Scientific Research and Essay Vol.3 (9), pp. 442-456, September 2008
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 © 2008 Academic Journals

Full Length Research Paper

Soil resources distribution, woody plant properties and land use in a lunette dune-pan system in Kalahari, Botswana

Samuel Mosweu

Department of Environmental Sciences, University of Botswana, Private Bag UB00704 Gaborone, Botswana. E-mail: mosweu@mopipi.ub.bw. Fax: +267 318 5097.

Accepted 13 August, 2008

The distribution of selected soil properties, selected woody vegetation properties, and land use in a lunette dune-pan system were investigated in the Sekoma area, which is located within the IGBP Kalahari Transect (KT) in Botswana. KT was established by the IGBP for studies focusing on both regional and global environmental changes. The study showed that the lunette dune-pan system exhibited substantial spatial heterogeneity in the distribution of the selected soil attributes. This limited the extent to which variation in the investigated vegetation characteristics could be explained on the basis of soil resources distribution. Encroacher plant species were found to be prevalent in the sites that were subjected to higher land use pressure. The study concluded that land use, particularly browsing, was the principal environmental driver and had precedence over the distribution of the selected soil attributes in relation to woody plant properties in the lunette dune-pan system.

Key Words: Kalahari, land use, lunette dune, pan, soil resources, woody plants.

INTRODUCTION

The environmental conditions and geographical position of the Sekoma lunette dune-pan complex make the system an ideal environment for the study of ecosystem dynamics. The complex is located within the 'megatransect' internationally referred to as the Kalahari Transect (KT) that has been established by the International Geosphere-Biosphere Programme (IGBP) for the study of both regional and universal environmental changes (Koch et al., 1995; Scholes et al., 2002; Shugart et al., 2004; Wang et al., 2007). Various environmental studies have been conducted along the KT (Koch et al., 1995; Scholes et al., 2002; Caylor et al., 2003; Scholes et al., 2004; Privette et al., 2004; Shugart et al., 2004; Wang et al., 2007). However, the studies tended to deal with the dynamics of plant communities, association between vegetation and the environmental factors, and the biogeochemistry and physical properties of soils without giving due attention to the lunette dune-pan systems existing within the KT. Despite this, environmental changes occurring in the lunette dune-pan systems have implications on the KT studies at both regional and global levels.

The Sekoma lunette dune-pan system comprises a pan and a number of lunette dunes located at the pan fringes. Pans have been described as close, ephemeral and often relict basins of varying scales and origins (Thomas and Shaw, 1991; Shaw and Thomas, 1997). Maximum density of pans has been reported as one pan per 22km^2 in the Kalahari Basin (Lancaster, 1978a, 1978b). On the other hand, lunette dunes are dunes that are commonly located on the downwind of a pan (Lancaster 1978a, b). Although the formation of pans and lunette dunes is controversial, the study of the Southern Kalahari pans by Lancaster 1978a, b indicated that the pans in the Kalahari originated through deflation while the lunette dunes were a result of sedimentation of the sand deflated from the pan floor.

Vegetation quality has degraded over time in the immediate environs of the Sekoma village. The lunette dunes remain the primary area which provides better forage resource base that is closest to the livestock water sources located in the pan. In other parts of the Kalahari region where pans are not associated with lunette dunes, livestock require a lot of energy to access forage resources which are normally far away from water sources (Chanda et al., 2003). It has been established that in other environments (Cornelius and Schultka, 1997; Moleele, 1998; Solomon et al., 2007; Ryerson and

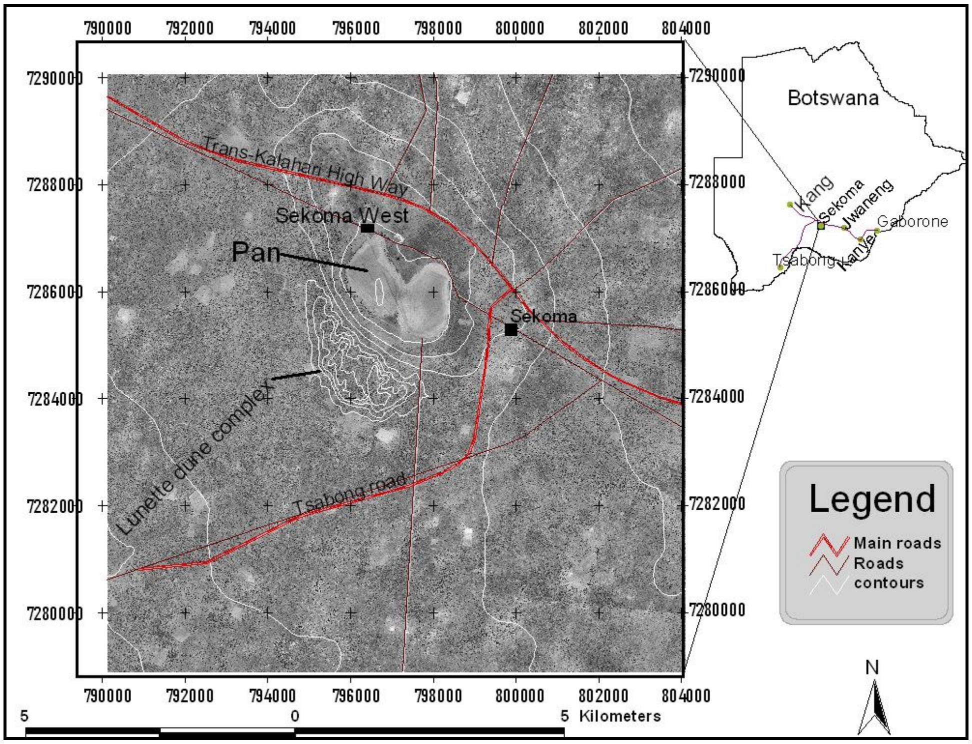

Figure 1. Location of the Sekoma lunette dunes.

Parmenter, 2001; Skarpe, 1986; 1990b) anthropogenic activities, livestock grazing and browsing invariably cause significant changes in inter alia, land-scape structure, vegetation community composition, vegetation structure, species diversity, species cover and habitat diversity. Thus, the main objectives of this study were to (i) examine the distribution of selected soil attributes, (ii) assess woody plant community composition, species distribution and cover, (iii) study the relationship between the selected soil attributes and land use, and (iv) investigate the impacts of land use and the effects of the distribution patterns of selected soil characteristics on woody plant community composition, species distribution and cover along a land use gradient in a lunette dune-pan system.

MATERIALS AND METHODS

Soils and vegetation sampling

Soils and vegetation sampling was conducted in November 2006. At this time of the year, herbaceous vegetation cover was very minimal due to late rains and could contribute insignificantly to this study. Therefore, the research focused on woody vegetation cover, adopting a land use gradient approach. Gradient approach has been used both regionally and globally to investigate environmental changes including ecosystem dynamics and vegetation properties (Koch et al., 1995; Scholes et al., 2002; Caylor et al., 2003; Scholes et al., 2004; Privette et al., 2004; Shugart et al., 2004; Wang et al., 2007). In addition, land use gradients have been used previously in various studies to assess the impacts of foraging on vegetation in arid and semi-arid environments (Walker and Heitschmidt, 1986; Tolsma et al., 1987; Andrew, 1988; Jeltsch et al., 1997; Moleele, 1998; Moleele and Perkins, 1998; Thrash, 1998; James et al., 1999; Thrash, 2000; Riginos and Hoffman, 2003). It has been established that gradients radiating from water sources or points, which in this study is the pan, indicated higher forage resources and environmental degradation closer to the water sources or point in comparison with areas further a field (Lange, 1969; Walker and Heitschmidt, 1986; Tolsma et al., 1987; Andrew, 1988; Jeltsch et al., 1997; Moleele and Perkins, 1998; James et al., 1999; Thrash, 2000; Ringrose and Hoffman, 2003). This approach was found useful in this study as the pan serves as the main source of water and the lunette dunes as the major forage resource base for livestock in the area. Furthermore, a gradient of land use was observed radiating from the pan fringes traversing the lunette dunes. Therefore, transects were established along a land use gradient, from the pan fringes across selected lunette dunes (Tshube, Leremela and Kebuang) to the mid-point of the slip face slope of the dunes (Figure 2). Sampling was carried out at the pan fringes (PF), wind ward slope (WS), dune crest (DC) and slip face slope (SS) which are indicated as 1, 2, 3, and 4 respectively in Figure 1.

