., 2008); moreover their grain quality is well suited to the various local processing.

In Burkina Faso, the variability of rainy season (irregularity, drought, etc.), degradation of soil fertility and insufficiency of arable farmland in some regions are the major constraints of sorghum production (MASA, 2014). Sorghum is grown under rainfed conditions on variable surfaces size often on families' farms. The dominant cropping system is extensive type (60% of households) with low or no use of mineral fertilizers. The growing areas devoted to each variety depend on its socio-economic and cultural importance. Delauney et al. (2008) reported in Burkina Faso that one season to another 70 to 90% of sorghum seeds used by farmers are auto-produced in their own farms.

Many studies have shown a great preference of local sorghum varieties in traditional farming systems in Africa. Farmers are attached to local varieties for different reasons: cultural practices and food preferences (Barnaud et al., 2007; Missihoun et al., 2012; Muui et al., 2013), biophysical, pests and diseases constraints (Teshome et al., 1997; 1999a; Seboka and Hintum, 2006; Mekbib et al., 2009). The diversity of characters allows each farmer to find the variety that suits to his context and his production objectives; that is why, Wood and Lenné (1997) underlined that "local varieties are a key component for traditional cropping systems"; they provide food security and well-being of traditional households (Cavatassi et al., 2005).

The importance and the role of plant genetic resources have been reported by Frankel (1974), Altieri and Merrick (1987), Bellon (1996), Wood and Lenné (1997). The threats in plant genetic resources of cultivated plants are various (Brush, 1986; Mercer and Perales, 2010); their loss will threaten the future generations (FAO, 1996). Burkina Faso like others countries in the world has led sorghum germplasm collections between 1960 and 2010 that are conserved ex-situ (vom Brocke et al., 2014). Some characterizations have been done (Zongo, 1991; Barro- Kondombo et al., 2010), but to date few information have been reported on local sorghum varieties erosion. The objective of this study is to assess the status of the local sorghum diversity grown in four regions of Burkina Faso and to identify the threats factors of diversity loss based on collection and climatic data.

MATERIALS AND METHODS

Collection areas

Local sorghum varieties have been collected in 2009 and 2010 in 73 villages of four regions of Burkina Faso: Centre-East, East, North, and South-West. The sampling areas are located between 9°27' and 14°18' North parallel and between the meridians 3°49' West and 2°20' East. The average annual rainfall varies from 500 mm in the North to 1100 mm in the South-West (Figure 1) (National Direction of Meteorology, 2011). Table 1 gives the agroclimatic variations in the study area.

Germplasm collection

The collection was preceded by a participatory diagnostic in each village. During the interview with farmers the varieties which still grown almost everywhere in the village, those threatened and those lost were inventoried. Each variety was nominated by its local name (vernacular name and synonymous). The farmers group provided the background of each variety: the status (local or improved variety), the origin [inherited from parents, introduced (purchasing, gift, etc.)], the date of the first introduction in the village, the frequency (abundance, rare, etc.), the uses, the local knowledge for each variety, the advantageous and disadvantageous agronomic characteristics and the factors that affect sorghum production and varietal diversity. Each farmer donor indicated how collected variety was managed in his farm. The varieties were collected according to their local names in each village. Fifteen (15) to 39 leaders of household (men, rare women and chief of village) have participated to group discussion in the villages.

Data analysis

Seven hundred and thirty-nine (739) local sorghum varieties were analysed in this study; among this material, 159 rare varieties threatened of loss in 66 villages were used to determine the threats factors of sorghum varietal erosion. Fifteen modalities of three descriptive variables were used in a Multiple Correspondence Analysis (MCA) (Escofier and Pagès, 1998) to establish the groups structure, these are: i) the cycle length (short cycle, intermediate cycle, long cycle); ii) the uses [fresh consumption, lain period sorghums, custom, ordinary consumption (thick porridge, local beer, etc.), consumed as rice, pharmacopeia, tincture, sweet-stem]; iii) the disadvantageous characteristics (unsuitable panicle shape according to farmers opinion, low grain quality, low productivity and sensitivity to drought). The village was setting as an additional variable. The analysis was led with XLSTAT software, version 2015.17.6 (Addinsoft 2015).

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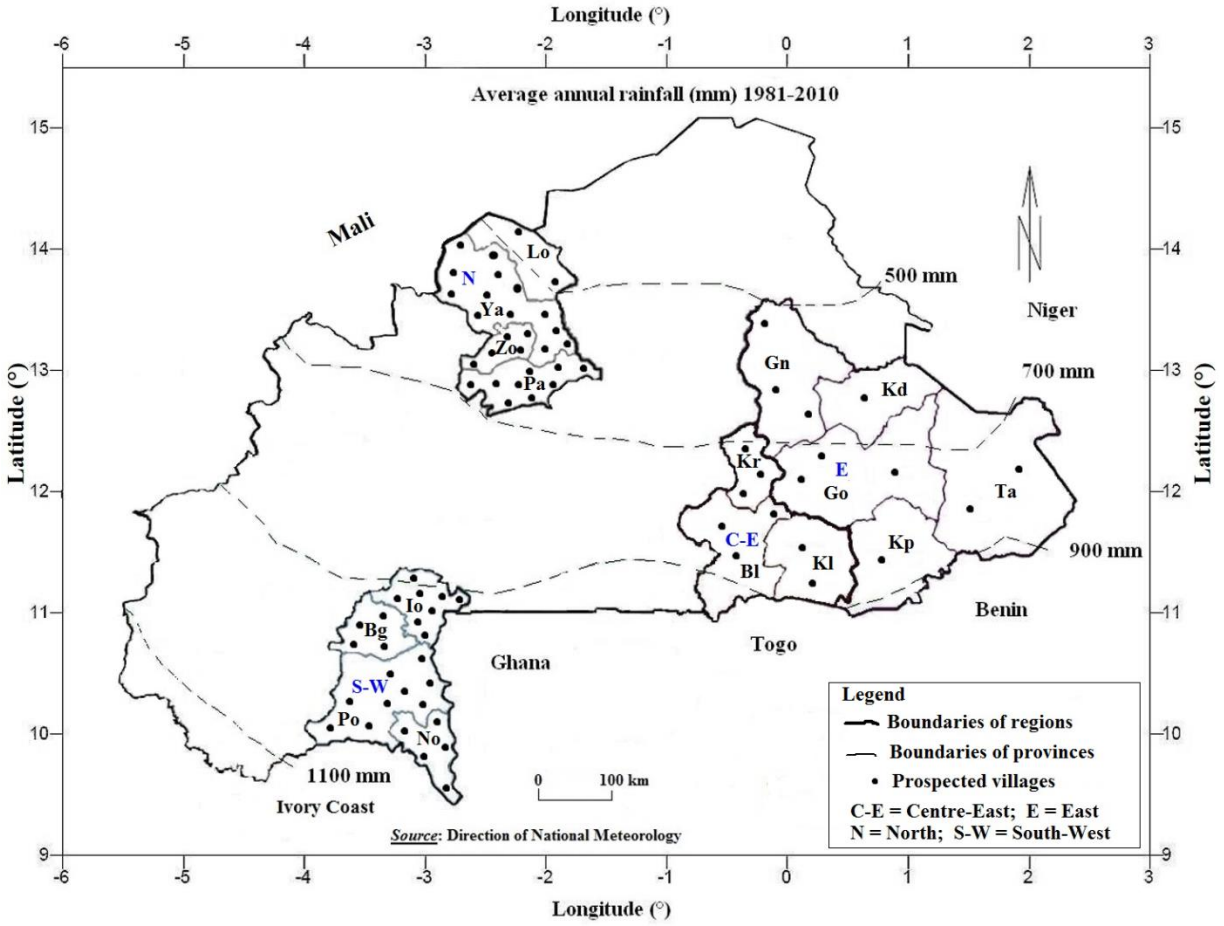

