

Diversity and population structure of some woodland species in communal areas of north western Botswana.

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Abstract— Plants in arid areas are widely used for timber, food, fire wood and livestock fodder. As a result they could be threatened by over-exploitation from overgrazing and overharvesting. These threats are exacerbated by lack of knowledge on the composition and population structure of woodland species. The aim of this study was to classify woodland species and determine their population structure. Sampling was conducted in 20 × 50m plots. In total 75 plots were sampled where canopy cover was estimated and diameter at breast height measured. Hierarchical cluster analysis was used to derive different communities. Indicator species analysis was utilized to determine the indicator value for different species in a given community. Plant species richness and diversity were determined for each plant community. Multi Response Permutation Procedures (MRPP) was used to determine the level of separation between the plant communities. Kruskal-Wallis test was exercised to compare species diversity and richness between woodland communities. Plant species were classified into four communities of *Acacia erioloba*-*Grewia bicolor*, *Terminalia sericea*-*Burkea africana*, *Acacia mellifera*-*Boscia albitrunca* and *Combretum collinum*-*Baphia massaiensis*. Results of MRPP showed that the communities were significantly ($p<0.05$) different from each other. Species richness and diversity were significantly lower in *Acacia mellifera*-*Boscia albitrunca* community. Populations of *Acacia erioloba*, *Philenoptera nelsii* and *A. nigrescens* showed bell-shaped structure while those of *Burkea africana*, *Boscia albitrunca* and *Combretum collinum* had reverse J-shaped pattern. *Terminalia sericea*, *Ziziphus mucronata* and *Colophospermum mopane* had only 2 or 3 classes skewed towards juveniles.

Keywords— Classification, Cluster analysis, Indicator value, Plant community and Population structure

I. INTRODUCTION

In semi-arid regions, plant community composition, distribution and population structure may be influenced by

climate change, water and nutrient availability [1]. Water availability influences moisture dependent processes such as germination and nutrient cycling [2]. Water stress mostly has negative influence on the establishment and growth of perennial species in arid and semi-arid regions [2]. Other environmental factors that may influence plant community composition, distribution and population structure include grazing, browsing, seed dispersal by herbivores and wood harvesting for subsistence use. Grazing may result in the establishment of opportunistic woody species leading to bush encroachment while over browsing results in tree and shrub destruction [3]. Plant species show differential response to livestock grazing. Other species increase in abundance while others reduce in response to livestock grazing [2]. This is as a result of herbivores actively selecting for or against a given plant species [4]. Livestock grazing also disrupts nutrient cycling, plant succession, vegetation stratification which contributes to soil erosion and a decrease in water availability to biotic communities [5].

Plants in arid habitats are widely used for timber, food, fire wood and cattle fodder by the human population [6]. They also contribute significantly to the overall ecosystem functioning through nutrient cycling, evapo-transpiration which influences the water cycle, soil erosion prevention and habitat provision [7]. In Botswana, woodland species also provide services and goods to humanity. Fruits of *Grewia* spp. are used for food, *Colophospermum mopane* provides habitat to the mopane worm (*Gonimbrasia belina*) which is used as relish and for monetary exchange [8], *Sclerocarya birrea* fruits are eaten and also used for production of beer to generate income and *Acacia* spp are mostly used for creating fences for livestock kraals [9]. Despite their importance, little is known about the composition, distribution and population structure of dryland woodland

species in northern Botswana. This is despite the fact that these resources are threatened by over-exploitation from overgrazing and over-harvesting. Woodland resources are also threatened by climate change which is projected to result in low rainfall amount and increased temperatures in Botswana [10]. Already Botswana is experiencing high temperatures, unreliable and low rainfall amounts [11] which climate change will exacerbate. Drought conditions and low temperatures may upset the current ecological functioning of ecosystems in Botswana by excluding the intolerant species. This may reduce biodiversity [12], nutrient cycling [13] and primary production [14]. As a result the changes in primary production, nutrient cycling and biodiversity may affect the economic status of the human communities who depend on the woodland resources. In order to conserve these resources there is need to generate information on their species composition and population structure. This can help in designing management policies and conservation strategies which can promote their sustainable use. It can also help in designing long term monitoring program. The current study aims at classifying dryland woodland communities and establishing the population structure of the constituent species in north western Botswana.