To ensure that the data obtained from sampling appropriately represents the environmental conditions prevailing in the study area, three quadrats of 20 x 20 m separated by 10 m were established at sampling points marked 1, 2, 3 and 4 (Figure 2). The quadrats were labeled as indicated in Figure 3 (Tshube 1-12, Leremela 13-24 and Kebuang 25-36). Vegetation and soil sampling was carried out in each of the 36 quadrats which were treated as sites (S) for the Detrended Correspondence Analysis (DCA) and the Canonical Correspondence Analysis (CCA). Soil samples were collected in the center of each quadrat using an auger that had a sample collection chamber length of 20 cm and a volume of ca. 23.75 ml. Therefore, about 23.75 ml per sample volume were collected. It was observed in the preliminary study that a soil profile

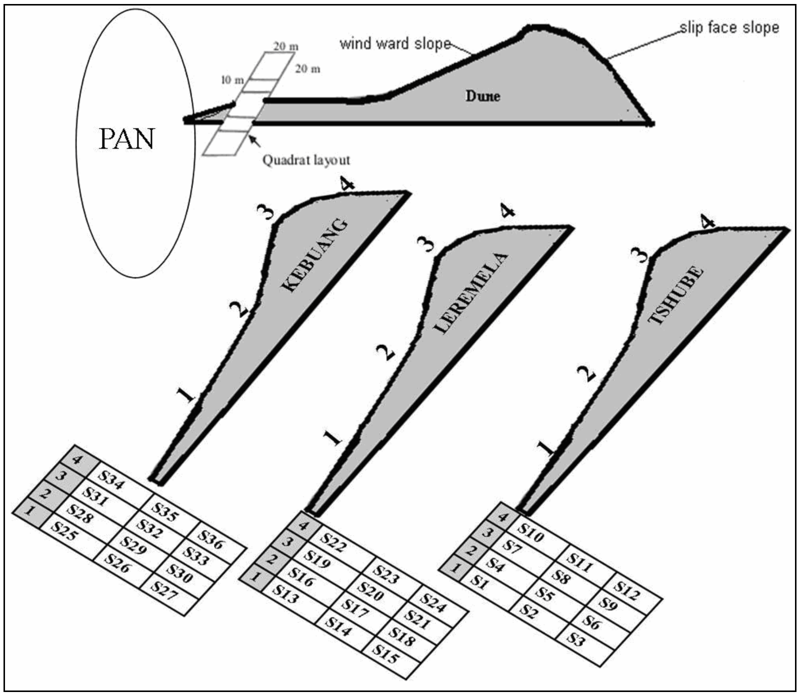

Figure 2. Location of sampling points along the transects/land use gradient. 1 = PF (Pan Fringes), 2 = WS (Wind ward Slope), 3 = DC (Dune Crest), 4 = SS (Slip face Slope).

established in the dunes did not show soil horizons. Therefore, to examine changes in the distribution of the selected soil attributes, samples were collected at the sampling depth (SD) of 0-20, 80-100, and 130-150 cm.

The study area

The study was carried out in Sekoma (Figure 1) where the general landscape is almost flat to gentle undulating plain with superficial aeolian sand deposits on dolomite and sedimentary rock (Ministry of Agriculture, 1991). The area is located within the KT, which has been set up as one of a set of IGBP transects and recognized for both regional and global environmental studies (Koch et al., 1995; Scholes et al., 2002, Scholes et al., 2004; Privette et al., 2004; Shugart et al., 2004; Wang et al., 2007). The dolomite Precambrian aquifer system characterizes the lithology of the area (Geological survey department, 1995). The general structure of vegetation in the area is defined as shrub savanna and the vegetation is classified as southern Kalahari bush savanna (Botswana national atlas, 2001). The mean annual rainfall in the area is about 400 mm (Bhalotra, 1985) and the rainfall season is characterized by erratic rainfall patterns. The study focuses on the lunette dune-pan system which is situated between the initial and the current location of theSekoma village (Figure 1).

Soil analyses

Determination of available phosphorus in this study was accomplished through the use of Olsen's method (Olsen et al., 1954). The UV-visible Spectrophotometer model UV-1601 Shimadzu set at 720 nm was engaged in the analysis of phosphorus. The sieve method was utilised in the investigation of particle size distribution. Due to minimal clay content of the sandy lunette dune-pan system soil, only the sand (% sand) and the combined silt and clay (%SC) fractions were investigated using the Retsch shaker and sieve of 50 µm mesh size. The % Sand was separated from SC on the basis that sand fraction is characterized by a particle size diameter of 50 µm to 2000 µm (ISRIC, 1993). Electrical conductivity (EC) and pH were determined on a 1:2 (soil:water) ratio as proposed by Sonnevelt and van den Ende (1971). The HANNA pH 210 pH meter was used to measure pH and the inoLab cond 730 WTW series EC meter was used to determine EC. Soil organic carbon (SOC) was determined through the Walkley-Black wet oxidation method after Van Reeuwijk (1993). The Barium Chloride ($BaCl_2$) method proposed by Hendershot and Duquette (1986) was chosen for this study as it provides a more efficient way of determining the exchangeable cations and the Effective Cation Exchange Capacity (ECEC) of a wide range of soil types (Hendershot and Duquette, 1986). The ECEC was calculated as the sum of exchangeable cations; Calcium (Ca), Magnesium (Mg), Pottasium (K), Sodium (Na), Aluminium (Al), Iron (Fe), and Magnesium (Mn). The atomic absorption spectrophotometer (AAS –SpectrAA 220FS, VARIAN) was used to measure the cations through direct determination as outlined by Fresenius et al. (1988). Quality control techniques that have been applied to analyses are described below.

- Procedural blanks: These were analyzed to determine the level of the target analyte in reagents, acids, sample vessels, glassware that were used in the analyses.
- Duplication of samples: Each sample was analyzed 3 times and the instrument was set to perform three replicates for each run.
- Reference control material: Solutions of known concentrations of the target analyte were analyzed to check for accuracy and precision of the method.
- Calibration curves: These are required for each instrumental analysis of a sample batch and they were produced for each analyte. The calibration curves were verified immediately using the

reslope calibration standard to determine if the initial cali-bration was acceptable for the analytical run.

• Calibration checks: After each and every five runs, calibration checks were carried out by reanalyzing the reslope standard used in the initial calibration to check the validity of the calibration curve before continuing the run.

Vegetation analyses

Vegetation analyses included species density, cover, distribution and composition of woody vegetation in the lunette dune-pan system. Species density was used to assess abundance. The number of individuals of each species present at a sampling point within a series of quadrats distributed along transects were determined and the average number relative to the size of a quadrat was calculated from the total sample. Species composition refers to a list of plant species that exist in a particular vegetation community (Bonham, 1989), and species distribution refers to the spatial range of a species. The Crown-Diameter method (after Muller-Dombois and Ellenberg, 1974) was used to determine crown cover (CC) for woody species. This method employs the following formula:

$$CC = \pi(\frac{D1+D2)}{4})^2$$

Where D_1 = First Crown Diameter (measured from the tree/bush perimeter across the centre to the other side of the perimeter), D_2 = Second Crown Diameter *(*measured perpendicular to D_1), and **CC** = Crown cover.

Land use study

Human and livestock population dynamics have a direct bearing on land use intensity. Therefore, a set of data on human and livestock population census was obtained from the Central Statistics Offices (CSO) and used to study temporal trends in human and livestock populations and to draw inferences pertaining to land use issues from the trends. The Sekoma village population census data were available, but livestock population data specific to Sekoma village was not available at CSO. Hence, district population data were used in this study. Reports from CSO on livestock censuses and surveys indicated that over the years agricultural districts have been changing. In the 1982 census report, the Southern agricultural region under which the Sekoma village falls was divided into three districts, while it was divided into five districts in the 1993 and 2004 reports. Thus, to maintain consistency, the 1993 and 2004 livestock censuses data were used. To augment the foregoing information, a mini-social survey was employed to examine human perceptions in relation to the impacts of land use on woody plant community composition, species distribution and cover in the lunette dune-pan system. The influence of human perceptions on their relationships with the environment was also studied. Key informants were chosen on the basis of their reliability in the provision of quality data with respect to land use aspects.

One form of questionnaire was designed and administered to the participating informants for data collection purposes. Two focused group discussions, one constituted by the chief and village elders and the other by the village development committee (VDC) were conducted. Questions were presented in an opened ended form toinformants and a pre-designed key was used in summarizing the responses. Additional information that could not be captured by the use of the questionnaire was noted during the discussions.

Analysis of soil-vegetation relationships

Data obtained from soil analyses constituting the selected environmental variables and plant species data from 36 sampling sites were analyzed through canonical ordination techniques in the form of DCA and CCA. The techniques were preferred because they are designed to identify major patterns in vegetation species distribution and plant community composition, and also to detect patterns of variation in the species data that can be best explained by the investigated environmental variables. The CANOCO programme version 3.0 of ter Braak (1989) was engaged in the analyses and the DCA and CCA diagrams were produced using Systat software Inco package; SigmaPlot version 9.0.1 of 2004.

The DCA ordination diagram was produced by plotting species scores and site scores (AX1 vs AX2). The diagram mirrors the estimated vegetation species distribution patterns and plant community composition in the lunette dune-pan system. Each site point in the DCA diagram lies at the centroid of the species points that occur at the site (Hill, 1979). Sites that lie close to the point of the species in the diagram are therefore likely to exhibit high density of that particular species (ter Braak, 1986).

The CCA ordination diagrams were produced by plotting species scores, site scores and biplot scores of environmental variables (AX1 vs AX2). The ordination diagrams emanating from CCA do not only portray patterns of variation in species composition and distribution, but also the major associations between the species and each of the environmental variables (ter Braak, 1986). They display points that represent species and sites, and arrows that represent environmental variables. The species and site points mutually portray the dominant patterns in community composition to the extent that these can be explicated by the environmental variables (ter Braak, 1988). The species points and the arrows of the environmental variables mutually depict the distribution of species along the gradient of each of the environmental variable (ter Braak, 1988). Only the direction and the relative length of the arrows convey essential information (ter Braak, 1986). The length of an arrow representing an environmental variable is considered to be equal to the rate of change in the score as inferred from the ordination diagram, hence a measure of how much the species distribution vary along that environmental variable gradient (Gauch, 1982a). As a result, important environmental variables are normally represented by longer arrows as compared to less important environmental variables. Gauch (1982a) and ter Braak (1988) emphasized that in the interpretation of the percentage of variance accounted for by the ordination diagram, it is worth noting that the aim is not 100% because the noise in the data may cause a significant fraction of the variance. Therefore, even an ordination diagram that explains only a low percentage may be practically enlightening (ter Braak, 1998; Gauch, 1982a; Myklestad and Birks, 1993).