Figure 1. Climatic zones of Burkina Faso and geographical locations of the 73 surveyed villages (National Direction of Meteorology, 2011; Ministry of Territorial Administration, 2010). Centre-East [Boulgou (Bl), Koulpélogo (Kl), Kouritenga (Kr)]; East [Gnagna (Gn), Gourma (Go), Komondjari (Kd), Kompienga (Kp), Tapoa (Ta)]; North [Lorum (Lo), Passoré (Pa), Yatenga (Ya), Zondoma (Zo)]; South-West [Bougouriba (Bg), Ioba (Io), Noumbiel (No), Poni (Po)].

Table 1. Agroclimatic variations in the four regions of study (Source: DGAT, 2006; National Direction of Meteorology, 2011)

Region	Altitude (m)	Land forms	Types of dominant soil	Temperature (°C)	Rainfall (mm)	Rainfall duration (month)
Centre-East	200	Upland, Lowland, Hills	Ferric-lixisol, Vertisol	13-42	700-950	5-6
East	100-200	Upland, Lowland, Hills	Ferric-lixisol, Oxisols	13-43 13-42	500-700 700-950	4 5-6
North	200-400	Upland, Lowland, Hills	Lithosols, Ferric-lixisol	13-43	500-700	4
South-West	300-500	Upland, Lowland, Hills	Oxisols, Ferric-lixisol	13- 41	900-1100	6-7

RESULTS

Varietal diversity described by farmers

Sorghum varieties were classified by farmers in short-cycle, intermediate and long cycle in correspondence to the duration of rainy season in each growing area. In the North region, the long cycle varieties are those whose maturity occurs after four months of cultivation and six months and more in the other three regions. The varietal

diversity managed by farmers can be grouped in three groups: i) food sorghums [varieties with grain consumed fresh, lain period varieties, varieties for ordinary consumption (thick porridge, local beer, etc.), sweet-stem varieties, varieties use like the “rice” with small grain mostly belong to the botanical race guinea-margaritiferum traditionally used in a culinary preparation similar to that of the rice]; ii) custom sorghums (varieties for rites in memory of ancestors); iii) local knowledge sorghums (tincture and pharmacopeia varieties).

If the glume and grain colour are ordinary used to name varieties, these are also designated by the names linked to agronomic characteristics (productivity, particularity of the cycle duration, grain characteristic, etc.). It is found special names for earliest cycle varieties (e.g. I will not sell my goat, the wife will not leave home), for long panicle varieties (horse tail), for varieties with closed glumes (blind sorghum). Other sorghums are designated by their adaptability to the soil type (varieties of lowlands, etc.) and by their resistance to parasitic weeds as striga. It is in this varietal panel that households choose varieties that are suitable to their cropping context, their food preferences and their production objectives.

From one to eight varieties are grown per household. The area devoted to each variety vary from less than 1000 m² to more than 5 ha. The growing areas and usages frequencies provide information on the evolutionary process of each variety at the village scale. A variety is abundant when it is cultivated in almost all farms on large areas and constitutes the essential of the subsistence production in the households. The frequent varieties are grown by a large number of farmers but often on a reduced area. The rare varieties are less found, often owned by one farmer, they are grown in general on small areas. The abundant and frequent varieties represent 45.6% and 32.9% of the collected diversity; they are less threatened by erosion risks compared to rare varieties (21.5%), their characteristics are suitable to farmers food needs, while the rare varieties are often used for specific purposes. Most of varietal diversity is cultivated in remote fields far from home and backyard fields. Nine point two percent (9.2%) to 17.1% of varieties in the villages are sown around the lowlands.

Varietal diversity collected in the villages

From three to eighteen varieties were collected in the 73 surveyed villages. The lowest varietal diversity (3 varieties) was found in the South-West and the highest (18 varieties) in the North (Table 2). On average, the varietal richness is higher in the North, East and Centre-East regions respectively (13.0; 11.7; 10.9 varieties) compared to the South-West region (6.1 varieties). A percentage of 60.6 of varieties would have been inherited from parents and were considered as old because they were grown for at least 30 years in the villages. The oldest varieties are found in the villages of Kampene (province of Poni) and Zabatourla (province of Boulgou); they would have been cultivated at least 89 and 95 years in these villages at collection time. Gnagna, Tapoa and Boulgou provinces would conserve more inherited varieties from parents, with respectively 70.3, 73.3 and 86.1% of their varietal diversity. Varietal introductions were higher in Zondoma and Bougouriba provinces with 52.9 and 77.3% of their current sorghum diversity. Among the introductions it has been found some improved varieties: IRAT 204 (North), Framida and ICSV 1049 (East and Centre-East), Sariaso 1 and Sariaso 2 in the South-West. The three first varieties belong to the botanical race caudatum, and the last two varieties to the botanical race guinea.

Varietal erosion and threats on sorghum diversity

The varietal erosion is almost observed everywhere in the villages. For all the sampling villages, 98 varieties were reported as lost. The circumstances of the losses were not always well elucidated, but would be due to rainfall decrease, to soils poverty, or have been abandoned in favour of maize growing. Seventy-three point five percent (73.5%) of lost varieties were found (Table 3). They are still grown in other villages in the production system often on small areas. The analysis of rainfall data from 1950 to 2010 shows a decreasing trend of rainfall in many sites illustrated here by data from four meteorological stations (Figure 2).

The signs of varietal erosion still exist in the villages. The MCA with the 15 modalities of variables related to cycle length, the usages and the disadvantageous characteristics allowed to structure and characterize the 159 rare varieties threatened of loss. All of the information is carried by six factorial axes.

The first two factorial axes (F1 x F2) explain 78.7% of the total variance (Figure 3). The axis one which carries the greatest part of total information (68.2% of variance) is explained by cycle lateness (24.8%), low grain quality (16.5 %), low productivity (14.6%), cycle earliness (14.2%), consumed fresh grain (9.6%), lain period sorghums (8.8%), custom sorghums (8.3%) and tincture sorghums (2.5%). The axis two is more explained by the sorghums use for pharmacopeia (22.2%), the intermediate cycle (16.0%) and the sweet-stem sorghums (13.1%). The axis three is essentially explain by "sorghums use as rice" (24.6%), panicle shape (18.1%) and ordinary sorghums (11.0%).