II. MATERIALS AND METHODS

A. Study Area

This study was conducted in sites along transect from Sehitwa to Gudigwa. The study sites were around the villages of Ngarange, Samochema, Seronga, Gudigwa, Gumare and Sehitwa (Fig. 1). The livelihood of the people in this region is mainly cattle farming, crop production and tourism.

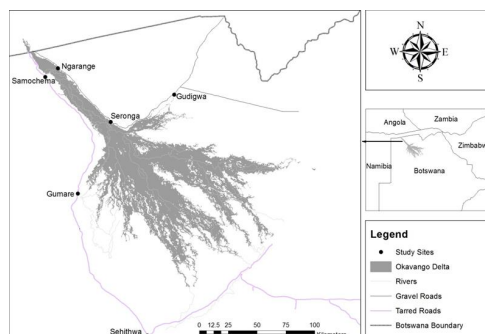


Fig. 1. Study sites in north western Botswana.

The climatic conditions in north western Botswana are semi-arid characterized by seasonal and variable rainfall. Rainfall occurs in one distinct season between November and March with a maximum of less than 400mm/yr. The daily temperatures range between a minimum of 22°C and maximum of 34°C [11]. The north western Botswana region is generally characterized by soils that are sandy, nutrient poor with low water holding capacity. Common woodland species in this region include *Terminalia sericea*, *Acacia erioloba*, *Acacia*

tortilis, *Acacia hebeclada*, *Acacia tortilis*, *Combretum collinum* and *Acacia mellifera*.

B. Vegetation Sampling

Plant species were sampled from randomly selected 20 × 50m plots placed 200m away from the main road. The plots were located at 50km intervals (using the GPS) away from each other along the road. In each plot plant floristic composition analysis was carried out. Species were identified and assigned estimated cover values. Unknown species were collected for further identification in the Peter Smith University of Botswana (PSUB) herbarium at the Okavango Research Institute (ORI) in Maun. For population structure, in each plot circumference was measured using a measuring tape for individuals with circumference of ≥15cm. In multi-stemmed plants, circumference was measured for each stem.

III. DATA ANALYSIS

A. Classification of Plant Communities

Plant communities were determined using Hierarchical cluster analysis (Flexible β linkage, $\beta = -0.25$, Sorensen distance, data relativized by maximum) and indicator species analysis in PC-ORD [15]. Indicator species was used to determine the characteristic species of each plant community [16]. Monte Carlo test was performed to test for significance of the indicator value for each species. The analysis started with determining the ideal number of classes. This was determined where mean p is minimized and the number of ecologically significant species maximized [16]. The ideal number of woodland communities was found to be four clusters. Multi-Response Permutation Procedures (MRPP) was used for pairwise comparisons of species composition between communities [16]. The test statistic T was calculated as: $T = (\delta_{\text{observed}} - \delta_{\text{expected}}) / s_{\text{dev}} \delta_{\text{expected}}$ to determine the extent of separation between communities. More negative values indicate stronger separation while less negative values show weak separation. Within group homogeneity was calculated as: $A = 1 - (\delta_{\text{observed}} / \delta_{\text{expected}})$. $A_{\text{maximum}} = 1$ when all items are identical within a group ($\delta = 0$), $A = 0$ when heterogeneity within groups equals expectation by chance, $A < 0$ with more heterogeneity within groups than expected by chance. The Kruskal-Wallis test was used to test for the statistical significant difference in diversity, richness and density between different plant communities.

B. Linear Regression Analysis for Inferring Recruitment Status

Diameter at breast height (dbh) was calculated from circumference measurements as; Diameter (d) = Circumference (C)/ π , where $\pi = 3.14$. Individuals of different plant species were grouped into 0-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70 and >70cm dbh size classes. Population structure of different tree species was assessed through linear regression analysis between $\ln(N_i + 1)$ and $\ln(m_i)$ [17, 18], where N_i is the number of individuals in the i th size class, and

mi is the mid-point of the size-class. The dbh class midpoint (mi) and the mean number of individuals ($N_i + 1$) in each class were used as independent and dependent variables respectively. Positive slopes of regression indicate no recruitment while negative ones show ongoing recruitment. The correlation coefficient r^2 shows the “goodness of fit” of the regression model, and thus gives some indication of the strength of the conclusion about recruitment status.