Eigenvalues (λ) of the DCA and CCA normally referred to as the "percentage variance accounted for" (ter Braak, 1988) were examined (Table 1). An Eigenvalue ranges from one to zero, and the higher the value the more important the ordination axis. Eigenvalues of ca. 0.3 and higher have been reported to be common in ecological applications. It is usually anticipated that the first two axes in the ordination diagram account for the biologically pertinent information (ter Braak, 1995).

Analyses of soil-land use relationships

To assess the relationships between land use and the selected soil properties in a lunette dune-pan system, Pearson's corre-lation was engaged. Soil variables were correlated with distance from PF to SS. On the basis of the observation that land use intensity showed an indirect proportional relationship with the distance from the pan fringes (PF) to the slip face slope (SS), distance from PF to SS was used as a surrogate for land use gradient in the analysis. The correlation mirrored the lateral relationships between soil characteristics and land use intensity (LUI). Furthermore, soil variables were correlated with sampling depth (SD) at all sampling

Table 1a. Soil properties in relation to average depth of the horizon in Tshube lunette dune toposequence.

ASD	P(ppm)				Ca (ppm)				ECEC (ppm)			
	P	W	C	S	P	W	C	S	P	W	C	S
1	5.01±7.00	1.15±0.19	1.08±0.29	2.05±0.32	2.53±0.35	3.52±1.16	3.72±0.57	3.34±0.44	8.05±2.56	8.59±1.84	8.36±1.75	7.74±2.54
2	0.99±0	0.65±0.09	0.77±0.28	0.88±0.10	4.34±0	5.46±1.07	5.90±1.03	3.69±1.13	13.62±0	10.2±0.86	10.37±2.08	8.05±1.34
3	0.60±0	0.33±0.02	0.95±0.23	0.88±0.24	4.30±0	7.09±2.39	5.76±0.31	4.15±0.27	14.32±0	12.47±0.11	10.01±1.87	8.14±1.81
	%OC				pH				EC (μS/cm)			
	P	W	C	S	P	W	C	S	P	W	C	S
1	2.65±0.08	2.64±0.33	2.44±1.50	2.31±0.39	7.77±0.11	7.69±0.18	7.83±0.58	7.22±0.13	250.67±71.00	273.67±75.96	194.90±150.82	162.53±23.48
2	2.38±0	2.64±2.02	3.59±1.89	2.61±1.48	9.04±0	9.15±0.03	9.07±0.27	8.85±0.34	90.40±0	86.27±4.70	90.30±5.01	78.30±2.67
3	3.2±0	4.11±1.41	2.63±1.21	2.96±1.43	9.09±0	9.16±0	9.16±0.24	9.41±0.43	111.20±0	89.85±6.01	80.70±11.97	85.57±10.24
	K (ppm)				Mg (ppm)				Na (ppm)			
	P	W	C	S	P	W	C	S	P	W	C	S
1	0.24±0.01	0.24±0.02	0.21±0	0.21±0.01	0.22±0.03	0.26±0.02	0.24±0.06	0.26±0.03	0.75±0.05	0.62±0.20	0.56±0.07	0.43±0.06
2	0.24±0	0.22±0.01	0.21±0.01	0.22±0.01	0.31±0	0.23±0.03	0.31±0.05	0.20±0.11	1.02±0	0.59±0.05	0.54±0.15	0.51±0.05
3	0.27±0	0.22±0.01	0.22±0.01	0.22±0.01	0.32±0	0.26±0.04	0.21±0.09	0.21±0.12	0.80±0	0.55±0.15	0.47±0.02	0.53±0.06

SD = Average Sampling Depth; **ASD 1, 2, 3,** = Average Sampling Depth 0 - 20 cm, 80 – 100 cm, 130 – 150 cm; P = Pan Fringes; **W** = Wind Ward Slope; **T** = Crest; **S** = Slip Face Slope; **NS** = Not Sampled; indurated material.

points along the gradient. This represented the vertical relationships between the soil characteristics and LUI along the gradient.

RESULTS

Soil properties

The results showed that Tshube lunette dune displayed very high %Sand that ranged from 95.90 to 99.30% and low %SC that ranged from 0.70 to 4.10% (Table 1a). In Leremela, %Sand ranged from 95.35 to 99.43% while %SC range was as low as 0.57 to 4.65% (Table 1b). In Kebuang lunette dune, %Sand ranged from 98.07 to 99.37%, whereas %SC ranged from 0.63 to 1.93% (Table 1c). Observations clearly indicated that there were no marked differences amongst the lunette dunes in relation to %Sand and %SC, and that they are all sandy lunettes. Table 1 show detailed summary of the results of analysis of the soil samples obtained from the study site.

Vegetation characteristics

It was observed that the key woody plant species inhabiting the Lunette dune-pan system were *Acacia erioloba, Acacia fleckii, Acacia hebeclada, Acacia mellifera, Boscia albitrunca, Ehretia rigida, Gardenia volkensii, Grewia flava, Rhigozum trichotomum, Rhus tenuinervis, Strychnos madagascariensis*, and *Ziziphus mucronata.* The results indicated that *G. volkensii* was a rare plant species in the study area. Only two lunettes, Kebuang and Leremela and three sampling sites (S23, S31, and S35) exhibited the presence of this plant species at densities of 175, 25, and 25 per hectare, respectively. *E. rigida, G. flava, S. madagascariensis*, *R. tenuinervis, and R. trichotomum* displayed similar trends in relation to species density in Leremela (Figure 3). In terms of species canopy cover, *A. mellifera* displayed dominance at all sampling sites. Each species displayed a distinct pattern in relation to species cover in Leremela. In Kebuang (Figure 3), *A. fleckii, E. rigida, G. flava, R. trichotomum* and *R. tenuinervis* displayed similar trends with regard to species density. The density of *S. madagascariensis* decreased from PF to SS. *A. mellifera* had a higher density at PF, while other species exhibited densities of less than 50 plants per hectare. In terms of species cover, *A. mellifera* generally showed higher and erratic cover (Figure 3).

Table 1b. Soil properties in relation to average depth of the horizon in Leremela lunette dune toposequence.

ASD	P(ppm)				Ca (ppm)				ECEC (ppm)			
	P	W	C	S	P	W	C	S	P	W	C	S
1	1.75±0.59	1.01±0.04	1.03±0.58	1.50±0.41	4.25±1.54	2.86±0.82	2.76±0.87	3.22±0.17	9.66±0.14	7.69±0.28	8.63±0.15	8.06±0.13
2	NS	0.43±0.18	0.52±0.14	0.89±0.34	NS	3.80±1.36	3.71±1.11	3.09±0.40	NS	9.31±0.31	9.17±0.28	8.10±0.26
3	NS	0.73±0.05	0.47±0.12	0.88±0.18	NS	4.30±1.13	3.69±1.83	2.75±0.81	NS	9.62±0.30	8.34±0.38	7.79±0.26
	%OC				pH				EC (µS/cm)			
	P	W	C	S	P	W	C	S	P	W	C	S
1	5.80±0.24	2.54±0.06	4.29±0.30	2.64±0.10	7.75±0.02	7.66±0.01	7.83±0.02	7.25±0.01	296.33±0.82	335.33±0.66	170.70±0.77	127.10±0.56
2	NS	2.43±0.03	1.74±0.07	2.18±0.12	NS	9.15±0	9.24±0	8.87±0.04	NS	98.97±0.06	99.73±0.03	65.23±0.12
3	NS	2.52±0.08	1.96±0.03	3.51±0.04	NS	9.21±0	9.22±0	8.81±0.03	NS	91.80±0.03	95.47±0.15	47.73±0.39
	K (ppm)				Mg (ppm)				Na (ppm)			
	P	W	C	S	P	W	C	S	P	W	C	S
1	0.24±0.01	0.24±0	0.24±0.01	0.21±0.02	0.23±0.13	0.26±0.04	0.21±0.05	0.18±0.04	0.72±0.10	0.52±0.36	0.68±0.13	0.45±0.01
3	NS	0.24±0.01	0.23±0.01	0.22±0.01	NS	0.27±0.07	0.23±0.02	0.28±0.10	NS	0.93±0.35	0.71±0.06	0.56±0.12
4	NS	0.24±0.01	0.23±0.01	0.22±0.02	NS	0.29±0.07	0.28±0.03	0.35±0.07	NS	0.77±0.10	0.75±0.04	0.56±0.10

SD = Average Sampling Depth; **ASD 1, 2, 3,** = Average Sampling Depth 0 – 20 cm, 80 – 100 cm, 130 – 150 cm; **P** = Pan Fringes; **W** = Wind Ward Slope; **T** = Crest; **S** = Slip Face Slope; **NS** = Not Sampled: indurated material.

Table 1c. Soil properties in relation to average depth of the horizon in Kebuang lunette dune toposequence.