Two sorghums groups can be distinguished on axis one of MCA: the custom sorghums characterized by lateness and low productivity; the lain period sorghums and tincture sorghums characterized by their earliness and their low grain quality. Two other groups have been also distinguished on axis two: the pharmacopeia sorghums characterized by their sensitivity to drought and sweet-stem sorghums.

Table 2. Presentation of collected varieties in 2009 and 2010 in the four regions of Burkina Faso.

Study region	Province of collection	Number of collected village	Total number of variety per province		Mean number of variety per village	Range of variety number per village	Percentage of improved varieties identified in the collection area	Age of the oldest variety in the province (year)	Name of the oldest varieties
			Inherited varieties	Introduced varieties					
Centre-East	Boulgou	3	37	6	14.3	[12;16]	0	95	Bouré Naga-zoula
	Koulpélogo	2	9	6	7.5	[7;8]	6.7	82	Belko
	Kouritenga	3	17	12	9.7	[7;14]	0	71	Sonmouï
East	Gnagna	3	26	11	12.3	[9;16]	2.7	72	Tchoadi
	Gourma	3	20	13	11.0	[8;13]	0	65	Zouanviéléga
	Komondjari	1	5	4	9.0	[9]	11.1	56	Kankan-yaré
	Kompienga	1	3	5	8.0	[8]	0	80	Icuari
	Tapoa	2	22	8	15.0	[15]	0	75	Manpuoli, Ibiari-moani, Ikparbinuani, Ku-dimangu
North	Lorum	2	10	6	8.0	[8]	6.3	66	Gnouga
	Passoré	9	72	49	13.4	[8;18]	0.8	83	Kiédogo Bôchimin
	Yatenga	13	112	58	13.1	[8;17]	0.6	78	Balinga
	Zondoma	5	33	37	14.0	[11;17]	0	74	Bonga
South-West	Bougouriba	4	5	17	5.5	[4;10]	0	76	Gnignan
	Ioba	8	35	29	8.0	[4;14]	0	75	Hamana-bilé
	Noumbiel	5	12	7	3.8	[3;5]	0	80	Tchar
	Poni	9	30	23	5.9	[5;9]	1.9	89	Djôsiê-blo
Total		73	448	291	10.1	-		-	

DISCUSSION

Dynamic of varietal diversity

The four regions of this study present a very contrasted environmental profile on the agro-ecological level and agricultural potentialities. The North region is particularly characterized by low availability of arable farmland, low soil fertility, rainfall constraints with recurring cereal deficits (MARHASA, 2015), which is not the case for the three other regions with better environmental conditions.

In Burkina Faso, the priority of farmers in cereal production is to ensure households food security. Each household choose to cultivate the cereals (sorghum, millet, maize) and varieties that suit to the family food preferences and their environmental production context. In the East, Centre-East and North regions, sorghum would be more consumed within households, while it is more intended for commercialization in the South-West, where families' consumption are preferentially focused on maize. Except the custom sorghum found everywhere in the "terroir" and managed by the tradition guarantors, the low varietal richness in the South-West could be explained by the low number of varieties consumed in households, the good characteristics and yield regularity of cultivated varieties that meet farmers' production objectives.

Many studies have shown a link between the level of varietal diversity and the natural and human factors (Brush and Meng, 1998; Seboka and Hintum, 2006). The results of this study are comparable to those of Brush and Perales (2007) who found a low diversity in local maize varieties in high altitude villages (more humid) compared to that of low altitude villages in the Chipas state of Mexico. Mekbib and al. (2009) found in the humid zone in the East of Ethiopia a low diversity in local sorghum (8.3 varieties) compared to the medium rainy zone (11.4 varieties). Barro-Kondombo et al. (2010) also reported a low diversity on local sorghum in the humid zone of Burkina Faso (7.3 varieties per village) compared to the low and medium rainy zones (12.3 to 17.5 varieties). In arid and semi-arid regions of Africa where climate vulnerability (Kouressy et al., 2008; Abdulai et al., 2012) and diverse stress can compromise the harvests it is usual that farmers manage a large diversity to attenuate the risks of bad harvests; this is probably the

Table 3. Situation of lost varieties in the four regions of Burkina Faso.

Region	Province	Reported number of lost varieties	Number of varieties found and still growing in other villages	Number of varieties not found	Name of lost varieties not found
Centre-East	Boulgou	4	3	1	Boukarga
	Koulpélogo	3	3	0	
	Kouritenga	6	5	1	Boukarga
	Gnagna	5	5	0	
East	Gourma	4	3	1	Touguelèpa,
	Komondjari	3	2	1	Soassa
	Kompienga	1	1	0	
	Tapoa	4	2	2	Jualiagamba, Manpaba
North	Lorum	1	1	0	
	Passoré	8	5	3	Wangoussougou, Yiliga, Pazini-yendé
	Yatenga	12	11	1	Rawoumdé
	Zondoma	10	7	3	Réogo, Samkaboudou, Wangoussougou
South-West	Bougouriba	6	2	4	Bordjonguô, Yibi-gnaman, Badjonka, Sokou
	Ioba	13	11	2	Wourzour, Napobsan
	Noumbiel	4	3	1	Danlar
	Poni	14	8	6	Bassa, Bazongo, Djoumwan, Gnêrêkononi, Nigapiêre, Vôvô
Total		98	72	26	

situation in the North more exposed to rainfall constraints and decline (Figure 2). Mercer and Perales (2010) reported that of all the factors influencing the plants diversity, climatic effects are the most important.

Varietal erosion

The structuration of sorghum groups by MCA showed that almost all the information is explained by the first two factorial axes (78.7%) (Figure 3). The analysis of groups characteristics shows that the cycle lateness, low productivity and low grain quality are disadvantageous characteristics for the sorghum groups attached to the axis one. The earliness is an advantageous character. For the lain period sorghums characterized by earliness, their growing on small areas would not mean necessarily an erosion risks because these varieties are essential, even vital; they allow to offset the cereal deficits of the end of rainy season. The evidence is that most early sorghum are among inherited varieties. Vom Brocke et al. (2010) showed that all of the many farmers' selection criteria of sorghum in Burkina Faso, the earliness of cycle, the grain quality (hard grain) and yield (grain and flour) were the most important.

Drought sensitivity is a handicap for pharmacopeia sorghums on axis two. Pharmacopeia sorghums, sweet-stem sorghums, tincture sorghums and "rice sorghums" not numerous in the varietal panel grown in the villages appear also to be affected by socio-cultural changes in food habits and usages. Nowadays, the use of pharmacopeia sorghums in healthcare tends to decline, also sorghums use like rice are simply replaced by "*Oryza sativa* and *Oryza glaberrima*".