IV. RESULTS

The number of plant communities was determined to be four. Four communities that were identified in this study are; *Acacia erioloba*-*Grewia bicolor*, *Terminalia sericea*-*Burkea africana*, *Acacia mellifera*-*Boscia albitrunca* and *Combretum collinum*-*Baphia massaiensis*. Pairwise MRPP comparisons between vegetation communities showed that they were significantly ($p < 0.05$) different from each other (Table I).

A. Description of Plant Communities

Acacia erioloba-*Grewia bicolor* plant community

This plant community was co-dominated by *Acacia erioloba* and *Grewia bicolor*. Other species found in the *Acacia erioloba*-*Grewia bicolor* plant community include *Acacia erubescens*, *Ziziphus mucronata*, *Searsia tenuinervis*, *Acacia nigrescens* and *Acacia tortilis* (Table II). The mean species diversity and richness in this community were 1.21 and 7.62 respectively. The evenness was 0.45 while dominance was 0.42 (Table III). This plant community is found in dry sandy soils.

Terminalia sericea-*Burkea africana* plant community

The co-dominant species in this plant community were *Terminalia sericea* and *Burkea africana*. This plant community was found in sandy soils and mostly comprises of deciduous plant species such as *Dichrostachys cinerea*, *Ximenia americana* and *Combretum engleri* (Table IV). The mean species diversity was 1.17 while richness was 7.70. The evenness and dominance indices were 0.48 and 0.44 respectively in this community (Table III).

Acacia mellifera-*Boscia albitrunca* plant community

This plant community was relatively characterized by few species that included *Acacia hebeclada* with an IV close to one of the dominant species (*B. albitrunca*) and *Peltophorum africanum* with a much lower IV. The dominant species in this community were *Acacia mellifera* and *Boscia albitrunca* (Table V). The species diversity and richness in this plant community were 0.87 and 4.56 respectively. Evenness and dominance were 0.59 and 0.55 respectively (Table III).

Combretum collinum-*Baphia massaiensis* plant community

The *Combretum collinum*-*Baphia massaiensis* plant community was found in deep sandy soils. Other species found in this community were *Grewia retinervis*, *Philenoptera nelsii*, *Colophospermum mopane*, *A. fleckii* and *Bauhinia petersiana* (Table VI). Mean species diversity and richness were 1.10 and 7.29 respectively; mean evenness and dominance were 0.45 and 0.46 respectively (Table III).

TABLE I. MULTI-RESPONSE PERMUTATION PROCEDURES
PAIRWISE COMPARISONS OF VEGETATION CLUSTERS

Classes	T	A	p
AE-GB ¹ vs AM-BA ²	-11.46883586	0.09929001	0.00000001
AE-GB vs CC-BM ³	-17.83214480	0.12307366	0.00000000
AE-GB vs TS-BA ⁴	-29.38757454	0.23821170	0.00000000
AM-BA vs CC-BM	-12.24795536	0.21384820	0.00000018
AM-BM vs TS-BA	-19.17013207	0.33718632	0.00000000
CC-BM vs TS-BA	-20.06260176	0.23461113	0.00000000

¹AE-GB (*Acacia erioloba*-*Grewia bicolor*), ²AM-BA (*Acacia mellifera*-*Boscia albitrunca*), ³CC-BM (*Combretum collinum*-*Baphia massaiensis*), and ⁴TS-BA (*Terminalia sericea*-*Burkea africana*).

B. Population Structure of Different Plant Species

Analysis of population structure yielded three diameter size classes patterns. *Acacia erioloba*, *Philenoptera nelsii* and *Acacia nigrescens* had bell-shaped structure with more individuals at 10-20cm size class (Fig. 2). *Burkea africana*, *Combretum collinum* and *Boscia albitrunca* were characterized by a reverse J-shaped population structure. For *B. africana*, there were missing individuals in 30-40cm, 50-60cm, 60-70cm and >70cm size classes while *Combretum collinum* was characterized by missing individuals at 50-60cm, 60-70cm and >70cm. There were also missing individuals at 30-40cm, 40-50cm, 50-60cm, 60-70cm and >70cm size classes in *Boscia albitrunca* (Fig. 3). *Terminalia sericea*, *Ziziphus mucronata* and *Colophospermum mopane* were characterized by small size classes of 0-10cm and 10-20cm (Fig. 4). All the species had negative regression size class distribution indicating on-going recruitment (Table VII).