ASD	P(ppm)				Ca (ppm)				ECEC (ppm)			
	P	W	C	S	P	W	C	S	P	W	C	S
1	3.59±0.29	1.51±0.08	1.33±0.12	1.71±0.88	4.91±1.24	3.52±1.34	4.12±1.05	2.56±0.39	10.08±2.50	8.44±3.01	10.51±3.22	7.89±1.22
2	NS	0.85±0.62	0.91±0.34	0.74±0.06	NS	5.40±0.39	5.36±0.83	3.17±0.51	NS	11.51±1.17	12.05±3.73	8.65±1.02
3	NS	1.00±0.35	0.73±0.27	0.69±0.14	NS	6.83±0.43	5.08±0.97	3.21±0.57	NS	12.51±2.28	11.51±4.13	9.11±1.41
	%OC				pH				EC (µS/cm)			
	P	W	C	S	P	W	C	S	P	W	C	S
1	7.06±2.77	3.43±0.95	3.26±1.80	3.45±1.64	7.79±0.38	7.83±0.31	8.09±0.43	7.40±0.24	287.13±106.714	145.97±8.86	89.60±37.20	79.8±28.47
2	NS	3.34±0.63	1.68±0.59	3.21±0.62	NS	9.00±0.14	9.35±0.03	8.94±0.29	NS	95.10±6.78	76.87±6.73	80.27±10.43
3	NS	1.43±0.19	1.25±0.64	2.74±1.57	NS	9.29±0.09	9.28±0.14	9.38±0.04	NS	70.87±21.55	71.50±4.23	73.47±18.27
	K (ppm)				Mg (ppm)				Na (ppm)			
	P	W	C	S	P	W	C	S	P	W	C	S
1	0.24±0.01	0.23±0.01	0.21±0	0.21±0.01	0.33±0.01	0.21±0.01	0.15±0.03	0.15±0.03	0.90±0.18	0.63±0.21	0.41±0.09	0.52±0.15
2	NS	0.22±0.01	0.21±0.01	0.21±0.01	NS	0.24±0.03	0.19±0.01	0.20±0.10	NS	0.82±0.28	0.84±0.31	0.42±0.16
3	NS	0.22±0.01	0.21±0.01	0.20±0.01	NS	0.22±0.02	0.21±0.02	0.17±0.04	NS	0.70±0.16	0.62±0.23	0.70±0.27

SD = Average Sampling Depth; **ASD 1, 2, 3,** = Average Sampling Depth 0 – 20 cm, 80 – 100 cm, 130 – 150 cm; **P** = Pan Fringes; **W** = Wind Ward Slope; **T** = Crest; **S** = Slip Face Slope **NS** = Not Sampled: indurated material.

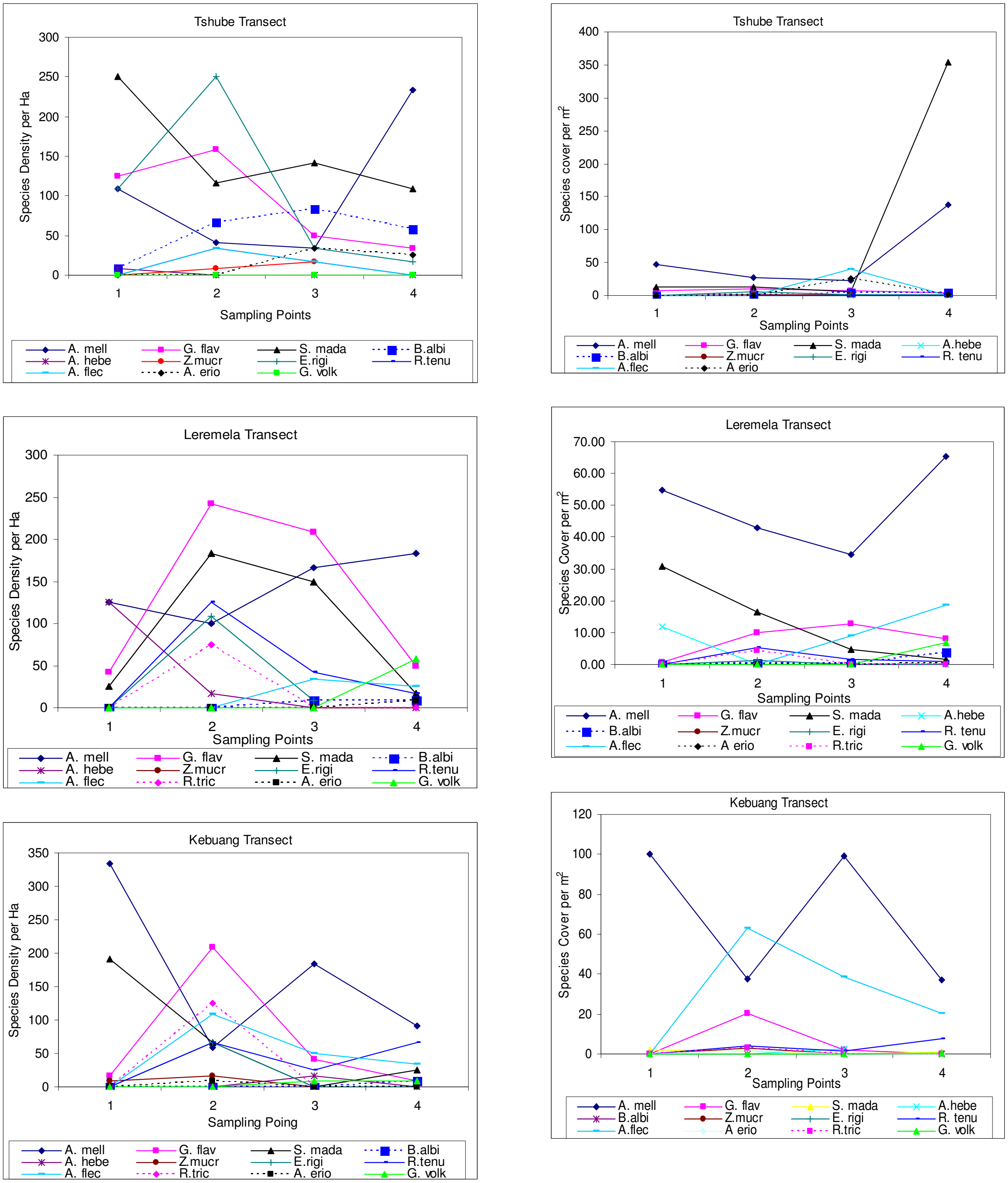

Figure 3. Species density and canopy cover along a land use gradient in the three lunette dunes. *Acacia erioloba* = A. erio, *Acacia fleckii* = A. flec, *Acacia hebeclada* = A. hebe, *Acacia mellifera* = A mell, *Boscia albitrunca* = B. albi, *Ehretia rigida* = E. rigi, *Gardeni volkensii* = G. volk, *Grewia flava* = G. flav, *Strychnos madagascariensis* = S. mada, *Rhigozum trichotomum* = R.tric, *Rhus tenuinervis* = R. tenu, and *Ziziphus mucronata* = Z.mucr

Land use issues affecting the lunette dune-pan system

It has been established through social survey that the village of Sekoma did not originate where it is currently situated. The village originated in the western side of the lunette dune-pan system and a large percentage of the villagers voluntarily decided to migrate to the eastern side of the lunette dune-pan system around 1924 - 1927. Hence for more than eight decades, Kebuang and Lere-

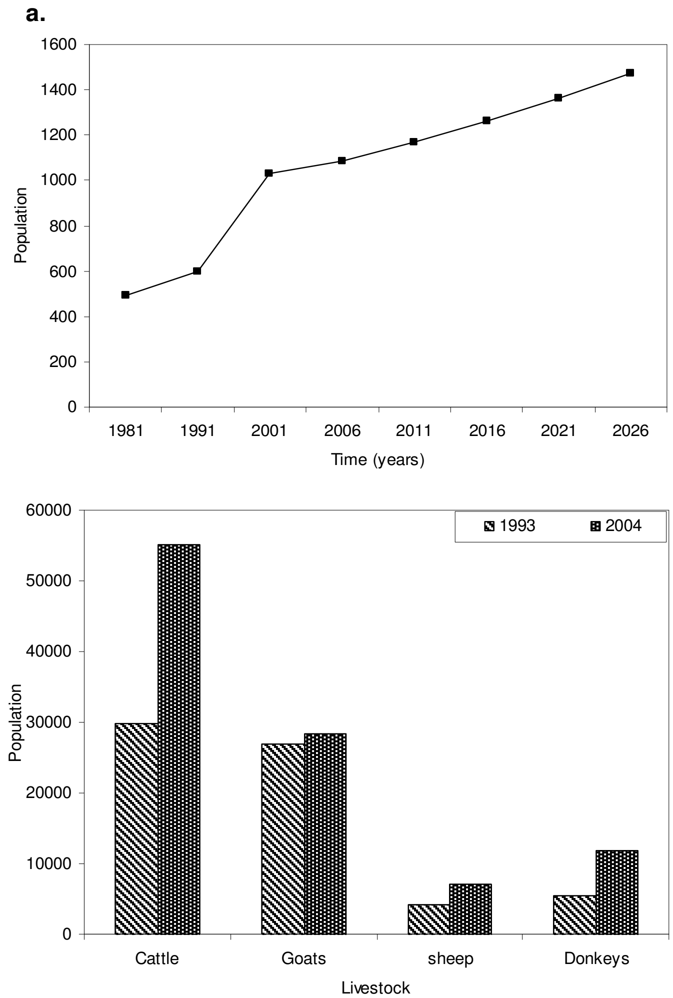

Figure 4. (a) Sekoma village human population census of 1981, 1991 & 2001 and projections of 2006-2026. (b) Livestock census of 1993 & 2004 (CSO, Botswana).

mela lunette dunes have been subjected to more land use pressure as compared to Tshube. It was observed that arable farming activities are non existent in the lunette dunes.

Data on the village population and the projected population growth (Figure 4a) indicated an increase in human population over time. In addition, an increase in livestock populations as evident from the 1993 and 2004 district livestock population census (Figure 4b) occurred in the area. This is believed to have caused an increase in the pressure on the forage resources from livestock. It was mentioned that insufficient grazing area in the villages that are in the vicinity of Sekoma has driven owners of livestock in those areas to move their livestock to the Sekoma area. This is perceived to be the main cause of a drastic decline in both forage quality and availability in the lunette dune-pan system. Spatial and temporal deterioration of forage resources in the lunettes have led to the perception that the system contributes insignificantly to livestock feed. However, observations indicated that, in spite of the scarcity of grazing resources in the lunettes, available browsing resources contributed considerably to livestock feed. Environmental degradation is said to be exacerbated by the fact that the expansion of the village is restricted by the ranches that have been allocated close to the village.