In Burkina Faso, despite of the increase of maize and cotton area in the East, Centre-East and South-West regions, the area devoted to sorghum remained quasi stable or slightly increased from 1 to 18% during the four years (2010-2014) followed the collection (MARHASA, 2015); the South-West region has increased its areas of 18% showing a general interest in sorghum. However, in general the decisions of farmers' (selection, production objectives, etc.) may change the dynamics of diversity and even contribute to its loss (Teshome et al., 1997; Tunstall et al., 2001). Local varieties may be abandoned at the village level when they no longer meet to farmers' production objectives (Missihoun et al., 2012a; Dossou-Aminon et al., 2014), but can be desired again later. If this is the case, the research office may contribute to find

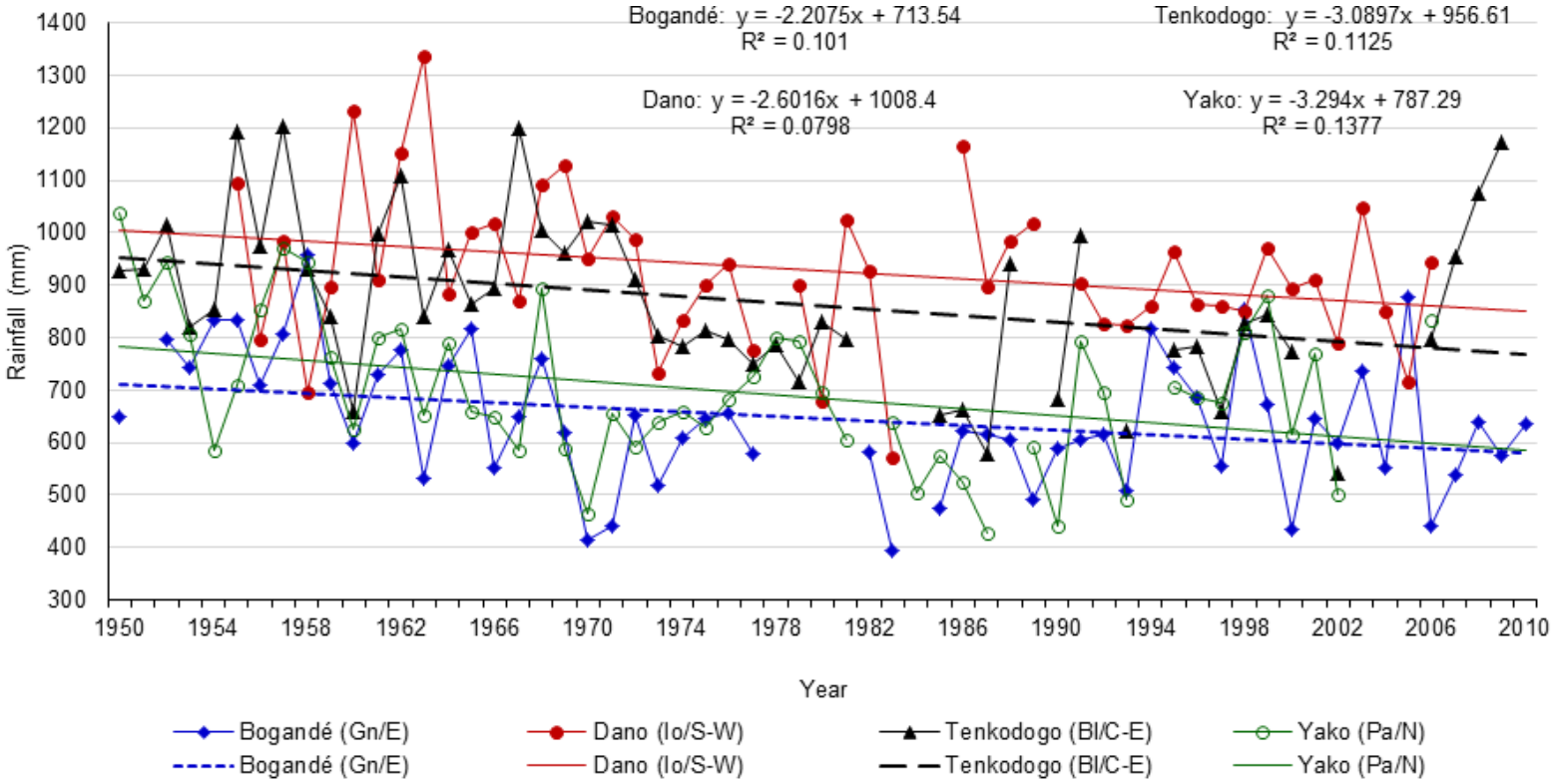

Figure 2. Evolution and trends of average rainfall (1950-2010) of four studies regions: Bogandé (East), Dano (South-West), Tenkodogo (Centre-East), Yako (North) stations (Source: National Direction of Meteorology, 2015)

some of them, either into other prospected villages as shown in our study or in its germplasm collections maintained ex-situ as the case in Burkina Faso where Flagnon (SCHV 159) and Gnossiconi (SCHV 162) (CNS, 2014), two local varieties of the North-West region lost a long time ago and sought-after by farmers, have been successfully reintroduced (vom Brocke et al., 2014.) because they were kept respectively since 1962 and 1969 in the gene bank of INERA Saria research station. A local variety named Soassa like that lost in Komondjari and not found in the sampled villages was also found in the Saria gene bank. This variety of long cycle and almost completely closed glumes was collected in the Tamasogo village of Ganzourgou province (Burkina Faso) and introduced in 1965.

In this context of varietal erosion, the taking into account of local sorghum diversity in the breeding programs is prior for its safeguard but not enough to save interest genes. Common actions involving farmers and research should be undertaken to avoid varietal erosion. As underlined Ramanatha Rao and Hodgkin (2002), "phytogenetic resource conservation merits far greater attention than it is now receiving".

Conclusion

This study on local sorghum variety in the four regions of Burkina Faso has shown that the diversity cultivated in the villages is dominated