TABLE VII. REGRESSION ANALYSIS SLOPE COEFFICIENTS FOR
DIFFERENT WOODLAND SPECIES IN THE COMMUNAL AREAS OF
NORTHERN BOTSWANA.

Woodland species	Slope coefficient	R ²
<i>Combretum collinum</i>	-2.67	0.81
<i>Acacia erioloba</i>	-1.60	0.47
<i>Terminalia sericea</i>	-2.25	0.81
<i>Burkea africana</i>	-1.99	0.74
<i>Philenoptera nelsii</i>	-1.97	0.69
<i>Acacia nigrescens</i>	-1.54	0.58
<i>Ziziphus mucronata</i>	-1.87	0.78
<i>Boscia albitrunca</i>	-2.32	0.88
<i>Colophospermum mopane</i>	-2.56	0.76

TABLE II. SPECIES COMPOSITION IN *ACACIA ERIOLOBA-GREWIA BICOLOR* COMMUNITY

Species	IV	p-Value	Growth form	Family
<i>Acacia erioloba</i>	56.6	0.0002	Tree/Shrub	Fabaceae
<i>Grewia bicolor</i>	32.5	0.0388	Shrub	Tiliaceae
<i>Acacia luederitzii</i>	18.5	0.0236	Shrub	Fabaceae
<i>Acacia nigrescens</i>	22.9	0.0412	Tree	Fabaceae
<i>Combretum hereroense</i>	19.6	0.0394	Shrub	Combretaceae
<i>Terminalia prunioides</i>	11.1	0.1130	Tree	Combretaceae
<i>Combretum imberbe</i>	18.0	0.0848	Tree	Combretaceae
<i>Acacia erubescens</i>	27.0	0.0354	Tree	Fabaceae
<i>Ziziphus mucronata</i>	26.2	0.0238	Tree	Rhamnaceae
<i>Searsia tenuinervis</i>	24.0	0.1104	Shrub	Anacardiaceae
<i>Gymnosporia senegalensis</i>	10.9	0.2226	Shrub	Ebenaceae
<i>Diospyros lycioides</i>	9.4	0.2432	Shrub	Ebenaceae
<i>Acacia tortilis</i>	21.8	0.0994	Shrub	Fabaceae
<i>Acacia ataxacantha</i>	3.7	1.0000	Shrub	Fabaceae

TABLE III. SPECIES DIVERSITY ($\pm$ SD), RICHNESS ($\pm$ SD), EVENNESS ($\pm$ SD) AND DOMINANCE ($\pm$ SD) IN DIFFERENT PLANT COMMUNITIES.

Vegetation community	Shannon diversity index	Mean species richness	Evenness	Dominance
<i>Acacia erioloba-Grewia bicolor</i>	1.21 $\pm$ 0.08	7.62 $\pm$ 0.54	0.45 $\pm$ 0.03	0.42 $\pm$ 0.04
<i>Terminalia sericea-Burkea africana</i>	1.16 $\pm$ 0.10	7.70 $\pm$ 0.77	0.48 $\pm$ 0.03	0.44 $\pm$ 0.04
<i>Acacia mellifera-Boscia albitrunca</i>	0.87 $\pm$ 0.16	4.56 $\pm$ 0.69	0.59 $\pm$ 0.03	0.55 $\pm$ 0.08
<i>Combretum collinum-Baphia massaiensis</i>	1.10 $\pm$ 0.09	7.29 $\pm$ 0.61	0.45 $\pm$ 0.02	0.46 $\pm$ 0.04