Harvesting of veld resources like firewood, thatching resources and medicinal plant resources usually contribute significantly in environmental degradation. However, these were not a subject for concern in relation to the lunette dune-pan system as it was reported that such resources are normally obtained elsewhere. Recreational activities, which may also affect the environment, were reported to be very uncommon in the study site. Therefore, the dominant land use activity in the area was found to be pastoral farming. Veld fires were reported as rare events in the area and it was indicated that the last veld fire occurrence was more than two decades ago.

Soil-vegetation relationships

The approximate vegetation species distribution patterns and plant community composition (Figure 5) in the lunette dune-pan system indicated that *G. volkensii* was a rare plant species in the area. Amongst the plant species, *A. hebeclada, A. fleckii, B. albitrunca, E. rigida, R. ternuinervis, R. trichotomum,* and *Z. mucronata* were found at relatively lower densities in the environment. Evident from the DCA results (Figure 5) was the dominance of two plant communities. One community was dominated by the *A. mellifera* and *A. erioloba*, and the other was dominated by *G. flava.*

The CANOCO programme automatically excluded some soil characteristics from the CCA (Figure 6) because they exhibited negligible variance at different SDs and the programme detected collinearity when fitting them. The CCA also indicated that *G. volkensii* was a rare plant species. Some sites were not displayed in the diagram (Figure 6) because they introduced polarity in the data points. Similar to the DCA, the CCA generally predicted the existence of two major plant communities, one dominated by *A. mellifera* and the other by *G. flava*.

It was observed that at SD 0-20 cm, axis 1 was strongly correlated with ECEC and SOC, SD 80-100 cm with Fe and P, and SD 130-150 cm with P and Fe. Axis 2 was found to be closely correlated with ECEC and Ca at SD 0-20 cm, P and Mg at SD 80-100 cm, and SOC and P at SD 130-150 cm (Table 1). Consequently, ECEC, SOC, P, Fe, Ca, and Mg were found to be the major soil properties that could be used to explain the observed plant species distribution patterns. Although the measured environmental variables could not explain the major variation observed in the investigated plant properties (eigen values lower than 0.3, Table 2), they sufficed to explain considerable variation in the species composition and distribution.

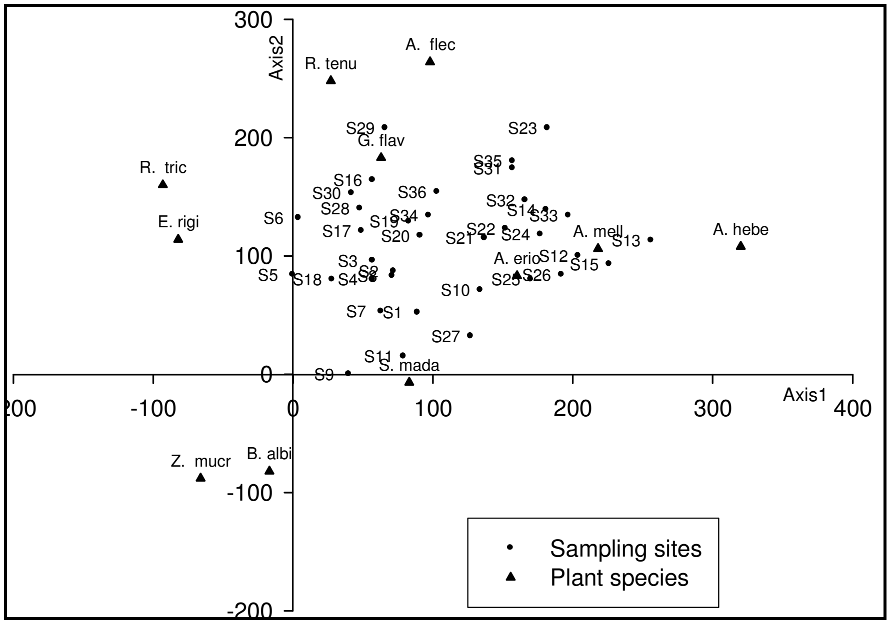

Figure 5. DCA results based on species density data and showing species distribution in the lunette dune complex (Scale =1 and multiplier =100). See Figure 3 for species full names.

Soil-land use relationships

Pearson's correlation between soil characteristics and LUI in Tshube indicated that only Na had a significant negative correlation (r =-0.991*,* P =0.009*,* α = 0.01) at SD 0–20 cm (Table 3) with LUI. Al and SOC also exhibited negative but insignificant correlations (r = -0.980*, P = 0.020* and *r = -0.958, P = 0.042* respectively, α = 0.05) with LUI at SD 0–20 cm. At SD 80-100 cm all soil characteristics indicated negative insignificant relationships with LUI at both α = 0.01 and α = 0.05. ECEC was the only soil variable that showed significant and negative relationship with LUI (r = -0.998, P = 0.002, α = 0.01) at SD 130-150 cm. Generally, all other soil variables indicated negative relationships with LUI except %Sand, P and pH (Table 3).

The relationships of all selected soil variables and SD at PF were not significant at both α = 0.01 and α = 0.05 (Table 3). At WS, only Fe (r = -0.937*,* P = 0.019, α =0.05) showed negative significant relationship with SD. % Sand and %SC (r = -0.892, P = 0.042 and r = 0.892*,* P = 0.042 respectively) at DC, and (r = -0.889, P = 0.044 and r = 0.889*,* P = 0.044 respectively) at SS exhibited significant relationships with SD at α = 0.05. In addition, K (r = 0.958*,* P = 0.010*,* α = 0.05) also indicated significant relationship with SD. All other soil variables were not significantly related to SD at DC and SS at both α = 0.01 and α = 0.05 in Tshube.

None of the selected soil variables showed a signifycant relationship with LUI as far as SD 0-20 cm is concerned in Leremela (Table 4). However, all variables displayed negative relationships with LUI except %Sand, Al and Mn. At SDs 80-100 cm and 130-150 cm, soil variables and LUI were not significantly related at both α = 0.01 and α = 0.05. It is worth highlighting the common negative relationships (Table 4) between soil variables and LUI in Leremela.

The solum at PF was less than 60cm in depth and only one SD (0-20 cm) was possible at PF in Leremela. Consequently, Pearson's correlation was not carried out for PF with respect to soil variables and SD (Table 4). However, Mn (r = 0.890, P = 0.043*,* α = 0.05) and Ca (*r* = 0.908, P = 0.033*,* α = 0.05) showed positive significant relationship with SD at WS. At DC, only Na (r = 0.984, P = 0.002*,* α = 0.01) displayed displayed a positive significant relationship with SD, while Mn (*r = 0.911, P = 0.031,* α = 0.05) and Ca (r = 0.922, P = 0.026*,* α = 0.05) indicated a positive relationship with SD. Mn (*r = 0.903, P = 0.036,* α = 0.05) was the only soil variable that showed a positive significant relationship with SD at SS (Table 4) in Leremela.

The relationships between the selected soil variables and LUI at SD 0-20 cm and SD 80-100 cm in Kebuang (Table 5) were not significant at both α = 0.01 and α = 0.05. Furthermore, all soil variables were negatively related to LUI except %Sand and Al. Only Ca (*r = -1, P = 0.013,* α = 0.05) displayed a perfect negative relationship with LUI at SD 130-150 cm. Similar to Leremela, the solum at PF in Kebuang was less than 60 cm in depth and only one SD (0-20 cm) was possible (Table 5). At WS, Ca (*r = 0.964, P = 0.008,* α = 0.01), ECEC (*r = 0.978, P = 0.004,* α = 0.01) and (*r = 0.885, P = 0.046,* α = 0.05) showed a positive significant relationships with SD. %Sand (*r = -0.923, P = 0.025,* α = 0.05), EC (*r = -0910, P =0.032,* α = 0.05) and Mn (*r = -0.938, P = 0.018,* α =0.05)