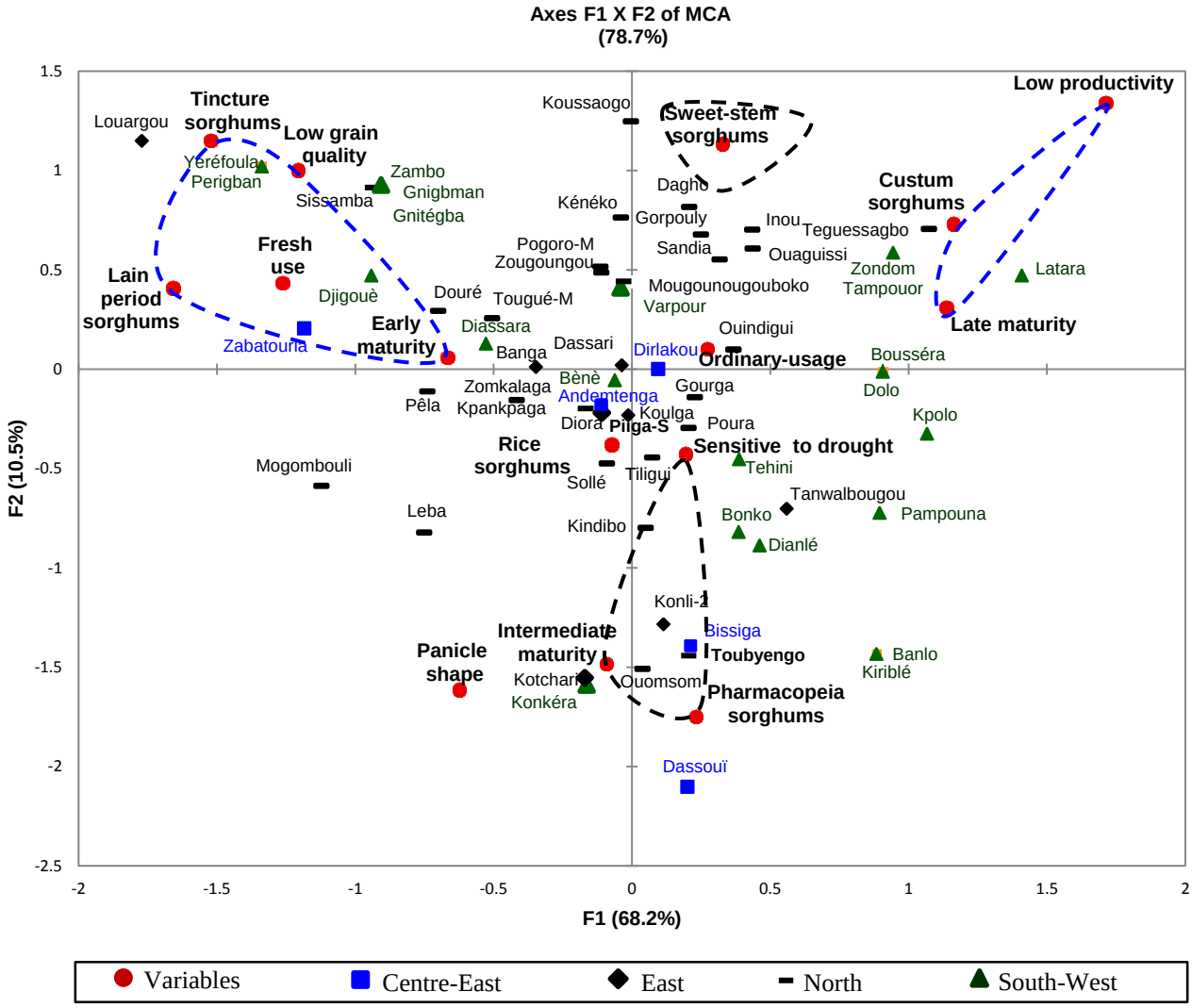

Figure 3. Graphical representation of the 15 modalities of descriptive variables for 159 rare varieties of the four study regions in Burkina Faso.

(60.6%) by inherited varieties from parents. Twenty six point five percent of lost varieties were not found in the sampled areas. The erosion threats exist at different levels. Among sorghums groups structured by MCA, pharmacopeia sorghums, sweet-stem sorghums, tincture sorghums and "rice sorghums" are more threatened by their low number in the varietal diversity grown and their low uses in the villages linked to socio-cultural changes. The tradition is transmitted from generation to generation, it is not evident that the young generation for diverse reasons (modification of production objectives, etc.) could maintain custom sorghums and local knowledge. None disposition exists at the regional level to safeguard diversity. It would be necessity to develop some efficient mechanisms to follow up sorghum diversity in order to avoid losing genes that could be useful for agriculture of the future.

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REFERENCES

Abdulai AL, Parzies H, Kouressy M, Vaksmann M, Asch F, Brueck H (2012). Yield stability of photoperiod sensitive sorghum (*Sorghum bicolor* L. Moench) accessions under diverse climatic environments. Int. J. Agric. Res. 7(1):17-32.