TABLE IV. SPECIES COMPOSITION IN *TERMINALIA SERICEA-BURKEA AFRICANA* PLANT COMMUNITY

Species	IV	p-Value	Growth form	Family
<i>Terminalia sericea</i>	91.6	0.0002	Shrub/Tree	Combretaceae
<i>Commiphora africana</i>	6.8	0.6457	Shrub	Burseraceae
<i>Dichrostachys cinerea</i>	25.3	0.2432	Shrub	Fabaceae
<i>Euclea divinorum</i>	3.9	0.7856	Shrub	Ebenaceae
<i>Ximenia americana</i>	14.0	0.3079	Shrub	Oleaceae
<i>Burkea africana</i>	26.8	0.0118	Tree	Fabaceae
<i>Pterocarpus angolensis</i>	4.3	0.6459	Tree	Fabaceae
<i>Combretum engleri</i>	12.7	0.1670	Shrub	Combretaceae
<i>Combretum mossambicense</i>	3.1	0.8906	Shrub	Combretaceae
<i>Ximenia caffra</i>	4.3	0.6431	Shrub	Oleaceae

TABLE V. SPECIES COMPOSITION IN *ACACIA MELLIFERA-BOSCIA ALBITRUNCA* PLANT COMMUNITY

Species	IV	p-value	Growth form	Family
<i>Acacia mellifera</i>	61.6	0.0002	Shrub	Fabaceae
<i>Boscia albitrunca</i>	56.0	0.0004	Tree	Capparaceae
<i>Acacia hebeclada</i>	53.1	0.0002	Shrub	Fabaceae

TABLE VI. SPECIES COMPOSITION IN *COMBRETUM COLLINUM-BAPHIA MASSAIENSIS* PLANT COMMUNITY

Species	IV	p-Value	Growth form	Family
<i>Combretum collinum</i>	56.0	0.0002	Tree	Combretaceae
<i>Grewia retinervis</i>	44.3	0.0084	Shrub	Tiliaceae
<i>Acacia fleckii</i>	16.6	0.1128	Shrub	Fabaceae
<i>Philenoptera nelsii</i>	25.3	0.1134	Tree	Fabaceae
<i>Bauhinia petersiana</i>	13.8	0.6109	Shrub	Fabaceae
<i>Baphia massaiensis</i>	55.1	0.0004	Shrub	Fabaceae
<i>Colophospermum mopane</i>	27.5	0.0128	Tree	Fabaceae
<i>Albizia versicolor</i>	4.6	0.7514	Tree	Fabaceae

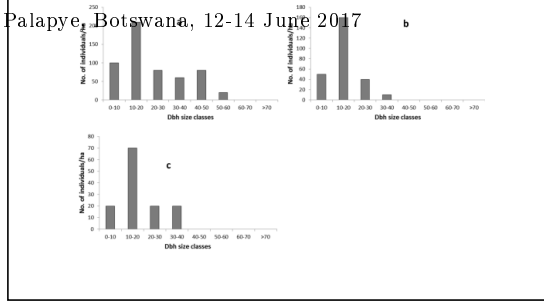


Fig. 2. The population structure of *Acacia erioloba* (a), *Philenoptera nelsii* (b) and *Acacia nigrescens* (c).

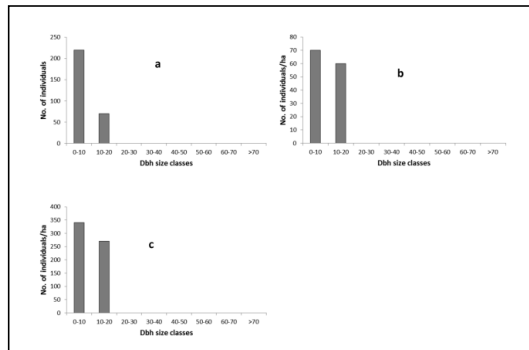


Fig. 4. The population structure of *Burkea africana* (a), *Combretum collinum* (b) and *Boscia albitrunca* (c).