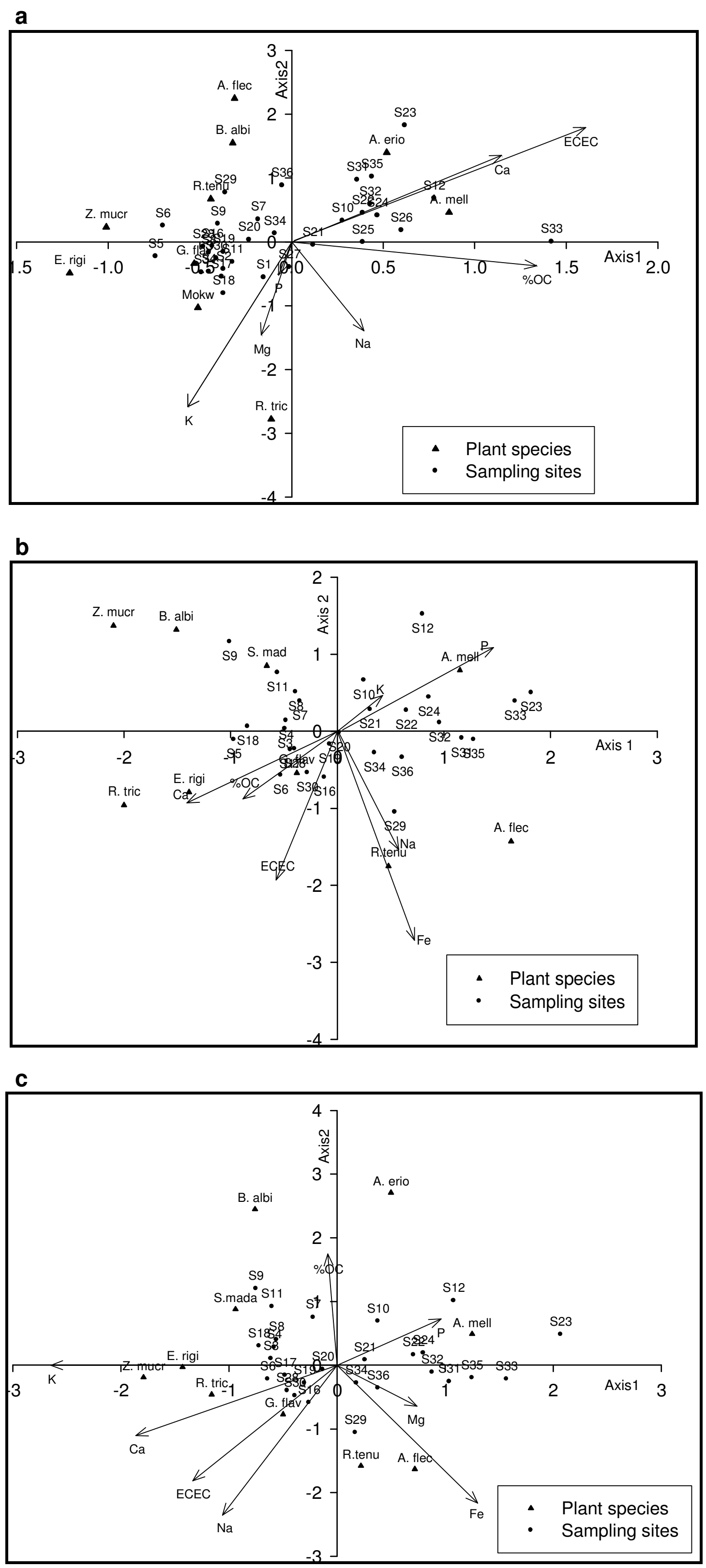

Figure 6. CCA ordination diagrams (a = 0-20, b = 80-100 and c = 130-150 cm depth) for the lunette dunes basing on the species frequency data; Environmental variables are represented by arrows (scale: 1 unit in the plot = 1 unit for the sites, 1 unit for the species & 10 units for the environmental variables. See Figure 3 for species full names.

Table 2. Eigenvalues of the first four axes and the species-environment correlations.

Axis	DCA	CCA 0-20cm		CCA 80-100cm		CCA 130-150cm	
	λ	λ	R	λ	R	λ	R
1	0.42	0.26	0.79	0.28	0.87	0.27	0.85
2	0.26	0.15	0.75	0.17	0.83	0.16	0.81
3	0.16	0.10	0.65	0.12	0.80	0.08	0.73
4	0.08	0.08	0.64	0.10	0.78	0.08	0.71

indicated significant negative relationships with SD at DC. On the other hand, SC (*r = 0.923, P = 0.025,* α = 0.05) showed a positive significant relationship with SD at DC (Table 5). At SS all soil variables were not significantly related to SD in Leremela.

DISCUSSION

The Sekoma lunette dunes were found to be at least 95% sandy from the surface layer to the depth of 150 cm and the soil profile showed no soil horizons. Therefore, the lunettes may be described as sandy lunette dunes. Sandy lunette dunes were found to be common in the southern Kalahari area (Thomas et al., 1993; Lancaster 1978a, b), despite the minimal attention alluded to them in studies related to the Kalahari area (e.g. IGBP-KT studies). The observed soil texture suggested that the Sekoma pan has recently contributed insignificant amount of sediments towards the lunette dune morphology, and that the sandy environs have recently contributed relatively significant amount of sediments towards the development and growth of the lunettes. This may indicate recent changes in the wind direction in the area.

The selected soil properties generally displayed distinct and erratic patterns both vertically and laterally along the land use gradient. Considerable spatial heterogeneity in the distribution of the selected soil attributes prevailed in the lunette dune-pan system. Heterogeneity in the soil resources have been associated with the existence of resources islands that normally form under shrub canopies (Herman et al., 1995; Wang et al., 2007; Wezel et al., 2000). The islands normally characterize micro site locations of high nutrients concentrations (Wang et al., 2007), largest amounts of mycorrhizal inoculum (Dhillion, 1999) reduced solar radiation and lower soil temperatures (Valiente-Banuet and Ezcurra, 1991), fine grained soils (Trappe, 1981). Therefore, the observed spatial heterogeneity may be linked to the sampling process during which some soil samples may have been collected from pockets of fertile soils, while others from islands of infertile soils.

The Sekoma lunette dunes are inhabited by *G. flava* and *A. mellifera* dominated plant communities. The densities and canopy covers of *A. mellifera* and *G. flava* showed dominance of the two plant species in Leremela and Kebuang lunette dunes as compared to Tshube lunette dune. *A. mellifera* and *G. flava* feature in the list of plant species which are referred to as bush encroachers. Amongst the three lunette dunes, Leremela and Kebuang are the closest dunes to the residential area and the pit wells, hence subjected to higher land use intensity in comparison with Tshube. Consequently, the observation suggested that trends in land use intensity contributed considerably to plant species distribution and canopy cover patterns in the system.

Minimal statistical significant relationships between soil properties and LUI, and soil variables and SD, and lack of distinguished patterns in the distribution of soil resources along the land use gradient indicated that the relationship between soil properties and land use was very nominal in the lunette dune-pan system. The spatial heterogeneity in soil resources distribution was found to be the main factor that introduced weakness in the link between soil properties and land use. As a result, spatial heterogeneity in soil resources con-strained the extent to which variation in the selected vegetation attributes could be explained on the basis of the selected soil properties in the lunette dune environment.

Previous studies (Louw, 1964) indicated that generally, soil moisture content in sandy dunes increases with soil depth and it is also normally higher at the dune crest as compared to the dune slopes. The foot of sandy dunes usually exhibits the lowest soil moisture content. Various studies have also established that soil moisture content plays a critical role in determining several vegetation properties in semi-arid to arid environments (Mahesh et al., 2005; Wang et al., 2007). It is on this basis that the dune crest was expected to be a favourable habitat for density and cover, followed by the dune slopes and the dune foot being the least. However, this study revealed that while other studies have vegetation and to display high plant species shown that in the sandy landscapes, soil moisture is one of the principal drivers of plant pro-perties, lunette dunes present unique environ-mental systems within semi arid to arid regions in which there are other major drivers that may significantly and almost equally influence plant properties.

Having investigated the relationship between the selected soil resource distribution and the selected vegetation properties and found very minimal relationships, land use-vegetation relationships were examined. Land use falls under the disturbance regime as far as the determinants of ecosystem properties are concerned (Mahesh et al., 2005). Veld fire frequency-vegetation and herbivory-vegetation relationships indicated that the reported frequency of veld fires in the lunette dune-pan environment did not warrant consideration of veld fires as one of the major determinants of vegetation properties in the lunette dune-pan environment. The low frequency of veld fires was not surprising because fuel resources in terms of grass biomass are normally insufficient in the system.

Table 3. Pearson's correlation (*r*) and significance levels (*P*) of the soil characteristics vs LUI (top part) and soil characteristics vs SD (bottom part) in Tshube.

SD		% Sand	% Silt &Clay	K	Mg	Na	Al	Mn	Fe	Ca	ECEC	P	SOC	pH	EC
0-20	*r*	0.930	-0.930	-0.905	0.732	-0.991(**)	-0.980(*)	-0.383	-0.905	0.646	-0.407	-0.626	-0.958(*)	-0.697	-0.872
	P	0.070	0.070	0.095	0.268	0.009	0.020	0.617	0.095	0.354	0.593	0.374	0.042	0.303	0.128
80-100	*r*	0.918	-0.918	-0.745	-0.538	-0.857	-0.856	-0.555	-0.837	-0.195	-0.930	-0.202	0.398	-0.660	-0.733
	P	0.082	0.082	0.255	0.462	0.143	0.144	0.445	0.163	0.805	0.070	0.798	0.602	0.340	0.267
130-150	*r*	0.944	-0.944	-0.736	-0.948	-0.778	-0.934	-0.786	-0.828	-0.167	-0.998(**)	0.666	-0.444	0.877	-0.826
	P	0.056	0.056	0.264	0.052	0.222	0.066	0.214	0.172	0.833	0.002	0.334	0.556	0.123	0.174
PF	*r*	-0.925	0.925	0.710	0.935	0.362	0.717	0.438	-0.613	0.913	0.921	-0.762	0.064	0.815	-0.697
	P	0.075	0.075	0.290	0.065	0.638	0.283	0.562	0.387	0.087	0.079	0.238	0.936	0.185	0.303
WS	*r*	-0.744	0.744	0.296	0.700	0.150	-0.788	0.596	-0.937(*)	0.301	0.671	-0.848	-0.439	0.713	-0.420
	P	0.149	0.149	0.628	0.188	0.810	0.114	0.289	0.019	0.622	0.215	0.070	0.460	0.177	0.481
DC	*r*	-0.892(*)	0.892(*)	0.117	0.097	-0.626	0.320	-0.852	-0.782	0.482	0.566	-0.345	-0.291	0.754	-0.741
	P	0.042	0.042	0.851	0.877	0.259	0.599	0.067	0.118	0.410	0.320	0.569	0.634	0.141	0.152
SS	*r*	-0.889(*)	0.889(*)	0.958(*)	-0.692	0.054	-0.675	-0.780	-0.645	0.334	0.013	-0.549	-0.577	0.830	-0.603
	P	0.044	0.044	0.010	0.196	0.931	0.211	0.120	0.240	0.583	0.984	0.338	0.309	0.082	0.282

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

Table 4. Pearson's correlation (*r*) and significant levels (*P*) of the soil characteristics vs LUI (top part) and soil characteristics vs SD (bottom part) in Leremela.