Altieri MA, Merrick LC (1987). *In situ* conservation of crop genetic resources through maintenance of traditional farming systems. Econ. Bot. 41(1):86-96.
Barnaud A, Deu M, Garine E, McKey D, Joly HI (2007). Local genetic diversity of sorghum in a village in northern Cameroon: structure and dynamics of landraces. Theor. Appl. Genet. 114:237-248.
Barro-Kondombo C, Sagnard F, Chantereau J, Deu M, vom Brocke K, Durand P, Gozé E, Zongo JD (2010). Genetic structure among sorghum landraces as revealed by morphological variation and microsatellite markers in three agroclimatic regions of Burkina Faso. Theor. Appl. Genet. 120:1511-1523.
Barro-Kondombo C, vom Brocke K, Chantereau J, Sagnard F, Zongo JD (2008). Variabilité phénotypique des sorghos locaux de deux régions agricoles du Burkina Faso: la Boucle du Mouhoun et le Centre-Nord. Cahiers Agric. 17:107-113.
Bellon MR (1996). The dynamics of crop infraspecific diversity: A conceptual framework at the farmer level. Econ. Bot. 50(1):26-39.
Brush SB (1986). Genetic diversity and conservation in traditional farming systems. J. Ethnobiol. 6(1):151-167.
Brush SB, Meng E (1998). A Farmers' valuation and conservation of crop genetic resources. Genet. Resour. Crop Evol. 45:139-150.
Brush SB, Perales HR (2007). A maize landscape: ethnicity and agro-biodiversity in Chiapas Mexico. Agric. Ecosyst. Environ. 121:211-221.
Cavatassi R, Hopkins J, Lipper L (2005). Crop Genetic Diversity, Food Security and Farm Household Well-being during Shocks. American Agricultural Economics Association annual meeting, Providence, Rhode Island. July 24-27, 2005.
Clerget B, Dingkuhn M, Chantereau J, Hemberger J, Louarn G, Vaksmann M (2004). Does panicle initiation in tropical sorghum depend on day-to-day change in photoperiod? Field Crops Res. 88:11-27.
CNS (Comité National des Semences) (2014). Catalogue National des Espèces et Variétés Agricoles du Burkina Faso. P 81.
Delaunay S, Tescar R-P, Oualbego A, vom Brocke K, Lançon J (2008). La culture du coton ne bouleverse pas les échanges traditionnels de semences de sorgho. Cahiers Agric. 17:189-194.
DGAT (Direction Générale de l'Aménagement du Territoire) (2006). Profil des régions du Burkina. P 290.
Dossou-Aminon I, Loko LY, Adjatin A, Dansi A, Elangovan M, Chaudhary P, Vodouhè R, Sanni A (2014). Diversity, genetic erosion and farmer's preference of sorghum varieties [*Sorghum bicolor* (L.) Moench] in North-Eastern Benin. Int. J. Curr. Microbiol. Appl. Sci. 3(10):531-552.
Escofier B, Pagès J (1998). Analyses factorielles simples et multiples, objectifs méthodes et interprétation, 3è ed, Bunod, Paris, ISBN 2 10 004127 4. P 284.
FAO (1996). The State of the World's Plant Genetic Resources for Food and Agriculture. Rome, Italy.
Faostat (2015). http://www.faostat.fao.org
Frankel OK (1974). Genetic conservation: our evolutionary responsibility. Genetics 78:53-65.
Kouressy M, Dingkuhn M, Vaksmann M, Heinemann AB (2008). Adaptation to diverse semi-arid environments of sorghum genotypes having different plant type and sensitivity to Photoperiod. Agric. For. Meteorol. 148:357-371.
MARHASA (Ministère de l'Agriculture, des Ressources Hydrauliques, de l'Assainissement et de la Sécurité Alimentaire) (2015). Statistiques agricoles 2009-2014.
MASA (Ministère de l'Agriculture et de la Sécurité Alimentaire) (2014). Etude pour l'élaboration d'une stratégie nationale en matière d'intrants et d'équipements agricoles au Burkina Faso. P 115.
Mekbib F, Bjornstad A, Sperling L, Synnevag G (2009). Factors shaping on-farm genetic resources of sorghum (Sorghum bicolor (L.) Moench) in the centre of diversity, Ethiopia. Int. J. Biodivers. Conserv. 1(2):45-59.
Mercer KL, Perales HR (2010). Evolutionary response of landraces to climate change in centers of crop diversity. Blackwell Publishing Ltd 3:480-493.
Missihoun AA, Agbangla C, Adoukonou-Sagbadja H, Ahanhanzo C, Vodouhè R (2012a). Gestion traditionnelle et statut des ressources génétiques du sorgho (*Sorghum bicolor* L. Moench) au Nord-Ouest du Bénin. Int. J. Biol. Chem. Sci. 6(3):1003-1018.
Muui CW, Muasya RM, Kirubi DT (2013). Identification and evaluation of sorghum (*Sorghum bicolor* (L.) moench) germplasm from Eastern Kenya. Afr. J. Agric. Res. Vol. 8(37):4573-4579.
Ramanatha Rao V, Hodgkin T (2002). Genetic diversity and conservation and utilization of plant genetic Resources. Plant Cell, Tissue Organ Cult. 68:1-19.
Sapin P (1984). Le sorgho et son amélioration. Synthèse Haute Volta 1961-1981, IRAT, Montpellier. P 86.
Seboka B, Hintum van T (2006). The dynamics of on-farm management of sorghum in Ethiopia: Implication for the conservation and improvement of plant genetic resources. Genet. Resour. Crop Evol. 5(53):1385-1403.
Shewayrga H, Jordan DR, Godwin ID (2008). Genetic erosion and changes in distribution of sorghum (Sorghum bicolor L. (Moench)) landraces in north-eastern Ethiopia Plant Genet. Resour. Character. Utilization 6(1):1-10.
Teshome A, Baum BR, Fahrig L, Torrance JK, Arnason TJ, Lambert JD (1997). Sorghum [*Sorghum bicolor* (L.) Moench] landrace variation and classification in North Shewa and South Welo, Ethiopia. Euphytica 97:255-263.
Teshome A, Fahrig L, Torrance JK, Lambert JD, Arnason JT, Baum BR (1999b). Maintenance of sorghum (*Sorghum Bicolor*, Poaceae) landrace diversity by farmers' selection in Ethiopia. Econ. Bot. 53(1):79-88.
Teshome A, Torrance JK, Baum B, Fahrig L, Lambert JDH, Arnason JT (1999a). Traditional farmers' knowledge of sorghum (*Sorghum bicolor* [Poaceae]) landrace storability in Ethiopia. Econ. Bot. 53(1):69-78.
Tunstall V, Teshome A, Torrance JK (2001). Distribution, abundance and risk of loss of sorghum landraces in four communities in North Shewa and South Welo, Ethiopia. Genet. Resour. Crop Evol. 48:131-142.
Vaksmann M, Traoré SB, Niangado O (1996). Le photopériodisme des sorghos africains. Agric. Dév. 9:13-18.
Vom Brocke K, Trouche G, Weltzien E, Barro-Kondombo CP, Gozé E, Chantereau J (2010). Participatory variety development for sorghum in Burkina Faso: farmers' selection and farmers' criteria. Field Crops Res. 119(1):183-194.
Vom Brocke K, Trouche G, Weltzien E, Kondombo-Barro CP, Sidibé A, Zougmoré R, Gozé E (2014). Helping Farmers Adapt to Climate and Cropping System Change Through Increased Access to Sorghum Genetic Resources Adapted to Prevalent Sorghum Cropping Systems in Burkina Faso. Exp. Agric. 50(2):284-305.
Wood D, Lenné JM (1997). The conservation of agrobiodiversity on-farm: questioning the emerging paradigm. Biodivers. Conserv. 6:109-129.
Zongo JD (1991). Ressources génétiques des sorghos (*Sorghum bicolor* L. Moench) du Burkina Faso : Evaluation agro-morphologique et génétique. Thèse de doctorat, Université d'Abidjan. P 175.