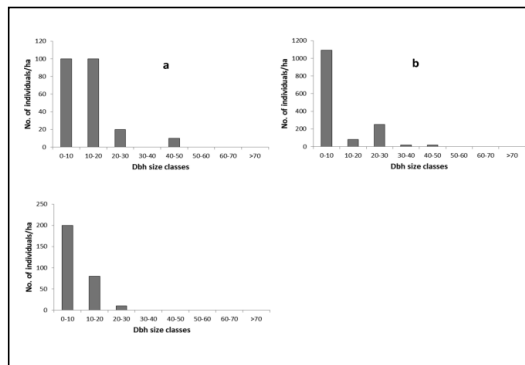


Fig. 3. The population structure of *Terminalia sericea* (a), *Ziziphys mucronata* (b) and *Colophospermum mopane* (c).

V. DISCUSSION

A. Plant Communities

This study revealed that there were four major plant communities in north western Botswana being; *Acacia erioloba*-*Grewia bicolor*, *Terminalia sericea*-*Burkea africana*, *Acacia mellifera*-*Boscia albitrunca* and *Combretum collinum*-*Baphia massaiensis*. The species composition and distribution of these plant communities may be influenced by climatic stress, availability of nutrients and water, grazing, browsing, seed dispersal and cutting of wood for subsistence use [3]. Grazing opens up new spaces for colonization by woody species [3] by removing the grass layer and reducing the competition for water [19]. Grazing may also affect the composition and distribution of plant species in dry land plant communities through selection by herbivores for or against a given species, trampling on vegetation which damages seedlings [5].

In north western Botswana, livestock farming is based on communal grazing where stocking rate is not controlled and consequently rangelands are prone to overgrazing. The influence of grazing on plant community composition and distribution can be inferred from the dominance of *A. mellifera*. This species is mostly associated with overgrazed habitats and has an invasive behavior [20]. The encroachment of *A. mellifera* in overgrazed areas was also found in the Kwazulu Natal region in South Africa [21] and Kalahari area, northern Botswana [19]. *Acacia mellifera* is able to succeed in colonizing overgrazed areas because of its shallow lateral root system [20] which enables it to use water from the surface of the soil [19]. This means that it stands a better advantage of surviving from little rain water as compared to other woodland species with deep root systems [19]. In Botswana rainfall is generally a limiting factor for plant growth [22] due to its low levels and unpredictability [23]. With the seasonal rains in northern Botswana being generally low (ca. 400mm) and the area being semi-arid [11] *A. mellifera* may have a competitive advantage over other species to use the little rainwater and be dominant in the grazed areas because of its shallow roots. Its roots extend to about 8cm-15cm from the stem, running parallel to the surface and can reach a maximum depth of 25cm [24]. In this study its invasive behavior was evident in that its community was the most species poor. This implies that other species were unable to compete with it the little water that is available. *Boscia albitrunca* which is the co-dominant species in *Acacia mellifera*-*Boscia albitrunca* plant community is a long drought tolerant species [25]. This suggests that it is an indicator of prevailing dry conditions in north western Botswana. In this case, dry conditions eliminate the grass layer and reduce its competition for water, nutrients and sunlight. As a result the seedlings of species such as *A. mellifera* which have shallow roots establish [19]. If this occurs in a sequence of years, it may result in the encroachment of woodland species. Fire may also play a crucial role in promoting bush encroachment of species such as *A. mellifera* through its role in removing the grass layer [26]. In our study evidence of the occurrence of fire was observed. However, this was not

quantified in terms of frequency, spatial extent and the last time it occurred as it was not within the scope of our study.

Another plant community identified in north western Botswana was *Terminalia sericea*-*Burkea africana*. The co-occurrence of *Terminalia sericea* and *Burkea africana* has also been reported in Savanna ecosystems such as Nylsvley Provincial Nature Reserve, northern Transvaal, South Africa [27], Miombo forest in Lupa forest reserve in Tanzania [28] and Hwange National park in Zimbabwe [29]. Both *Terminalia sericea* and *Burkea africana* have shallow root systems which enable them to recover water from little rains that prevail in north western Botswana [30]. The shallow rooting system in *T. sericea* and *Burkea africana* enables them to successfully compete with grasses for available water and nutrients with grass species which are also shallow rooted [31]. These species are also fast growers which enables them to out-compete other species that such as *Baikiaea plurijuga* that are slow growers [27]. This also implies that their fast growth allows them to escape the dry season. Once the dry season sets in they will be at a stage where they can tolerate it following the development of tap roots for accessing deep groundwater sources. *Burkea africana* and *T. sericea* are also able to photosynthesize at lower soil moisture content [30] which again explains their dominance in the dry region of north western Botswana. *Terminalia sericea* could also be an indicator of disturbance and it is one of the early colonizers of a disturbed site [28]. In our case this could be an indication that the communal areas are disturbed by grazing which seems to be the main source of disturbance.