SD		%Sand	%Silt & Clay	K	Mg	Na	Al	Mn	Fe	Ca	ECEC	P	SOC	pH	EC
0-20	*r*	0.882	-0.882	-0.831	-0.754	-0.646	0.278	0.049	-0.619	-0.607	-0.580	-0.259	-0.644	-0.665	-0.874
	P	0.118	0.118	0.169	0.246	0.354	0.722	0.951	0.381	0.393	0.420	0.741	0.356	0.335	0.126
80-100	*r*	0.789	-0.789	-0.990	0.234	-0.995	0.282	0.240	-0.894	-0.919	-0.912	0.941	-0.354	-0.724	-0.856
	P	0.421	0.421	0.091	0.850	0.061	0.818	0.846	0.295	0.258	0.269	0.219	0.770	0.485	0.346
130-150	*r*	0.610	-0.610	-0.971	0.794	-0.903	-0.089	0.982	0.866	-0.992	-0.974	0.375	0.631	-0.855	-0.829
	P	0.582	0.582	0.154	0.416	0.282	0.943	0.121	0.333	0.081	0.144	0.755	0.566	0.347	0.377
WS	*r*	-0.788	0.788	0.198	-0.063	0.566	0.150	0.890(*)	-0.419	0.908(*)	0.859	-0.324	-0.607	0.733	-0.696
	P	0.114	0.114	0.749	0.920	0.320	0.810	0.043	0.483	0.033	0.062	0.594	0.278	0.159	0.191
DC	*r*	-0.593	0.593	-0.306	0.446	0.984(**)	-0.604	0.911(*)	-0.554	0.922(*)	0.690	-0.858	-0.797	0.829	-0.766
	P	0.292	0.292	0.617	0.451	0.002	0.281	0.031	0.332	0.026	0.198	0.063	0.107	0.083	0.131
SS	*r*	-0.767	0.767	-0.430	0.796	0.198	-0.171	0.903(*)	0.682	-0.591	-0.046	-0.671	0.349	0.768	-0.654
	P	0.130	0.130	0.470	0.107	0.749	0.784	0.036	0.205	0.294	0.942	0.215	0.565	0.130	0.231

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

Table 5. Pearson's correlation (*r*) and significant levels (*P*) of the soil characteristics vs LUI (top part) and soil characteristics vs SD (bottom part) in Kebuang.

SD		%Sand	%Silt & Clay	K	Mg	Na	Al	Mn	Fe	Ca	ECEC	P	SOC	pH	EC
0-20	*r*	0.937	-0.937	-0.944	-0.925	-0.839	0.657	-0.850	-0.243	-0.839	-0.460	-0.717	-0.772	-0.423	-0.916
	P	0.063	0.063	0.056	0.075	0.161	0.343	0.150	0.757	0.161	0.540	0.283	0.228	0.577	0.084
80-100	*r*	0.840	-0.840	-0.866	-0.797	-0.852	0.023	-0.991	-0.427	-0.875	-0.782	-0.660	-0.070	-0.149	-0.765
	P	0.365	0.365	0.333	0.413	0.350	0.985	0.084	0.719	0.322	0.429	0.541	0.955	0.905	0.446
130-150	*r*	0.997	-0.997	-0.933	-0.952	-0.034	0.391	-0.993	-0.803	-1.000(*)	-0.973	-0.928	0.805	0.850	0.959
	P	0.053	0.053	0.234	0.199	0.978	0.744	0.073	0.407	0.013	0.150	0.243	0.405	0.353	0.183
WS	*r*	-0.725	0.725	-0.606	0.690	0.300	0.885(*)	-0.409	0.120	0.964(**)	0.978(**)	-0.461	-0.744	0.839	-0.836
	P	0.166	0.166	0.279	0.197	0.624	0.046	0.494	0.847	0.008	0.004	0.435	0.149	0.076	0.078
DC	*r*	-0.923(*)	0.923(*)	-0.675	0.829	0.447	0.020	-0.938(*)	-0.596	0.677	0.742	0.444	-0.683	0.759	-0.910(*)
	P	0.025	0.025	0.212	0.083	0.450	0.974	0.018	0.289	0.209	0.151	0.454	0.204	0.137	0.032
SS	*r*	-0.760	0.760	0.333	0.752	-0.201	0.732	-0.233	0.501	0.540	0.530	-0.696	-0.775	0.804	-0.038
	P	0.136	0.136	0.584	0.142	0.746	0.160	0.706	0.390	0.348	0.358	0.192	0.124	0.101	0.952

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

In relation to land use, the Sekoma community indicated that the lunette dune-pan system is important mainly for the provision of water for livestock primarily from pit wells located within the pan (Figure 7a) as the pan does not hold surface water for long periods of time. In line with field observations, the community reported scarcity in grazing resources in the area and it was believed to be caused mainly by the ever increasing live-stock populations (Figure 7b), low amounts of rainfall and erratic rainfall patterns. The comm.-unity did not consider the lunette dune environ-ment as an important resource base for forage resources in the area. In spite of this, it was observed that herbivory, chiefly in the form of browsing, contributed substantially in the influence of vegetation properties in the area. This mani-fested through the observed imprints of browsing predominance in the area.

Herbaceous cover in the area was almost non-existent during the time of sampling and encro-achment indicator (*A. mellifera* and *G. flava*) were found to be highly associated with the sites that were subjected to relatively high land use inten-sity. It may be argued that this had some-thing to do with sampling time, but many researchers have attributed it to anthropogenic activities (Tolsma et al., 1987; Ringrose et al., 1996; Moleele, 1998; Moleele and Perkins, 1998). Grazing and tram-pling in the lunette dune-pan environment by live-stock and pressure from both livestock and hu-man on vegetation was identified as the main causes of bare soil patch development in the area. This condition is known to facilitate invasion of woody species (Tolsma et al., 1987; Moleele, 1998; Moleele and Perkins, 1998), the process of which normally culminates in bush encroachment or thickening as observed in the sites located closer to the village and the pit wells. It has been established that where paucity in grazing resour-ces exists like in the study area, browse resources contribute significantly to live-stock feed (Tolsma et al., 1987; Scholte, 1992; Moleele, 1998; Moleele and Perkins, 1998). It is for this reason that the observed imprints of selectivity of livestock on browse resources, which manifested through the predominance of encroach-ment indicator plant species (*A. mellifera* and *G. flava*), were linked with high pressure experienced by browse resources in the area.

Conclusion

A wide range of environmental research work including changes in ecosystem dynamics, vege-tation composition and structure in semi arid and arid environments has been previously conducted (Koch et al., 1995; Scholes et al., 2002; Wang et al., 2007). One of the international programmes that focus on the study of semi arid and arid environments is the International Geosphere-Bio-sphere Programme (IGBP) (Koch et al., 1995; Scholes et al., 2002; Shugart et al., 2004; Wang et

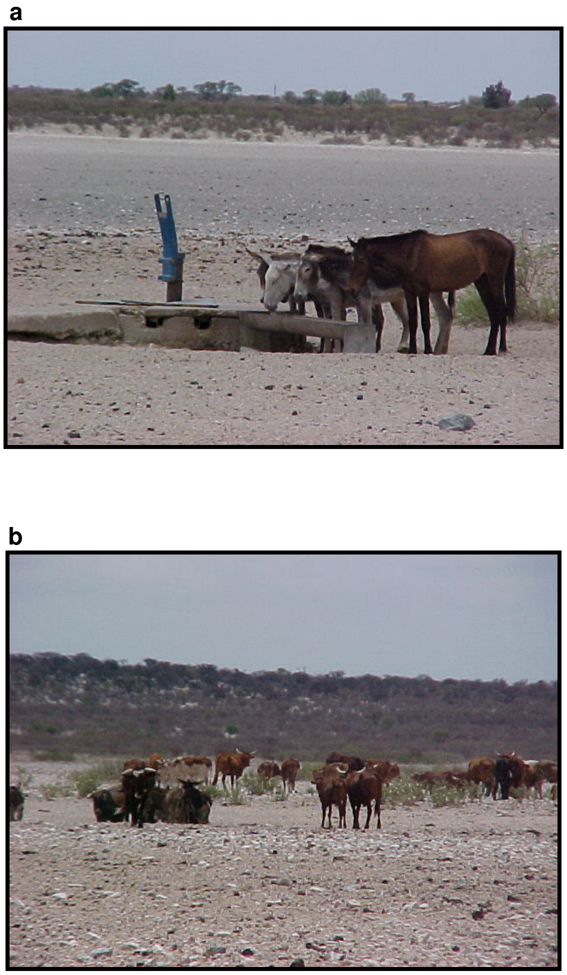

Figure 7. (a) One of the pit wells located within the pan. **(b)** High livestock density; background shows lunette dunes.

al., 2007). In spite of this, lunette dune-pan systems existing within semi arid and arid environments continue to receive very little attention from researchers. Therefore, this research essentially provides needed insights on the poorly researched sandy lunette dune-pan systems. It is hoped that the study will complement other ongoing research work on semi arid and arid environments.

Generally, this study has established that the environment of the Sekoma lunette dune-pan system exhibited considerable spatial heterogeneity in soil characteristics. This limited the extent to which variation in the investigated vegetation attributes could be explicated on the basis of the distribution patterns observed in the selected soil characteristics. The complex was to a large extent dominated by the encroacher plant species (*A. mellifera* and *G. flava*). Assessment of soil, vegetation and land use relationships lead to the conclusion that land use, particularly browsing, was the main environmental driver and had precedence over the distribution of the selected soil attributes in relation to woody plant community composition, species distribution and cover in the lunette dune-pan system.