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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^2 plots were used to estimate the spatial cover of herbaceous species. MNR exhibited high species, genera and family richness, but low diversity and eveness. The diversity and eveness values of woody species were 1.44 and 0.38, respectively. Density of woody species was about 4,785 ha^{-1}. 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^{-1}. The nutritional values of the species ranged between low and high while there was no information on the nutrtion 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, 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 evolutionaryily 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 carying 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; Käller, 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 (Käller, 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 activitiesincluded, 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^{-1}) with their scientific and family names, frequencies (FR, %), dominance (Do, m^2 ha^{-1}), 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**
Dichrostachys cinerea (L.) Wight and Arn.	Fabaceae	1119.4	100	4.040	23.66	3.79	11.89	39.33	L
Euclea undulata Thunb.	Ebenaceae	622.9	100	0.920	13.17	3.79	2.71	19.67	L
Combretum apiculatum Sond.	Combretaceae	474.6	90	6.310	10.04	3.41	18.57	32.02	M-H
Grewia flavescens Juss.	Tiliaceae	435.0	80	0.000	9.20	3.03	0.00	12.23	H
Grewia flava DC.	Tiliaceae	399.9	100	0.020	7.19	3.79	0.06	11.04	H
Grewia bicolor Juss.	Tiliaceae	372.1	100	0.130	7.87	3.79	0.38	12.04	H
Acacia erubescens Welw. ex Oliv.	Fabaceae	232.8	100	3.170	4.93	3.79	9.33	18.04	L
Acacia mellifera (Vahl) Benth.	Fabaceae	230.7	90	3.020	4.88	3.41	8.89	17.18	L
Acacia tortilis (Forssk.) Hayne	Fabaceae	201.6	100	5.600	4.27	3.79	16.48	24.54	L/H
Sterculia africana (Lour.) Fiori	Sterculiaceae	141.5	70	7.240	3.00	2.65	21.30	26.96	NA
Grewia retinervis Burret	Tiliaceae	80.7	90	0.050	1.71	3.41	0.15	5.27	H
Peltophorum africanum Sond.	Fabaceae	67.9	100	1.700	1.44	3.79	5.00	10.23	H
Boscia foetida Schinz	Capparaceae	46.7	90	0.010	0.99	3.41	0.03	4.43	H
Rhus leptodictya Diels	Anacardiaceae	39.7	80	0.040	0.85	3.03	0.12	3.99	H
Ehretia rigida (Thunb.) Druce	Bignoniaceae	39.0	90	0.070	0.82	3.41	0.21	4.44	M-H
Pappea capensis Eckl. and Zeyh.	Sapindaceae	36.8	100	1.000	0.78	3.79	2.94	7.51	H
Combretum imberebe Wawra	Combretaceae	36.0	80	0.360	0.76	3.03	1.06	4.85	M-H
Gymnosporia senegalensis (Lam.) Loes.	Celastraceae	33.2	100	0.280	0.70	4..55	0.83	6.1	M-H
Tarchonanthus camphoratus L.	Asteraceae	26.6	80	0.001	0.57	3.03	0.00	3.60	L
Terminalia sericea Burch. ex DC.	Combretaceae	25.7	20	0.260	0.55	0.76	0.77	2.07	M
Commipora pyracanthoides Engl.	Burseraceae	23.8	50	0.050	0.51	1.89	0.15	2.55	L-M
Acacia nilotica (L.) Willd. ex Delile	Fabaceae	20.7	70	1.000	0.44	2.65	2.94	6.04	L-H
Combretum hereroense Schinz	Combretaceae	14.4	50	0.180	0.30	1.89	0.53	2.72	M-H
Acacia rubusta Burch.	Fabaceae	13.8	70	1.000	0.30	2.65	2.94	5.89	L-M
Carissa bispinosa (L.) Desf. ex Brenan	Apocynaceae	12.8	40	0.160	0.27	1.52	0.47	2.26	M
Ehretia amoena Klotzsch	Bignoniaceae	6.7	40	0.004	0.15	1.52	0.01	1.67	NA
Ximenia americana L.	Olacaceae	6.6	50	0.100	0.15	1.89	0.29	2.34	M-H
Ziziphus mucronata Willd.	Rhamnaceae	5.5	70	0.030	0.11	2.65	0.09	2.85	M-H
Ximenia caffra Sond.	Olacaceae	5.1	50	0.010	0.11	1.89	0.03	2.03	M-H
Acacia caffra (Thunb.) Willd.	Fabaceae	3.7	40	0.290	0.08	1.52	0.85	2.45	L-M
Berchemia zeyheri (Sond.) Grubov	Rhamnaceae	1.6	20	0.000	0.04	0.76	0.00	0.80	NA
Acacia gerrardi Benth.	Fabaceae	1.3	10	0.100	0.02	0.38	0.29	0.69	L
Sclerocarya birrea (A.Rich.) Hochst.	Anacardiaceae	1.1	50	0.210	0.02	1.89	0.62	2.53	H
Gardenia volkensii K.Schum.	Rubiaceae	1.0	10	0.050	0.02	0.38	0.15	0.55	NA
Acacia karroo Hayne	Fabaceae	0.9	100	0.010	0.02	3.79	0.03	3.84	M-H

Table 1. Contd.

Ozoroa paniculosa (Sond.) R. Fern. and A. Fern.	Anacardiaceae	0.7	10	0.001	0.02	0.38	0.00	0.40	H
Boscia albitrunca (Burch.) Gilg and Gilg-Ben.	Capparaceae	0.6	10	0.000	0.02	0.38	0.00	0.40	M-H
Rhigozum brevispinosum Kuntze	Bignoniaceae	0.5	40	0.000	0.01	1.52	0.00	1.53	H
Dombeya rotundifolia (Hochst.) Planch.	Sterculiaceae	0.4	20	0.010	0.01	0.76	0.03	0.80	H
Vangueria infausta Burch.	Rubiaceae	0.3	10	0.000	0.01	0.38	0.00	0.39	NA
Olea europaea L.	Oleaceae	0.2	20	0.000	0.00	0.76	0.00	0.76	NA
Acacia luederitzii Engl.	Fabaceae	0.1	10	0.010	0.00	0.38	0.03	0.41	L
Berchemia discolor (Klotzsch) Hemsl.	Rhamnaceae	0.1	10	0.000	0.00	0.38	0.00	0.38	NA
Combretum zeyheri 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 (herefater 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 24º 44' 20.81" S and 25º 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 32ºC from November to February to 22ºC in late June to August. The mean minimum daily temperature varies from 22ºC from November to February to 4ºC 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, course 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 co mmon componentsare *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

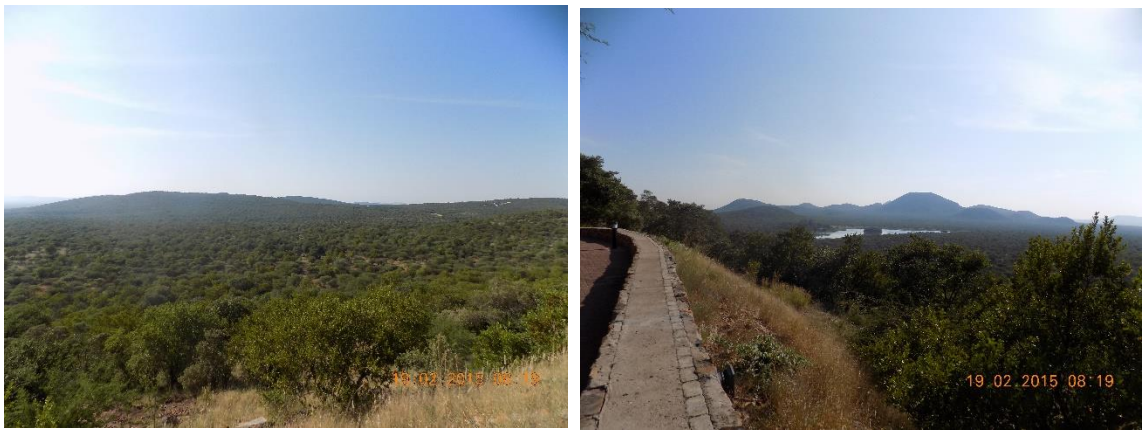

Figure 2. Partial views of the vegetation of Mokolodi Nature Reserve (Photo by Demel Teketay).

A B

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 aquisition 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 accommadation, 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 Hartebeeest (*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 ± 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 × 1 m (1 m^2) 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:

$$H' = -\sum_{i=1}^{5} Pi \ln Pi$$

where, H' = Shannon index, S = species richness, P_i = proportion of *S* made up of the i^{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^{-1}. *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^{-1}) and nutritional values.

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

Table 2. Contd.