The other two plant communities identified in this study were *Acacia erioloba*-*Grewia bicolor* and *Combretum collinum*-*Baphia massaiensis*. The distribution of these communities is also linked to the availability of water. They are found in sandy soils with low water holding capacity. In order to survive this, they should be adapted to dry conditions. *Baphia massaiensis* is able to tolerate short periods of drought and flowers from October to March, with leaves growing mainly from October to June [32]. This life cycle suits the semi-arid conditions of Botswana which are generally characterized by rains from October to March, and dry conditions during the winter season from around May to August. The shedding of leaves after June is a response to dry conditions and it is meant to reduce the loss of water through evaporation. *Baphia massaiensis* is also important for providing forage for livestock and game [32]. Therefore, browsing from game and livestock may influence its performance and growth. Its abundance could suggest that it is not heavily relied on for browsing in northern Botswana. This implies that the grass is the main source of forage for the livestock in this area hence the dominance of *A. mellifera* which suggests grass over-grazing. *Acacia erioloba*, *Grewia bicolor* and *Combretum collinum* were also found in sandy soils. These species are also adapted to growing in semi-arid conditions prevailing in north western Botswana. As previously stated, annual rainfall in north western Botswana is low. As a result plant species that establish in this region should be

adapted to low water availability and seasonal rainfall. These species are adapted to low water content through development of tap roots and shedding of leaves during the winter season when it is dry.

In addition to grazing and climatic conditions, plant community composition in north western Botswana may also be influenced by human use. Human use of woodland species include gathering of firewood, cutting poles for fencing homes, fields and kraals, felling for road making and human settlement [33]. Historically, acacia species in Tsao, Nokaneng, Gumare and Sepopa were cut to prevent the spread of tsetsefly [33]. Furthermore, human communities in north western Botswana harvest woody species for fire wood [34]. In addition to this our field observations showed that woodland species are also used for building of traditional huts, fencing kraals and homesteads. Woodland plants may also be affected by land clearing for cultivation [35]. These uses may also have an impact on the abundance and distribution of the preferred species. Human induced fire could be one of the factors that influence species composition and distribution of woodland plants in northern Botswana [35]. During our study we observed scars of fire. Fire may exclude intolerant species and promote the establishment of tolerant ones. Its influence may be a function of season, frequency, areal extent and height. For instance in northern Botswana high fire frequency reduced tree densities of *Baikiaea plurijunga*, but increased densities of shrubs and seedlings [36].

B. Population Structure of Different Plant Species

The population structure of tree species in north western Botswana can be grouped into three categories of bell, reverse J shaped and two class pattern dominated by more individuals in the 0-10cm and 10-20cm size classes. In the bell-shaped pattern, the species were characterized by more individuals skewed towards the 10-20cm size class. Tree species with the bell-shaped population structure were *Acacia erioloba*, *Philenoptera nelsii* and *Acacia nigrescens*. The bell-shaped population structure could indicate that there was a massive recruitment of individuals in the middle size classes when the conditions were favourable [37, 38]. In our case, this massive recruitment may have taken place recently as all the species with the bell-shaped structure had more individuals in the relatively young size class of 10-20cm suggesting that over the years there was suppression of growth of individuals from the smaller size classes into the larger ones.