ACKNOWLEDGEMENT

I would like to thank Dr J. Atlhopheng and Dr M.P. Setshogo for their invaluable contribution in this research work. Special thanks to the Sekoma community who allowed me to carry out this research work within their territory.

REFERENCES

Andrew MH (1988). Grazing impact in relation to livestock watering points. Trends in Ecology and Evolution, 3: 336-339.
Bhalotra YPR (1985). Rainfall maps of Botswana. Gaborone. Department of Meteorological Services.
Bonham CD (1989). Measurements for Terrestrial Vegetation. Wiley, New York.
Caylor KK, Shugart HH, Dowty PR, Smith TM (2003). Tree spacing along the Kalahari transect in Southern Africa. J. Arid environ. 54: 281-296.
Chanda R, Totolo O, Moleele N, Setshogo M, Mosweu S (2003). Prospects for subsistence livelihood and environmental sustainability along the Kalahari transect: The case of Matsheng in Botswana's Kalahari rangelands. J. Arid Environ. 54: 425-445.
Cornelius R, Schultka R (1997). Vegetation structure of heavily grazed range in Northern Kenya: ground vegetation. J. Arid Environ., 36: 459-474.
Fresenius W, Quentin KE, Schneider W (1988). Water Analysis A Practical Guide to Physico-Chemical, Chemical and Microbiological Water Examination and Quality Assurance. Springer-Verlag, Berlin, Germany.
Gauch HG (1982a). Multivariate analysis in community ecology. England: Cambridge University Press.
Geological Survey Department (1995). Groundwater pollution vulnerability map of Republic of Botswana. Gaborone, Botswana: Government Printers.
Hendershot WH, Duguetts M (1986). A simple barium chloride method for determining cation exchange capacity and exchangeable cations. Soil Sci. Soc. Am. J., 50: 605-608.
Herman RP, Provencio KR, Herrera-Matos J, Torrez RJ (1995). Resource islands predict the distribution of heterotrophic bacteria in Chihuahuan desert soils. Appl. Environ. Microbiol. 61: 1816-1821.
Hill MO (1979). TWINSPAN: A Fortran Program for Arranging Multivariate Data in an Odered Two-Way Table by Classification of the Individual and Attributes. New York: Cornell University.
International Soil Reference and Information Centre. (1993). Procedures for soil analysis. (4^{th} ed). Netherlands: Wageningen.
Jeltsch F, Milton SJ, Dean WR, Van rooyen N (1997). Simulated pattern formation around artificial waterholes in the semi-arid Kalahari. J. Vegetation Sci. 8: 177-188.
Koch GW, Scholes RJ, Steffen WL, Vitousek PM, Walker BH (1995). The IGBP terrestrial transect: science plan, Report No.36. International Geosphere-Biosphere Programme, Stockholm.
Lancaster IN (1978a). The pans of Southern Kalahari, Botswana. Geo. J. 144: 81-98.
Lancaster IN (1978b). Composition and formation of Southern Kalahari pan margin dunes. Zeitschrift für Gemorphologie, NF, 22: 148-169.
Lange RT (1969). The piosphere: sheep track and dung patterns. Journal of Range Management, 22: 396-400.
Louw PA (1964). Bodemkundige aspekte van die Kalahari-Gemsbokpark. Koedoe 7: 156-172.
Mahesh S, Hanan PN, Scholes RJ, Ratman J, Augustine DJ, Cade BS, Gignoux J, Higgins SI, Le Roux X, Ludwig F, Ardo J, Banyikwa F, Bronn A, Bucini G, Caylor KK, Coughenour MB, Diouf A, Ekaya W, Feral CJ, February EC, Frost PGH, Hiernaux P, Hrabar H, Metzger

KL, Prins HHT, Ringrose, S., Sea, W., Tews, J., Worden, J., & Zambatis, N. (2005). Determinants of woody cover in African savannas. Nature, 438(8): 846-849.

Ministry of Agriculture. (1991). Land systems map of the Republic of Botswana. Soils mapping and advisory services project. Gaborone, Botswana: Government Printer.

Moleele NM (1998). Enchroacher woody plant browse as feed for cattle. Cattle's diet composition for three seasons at Olifants Drift, Southeast Botswana. J. Arid Environ.40: 255-268.

Moleele NM, Perkins JS (1998). Encroaching woody plant species and boreholes: is cattle density the main driving factor in the Olifants Drift communal grazing lands, South-eastern Botswana? J. Arid Environ. 40: 245-253.

Muller-Dombois D, Heinz E (1974). Aims and Methods of Vegetation Ecology. New York: John Wiley and Sons.

Myklestad A, Birks HJB (1993). A numerical analysis of the distribution patterns of Salix L. species in Europe. J. Biogeo. 20: 1 1-32.

Olsen SR, Cole CV, Watanabe FS, Dean LA (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S. Dep. of Agric. Circ. p. 939.

Privette JL, Tian Y, Roberts G, Scholes RJ, Wang Y, Caylor KK, Frost P, Mukelabai M (2004). Vegetation structure characteristics and relationships of Kalahari woolands and savannas. Global Change Biology, 10: 281-291.

Reginos C, Hoffman MT (2003). Changes in population biology of two succulent shrubs along a grazing gradient. J. Aplli. Ecol. 40: 615-625.

Ringrose S, Vanderpost C, Matheson W (1996). The use of remotely sensed data and GIS data to determine causes of vegetation cover change in Southern Botswana. Appl. Geo. 16: 225-242.

Ryerson DE, Parmenter RR (2001). Vegetation change following removal of keystone herbivores from desert grasslands in New Mexico. J. Vegetation Sci. 12: 167-180.

Scholes RJ, Dowty, PR, Caylor K, Parsons DAB, Frost PGH, Shugart HH (2002). Trends in savanna structures and composition along an aridity gradient in the Kalahari. J. Vegetation Sci. 13: 419-428.

Scholte PT (1992). Leaf litter and Acacia pods as feed for livestock during the dry season in Acacia-Commiphora bushland, Kenya. J. Arid Environ. 22: 271-276.

Shaw PA, Thomas SG (1997). Pans, playas and salt lakes: In: Thomas DSG (Ed.). Arid Zone Geomorphology; Process, Form and Change in Drylands. New York: John Wiley and Sons.

Shugart HH, Macko SA, Lesolle P, Szuba TA, Mukelebai MM, Dowty P, Swap RJ (2004). The SAFARI 2000 Kalahari transect wet season Campaign of year 2000. Global Change Biology, 10: 273-280.

Skarpe C (1986). Plant community structure in relation to grazing and environmental changes along a North South transect in Western Kalahari. Vegetation, 68: 3-18.

Skarpe C (1990b). Structure of woody vegetation in disturbed and undisturbed arid savanna, Botswana. Vegetation, 8: 11-18.

Solomon TB, Snyman HA, Smit GN (2007). Cattle-rangeland management practices and perceptions of pastoralists towards rangeland degradation in the Borana zone of southern Ethiopia. J. environ. Manage. 82: 481-494.

Sonnevelt, C., & vanden Ende, J. (1971). Soil analysis by means of a 1:2 volume extract. Plant Soil, 35, 505-506.

Ter Braak CJF (1988). Program CANOCO Manual. Ministry of Agriculture and fisheries, Agricultural Mathematics Group (DLO). The Netherlands: Wageningen.

Ter Braak CJF (1995). Ordination. In Jongman RHG, ter Braak CJF, van Tongeren OFR (Eds.). Data analysis in Community and landscape ecology. Great Britain: Cambridge University Press.

Ter Braak CJF, Looman CWN (1986). Weighted averaging, logistic regression and the Gaussian response model. Vegetation, 65: 3-11.

Ter Braak, C.J.F. (1986). Canonical Correspondence Analysis: A new
Eigenvector Technique for Multivariate Direct Gradient Analysis. Ecology, 67, 5 1167-1170.

Ter Braak, C.J.F. (1987). The analysis of vegetation-environment relationships by canonical correspondence analysis. Vegetatio, 69, 69-77.

Thomas DSG, Nash DJ, Shaw PA, Van der Post C (1993). Present day lunette sediment cycling at Witpan in the arid southwestern Kalahari Desert. Catena, 20: 515-527.

Thomas DSG, Shaw PA (1991). The Kalahari environment. Cambridge: Cambridge University Press.

Thrash I (1998). Impact of large herbivore at artificial watering points compared to that at natural watering points in Kruger National Park, South Africa. J. Arid Environ. 38: 315-324.

Thrash I (2000). Determinants of the extent of indigenous large herbivore impact on herbaceous vegetation at watering points in the north-eastern low veld, South Africa. J. Arid Environ. 44: 61-72.

Tolsma DJ, Ernst W.H.O, Verwey RA (1987). Nutrients in soil and vegetation around two artificial waterpoints in eastern Botswana. J. Appl. Ecol. 24: 991-1000.

Van Reeuwijk LP (1993). Procedures for Soil Analysis. International Soil Reference and Information Centre Technical Paper No.1.

Walker JW, Heitschmidt RK (1986). Effects of various grazing systems on type and density of cattle trails. J. Range Manage., 39: 428-431.

Wang L, D'Odorico P, Ringrose S, Coetzee S, Macko SA (2007). Biogeochemistry of Kalahari sands. J. Arid Environ. 71: 259-279.

Wezel A, Rajot JL, Herbrig C (2000). Influence of shrubs on soil characteristics and their function in the Sahalian agro-ecosystems in semi-arid Niger. J. Arid Environ. 44: 383-398.