Acrotome inflata Benth.	Lamiaceae	0.05	Not available
Aptosimum lineare Marloth and Engl.	Scrophulariaceae	0.05	Not available
Ceratotheca triloba (Bernh.) Hook. *f*.	Pedaliaceae	0.05	Not available
Chamaesyce inaequilatera (Sond.) Soják	Euphorbiaceae	0.05	Not available
Crotalaria lotoides Benth.	Fabaceae	0.05	Not available
Digitaria eriantha Steud.	Poaceae	0.05	Very High
Eragrostis pallens Hack.	Poaceae	0.05	Poor
Hibiscus cannabinus L.	Malvaceae	0.05	Not available
Indigofera holubii N. E. Br.	Fabaceae	0.05	Not available
Kyllinga alba Nees	Cyperaceae	0.05	Not available
Lippia javanica (Burm.f.) Spreng.	Verbenaceae	0.05	Not available
Macrotyloma axillare (E.Mey.) Verdc.	Fabaceae	0.05	Not available
Portulaca oleracea L.	Portulacaceae	0.05	Not available
Sansevieria aethiopica Thunb.	Dracaenaceae	0.05	Not available
Senna italica Mill.	Fabaceae	0.05	Not available
Setaria verticillata (L.) P.Beauv.	Poaceae	0.05	Fairly Good
Solanum delagoense Dunal	Solanaceae	0.05	Not available
Striga asiatica (L.) Kuntze	Scrophulariaceae	0.05	Not available
Tephrosia lupinifolia DC.	Fabaceae	0.05	Not available
Bare Ground		55.33	
Total		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 eveness (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, traslating into a total density of 4,784.8 ha^{-1} with a range of 0.1 and 1,119 stems ha^{-1} (Table 1). The five densest woody species in the study site were *Dichrostachys cinerea* (L.) Wight and Arn. (1,119 stems ha^{-1}), *Euclea undulata* Thunb. (623 stems ha^{-1}), *Combretum apiculatum* Sond. (475 stems ha^{-1}), *Grewia flavescens* Juss. (435 stems ha^{-1}) and *Grewia bicolor* Juss. (372 stems ha^{-1}). In contrast, *Vangueria infausta* Burch. (0.3 stems ha^{-1}), *Olea europaea* L. (0.2 stems ha^{-1}), *Combretum zeyheri* Sond. (0.1 stems ha^{-1}), *Berchemia discolor* (Klotzsch) Hemsl. (0.1 stems ha^{-1}) and *Acacia luederitzii* Engl. (0.1 stems ha^{-1}) exhibited the five lowest densities (Table 1).

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

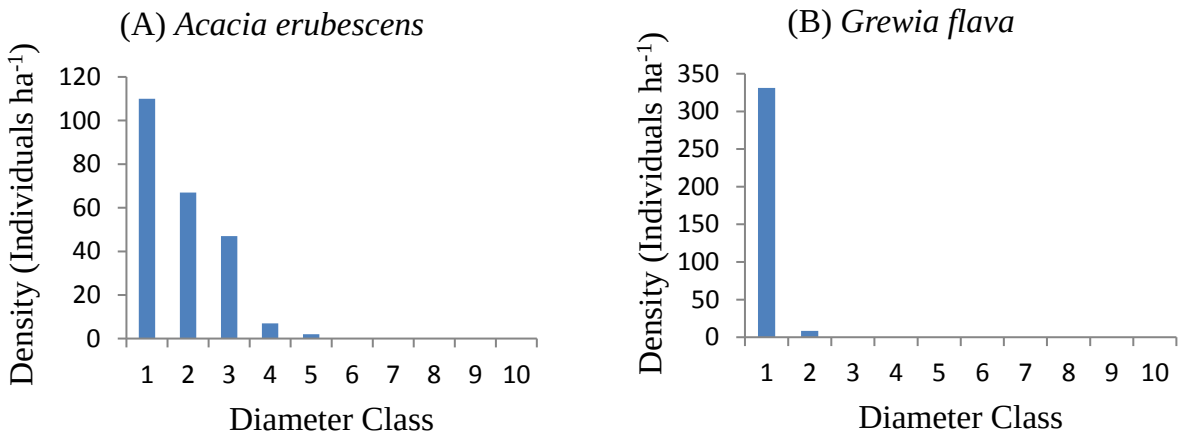

Figure 4. Population structure of woody species recorded at Mokolodi Nature Reserve [diameter class (DBH): 1 = < 2 cm; 2 = 2-5 cm; 3 = 5-10 cm; 4 = 10-15 cm; 5 = 15-20 cm; 6 = 20-25 cm; 7 = 25-30 cm; 8 = 30-35; 9 = 35-40; 10 = > 40 cm].

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^2 ha^{-1} and ranged between very close to zero and 7.24 m^2 ha^{-1} (Table 1). The five dominant woody species in the study site were *Sterculia africana* (Lour.) Fiori (7.24 m^2 ha^{-1}), *C. apiculatum* (6.31 m^2 ha^{-1}), *A. tortilis* (5.6 m^2 ha^{-1}), *D. cinerea* (4.04 m^2 ha^{-1}) and *A. erubescens* (3.17 m^2 ha^{-1}). More than 77% of all the woody species exhibited dominance values of less than one m^2 ha^{-1} (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 proprotion of spatial (ground) cover of all the herbaceous species in the study site was 44.67% ha^{-1} and ranged between 0.05 (19 spp.) and 7.1 (*Eragrostis lehmannia* Nees) percent ha^{-1} while that of the bare ground represented 55.33% ha^{-1} (Table 2). The herbaceous species, which exhibited average proportions of spatial cover above 2% ha^{-1}were *Eragrostis lehmannia* Nees (7.1% ha^{-1}), *Tragus berteronianus* Schult. (3.5% ha^{-1}), *Eragrostis rigidior* Pilg. (3.47% ha^{-1}), *Waltheria indica* L. (2.83% ha^{-1}), *Panicum maximum* Jacq. (2.25% ha^{-1}) and *Aristida congesta* Roem. and Schult (2.14% ha^{-1}) (Table 2). The average proportions of spatial cover of 57 of the herbaceous species (about 83%) were less than 1% ha^{-1}.

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 nutrtion 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 exclosure 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 exclosure of more than 10 years (32 spp., 12 familes and 19 genera) and open area adjacent the area exclosure (24 spp., 10 familes 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 an 0.38, respectively) are much lower than those reported for Shorobe (2.18 and 0.6, respectively), Maun (area exclosure 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 exclosure 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 resitant 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 were 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 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 syndrom, 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 lso expensive to control, which was estimated at USD 100 to 150 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^{-1}) (Smith, 2003). These charcteristics 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^{-1} 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^{-1} 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 reults also revealed that for a considerable number of species, that is, 16 and 55% of the woody species and herbaceous species, resepctvely, 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 eveness 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 inicative 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 nutritonal 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.

El-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 Utilizatio, 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, accessed on 16-01-2016).

Hunde A, Thulin M (1989). *Mimiosoideae*. 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.

Käller 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, Sween.

Louga EJ, Witkowski ETF, Balkwill K (2000). Differential utilisation and ethnobotany of trees in Kitulangalo 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 exclosed 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 2008. 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). Agroforestree 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, 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/FGRCP, 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.l 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, 5th 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). Agroforestree 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 Abebaye Forests, Northwestern Ethiopia. J. Forest. Res. 22:315-328.

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