The environmental bottlenecks which may suppress rejuvenation of tree species include fire, logging and grazing [39, 37]. Fire may suppress recruitment of individuals by killing them before they grow into the next size class [39]. In terms of logging, our results suggest that the individuals were cut for poles used for construction of human settlement in our study area. Big individuals in the larger size classes such as 40-50cm, 50-60cm and 60-70cm are likely to be preferred since they are strong and durable which is suitable for the construction of a strong structure. Other studies have also showed that logging of woodland species resulted in bell-

shaped population structure. This was found in *Prosopis africana* in Burkina Faso [40] and Senegal [39]. Logging also had negative impact on the population structures of woodland species with species such as *Cordyla pinnata*, *Pterocarpus erinaceus* and *Terminalia macroptera* affected in Fathala Forest in Senegal [39]. The impact of this is exacerbated by increasing human population in the area which results in increased demand of the building materials [40]. Less grazing may result in more grass cover which competes with the seedlings for sunlight, water and nutrients resulting in suppression of their recruitment [39]. Conversely, grazing of the seedlings may also inhibit their recruitment into the next growth stage [38]. This suggests that there could be interplay between fire, logging and grazing influencing recruitment of tree species in north western Botswana. However, until further research is conducted on the environmental factors that drive the population structure dynamics in northern Botswana it will be difficult to know their role in recruitment of tree species.

Combretum collinum, *Burkea africana* and *Boscia albitrunca* had a reverse J-shaped population with more individuals in the smaller size classes than in the larger ones. All these species did not have any individuals in the larger size classes. *Burkea africana* and *C. collinum* only had individuals up to the 40-50cm size class while *Boscia albitrunca* had individuals up to 20-30cm size class. Generally, the reverse J-shaped population structure is regarded as being healthy as the individuals in the lower size classes are recruited to replace the aging and dying older ones [39, 41, 37, 38]. The strong negative regression slopes in these species seemed to prove this correct. However, as can be expected some of the individuals die before maturity hence a decline in their number in the larger size classes. The death of the individuals between the different growth stages could be attributed to the factors such as fire, herbivory and logging already discussed for the bell-shaped pattern in the previous section.

The last group of species was those that had only two size classes of 0-10m and 10-20m which were *Terminalia sericea*, *Ziziphus mucronata* and *Colophospermum mopane*. While this is a once off study seeking to understand population structure patterns which may be a product of environmental controls, the result here suggest that the individuals of these species could be unable to be recruited beyond the 10-20cm size class. This could result from unfavorable growth conditions, poor dispersal mechanisms and slow growth [39]. It may also imply that individuals of these species are selectively removed before reaching the other growth stages [38]. In the communal setting like our study area the removal of individuals of these species could mainly be a product of human logging for construction materials [40]. However, these results should be interpreted with caution as there could be some individuals missed during our sampling campaign. This could especially be more applicable to *C. mopane* in which we missed some of its patches which fell outside our selected sampling plots.

C. Implications for Management

The results of this study point to the conservation need of *Colophospermum mopane*, *Terminalia sericea* and *Ziziphus mucronata* to facilitate the recruitment of their individuals beyond the 10-20cm size class. This could be achieved through enclosures to exclude the impact of both humans and their livestock. The enclosures have been successful in rehabilitation of tree species in woodland habitats in Ethiopia [42, 43]. Species with the bell shaped recruitment pattern should also be considered for protection especially that the recruitment of their individuals appears to stall at the 10-20cm size class. There should also be efforts towards raising education awareness for the sustainable use of the woodland resources in the human communities in northern Botswana. However, this should be preceded by studies on the extent to which the communities rely on the woodland species. There is also need to determine the correct livestock stocking capacity in the area so the farmers can be advised on the correct number of cattle to keep.

VI. CONCLUSION

Four plant communities of *Acacia erioloba*-*Grewia bicolor*, *Terminalia sericea*-*Burkea africana*, *Acacia mellifera*-*Boscia albitrunca* and *Combretum collinum*-*Baphia massaiensis* occur in north western Botswana. Species composition in these communities may be a product of a suite of environmental factors including fire, rainfall and grazing. The presence of *A. mellifera* could be an indication of an overgrazed rangeland in northern Botswana which may imply overstocking in the area. Tree species in north western Botswana had different patterns of population structure which could be a result of human use and livestock grazing/browsing. *Acacia erioloba*, *Philenoptera nelsii* and *A. nigrescens* showed bell-shaped structure while *Burkea africana*, *Boscia albitrunca* and *Combretum collinum* had reverse J-shaped pattern. *Terminalia sericea*, *Ziziphus mucronata*, and *Colophospermum mopane* had only 2 or 3 classes skewed towards juveniles.

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