EJE 2018, 4(2): 41-48, doi: 10.2478/eje-2018-0011

Trends of phanerophyte encroacher species along an aridity gradient on Kalahari sands, central Namibia

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ABSTRACT

Poor rangeland management, especially overstocking and under-burning coupled with climate change on southern African savannas, have brought about a serious ecological problem of bush encroachment. Bush encroachment leads to many ecological implications such as extirpation or extinction of plant species and a colonisation by opportunistic species leading to unwanted changes in plant species composition, structure and loss of species diversity. Furthermore, bush encroachment has a negative impact on the country's progress in terms of conservation efforts, economic stability and livelihood. Namibian livestock ranchers forego an estimated N$ 700 million loss yearly linked to bush encroachment. Studies focusing on particular bush encroacher species enable the devise of ecologically sound management strategies by land manager, farmers and scientists for the prevention and control of bush encroachment. Therefore, this study was undertaken to determine the main encroacher species and their relationship to the environmental factors along an aridity gradient on Kalahari sands in central Namibia. Results disclosed that *Acacia erioloba* E.Mey., *Acacia mellifera (Vahl) Benth. ssp. dentines (Burch.) Brenan, Combretum collinum Fresen., Terminalia sericea Burch. Ex DC., Grewia spp., Bauhinia petersiana Bolle ssp. macrantha (Oliv.) Brummitt & J.H. Ross* were the main encroacher species, and mean annual rainfall was the main environmental factor influencing their distribution. Nanophanerophyte from different encroacher species were recorded mainly from 400 mm to 500 mm mean annual rainfall, mesophanerophyte recorded from 280 mm to 450 mm, while microphanerophyte were widely distributed over the rainfall gradient. Bush encroachment was recorded at 440 mm mainly due to the poor rangeland management. Information from this study should be used as a baseline for conservation and restoration attempts towards savanna rangelands.

KEYWORDS

Bush encroachment, density, environmental factors, Kalahari sands, aridity gradient

INTRODUCTION

Southern African savannas are faced with a serious ecological problem of bush encroachment whereby the agricultural productivity gets affected. For example, studies have shown that about 10–20 million ha in South Africa (Ward 2005), 3700000 ha in Botswana (Moleele *et al.* 2002) and 26 million ha in Namibia (De Klerk 2004) has been affected by bush encroachment. According to Roques *et al.* (2001), De Klerk (2004) and Ward (2005), the main factors causing bush encroachment on southern African savannas are climate change and poor rangeland management especially overstocking and under-burning. Bush encroachment is basically the expansion of woody vegetation at the expense of the herbage vegetation in savanna ecosystems. Savannas are characterised by unpredictable dry and rainy seasons. This makes savannas rather unstable and susceptible to bush encroachment since bush encroachment has been associated with inter-annual rainfall variability (Angassa and Oba 2008; Kulmatiski and Beard 2013). Reduced competition from grasses coupled with increased soil moisture availability culminates into survival and growth of woody plant seedlings into bush thickets. These corroborate with the widely documented trend of increasing woody plants with mean annual rainfall on the savanna ecosystems (Scholes *et al.* 2002; Sankaran *et al.* 2005, Kgosikoma and Mogotsi 2013 and Archer *et al.* 2017).

Namibia is one of the southern African countries that is highly vulnerable to the adverse effects of bush encroachment due to its high dependence on agriculture and tourism. According to Magwedere *et al.* (2012), agriculture supports about 70% of the Namibian population. However, only a small percentage of the soil is suitable for crop farming (< 1%), leading to livestock and wildlife farming dominating. This has resulted to a greater economic weight currently placed on the meat industry and the tourism sector in Namibia (Magwedere *et al.* 2012). However, the meat industry and tourism sector is threatened by loss of suitable habitants for animals due to bush encroachment. Bush encroachment leads to many ecological implications such as, extirpation or extinction of species, for example, bush encroachment has been associated with the extinction of *Gyps coprotheres* in Namibia (De Klerk 2004). In addition, bush encroachment leads to colonisation of savannas by opportunistic species leading to unwanted changes in species composition and structure. Ratajczak *et al.* (2012) determined the consequences of woody encroachment on plant species richness by performing a meta-analysis of 29 studies from 13 different grassland/savanna communities in North America. Ratajczak *et al.* (2012) results depicted a decrease in the species richness with an increase in the woody plant encroachment in all 13 communities. Furthermore, bush encroachment has a negative impact on the country's progress in terms of conservation efforts, economic stability and livelihood. This corroborates with De Klerk (2004) and Joubert *et al.* (2008) who stated that the Namibian livestock ranchers forego an estimated N$ 700 million loss yearly linked to bush encroachment.

Since the realisation of bush encroachment, several efforts have been directed to bush control. First by farmers and later by scientist, government and non-governmental organisations. The Namibian government has declared the control of bush encroachment as a national priority in its fifth National Development Plan (NDP5). Several studies have been conducted on bush encroachment in Namibia (Bester 1999; De Klerk 2004; Zimmermann *et al.* 2008; Christian *et al.* 2010; Stafford *et al.* 2017). *Acacia mellifera* and *Dichrostachys cinerea* consecutively are the most widely distributed encroacher species in the country and have the ability to change vegetation type (De Klerk 2004). The latter led to their classification as the most aggressive encroacher species in Namibia. These species can change savannas consisting of various species to predominantly either black thorn or sickle bush thickets (Bester 1999). Other main encroacher species in Namibia are, *Terminalia prunioides*, *Terminalia sericea*, *Colophospermum mopane*, *Acacia erubescens*, *Acacia fleckii* and *Acacia reficiense* and *Grewia flava* (Bester 1999).

Studies have encouraged turning bush harvest into a big income generating industry (biomass commercialisation). According to Honsbein and Lindeque (2017), biomass commercialisation of the resultant biomass from bush encroachment will have significant benefits of job creation in decentralised parts of the country as well as economic growth. It is therefore paramount to understand trends of encroacher species in the country. Studies focusing on particular bush encroacher species enable the devise of ecologically sound management strategies by land manager, farmers and scientists for the prevention and control of bush encroachment. To generate information and form a better view of bush encroachment in Namibia, the present study identified bush encroacher species, their dominant life forms and their relation to environmental factors. Ward (2005) argued that multi-factorial experiments that includes causal factors such as rainfall and soil nutrients are vital.

The present study successfully identified the relationship between several encroacher species and environmental factors along the aridity gradient on Kalahari sands in central Namibia. The Kalahari forms a clear south to north gradient of increasing mean annual precipitation of 150 mm per annum to over 1200 mm per annum (Scholes *et al.* 2002). This gradient extends from the vineyards on the margins of the Orange River at Upington, South Africa to the north of the Congo River into the south-east corner of Equatorial Gabon (Thomas 2002). The main aim of the study was to identify bush encroacher species, their dominant life forms and their relation to environmental factors along an aridity gradient on Kalahari sands in central Namibia.

1. MATERIALS AND METHODS

1.1. Study sites

Kalahari is a sandy, largely semi-arid region that lies within the southern African summer rainfall zone (Thomas and Shaw 1991; Scholes *et al.* 2002; Thomas 2002). According to Wang *et al.* (2007), the Kalahari gradient is an ideal environment to study changes in; ecosystem dynamics, vegetation composition and structure, and nutrient cycles along a spatial precipitation gradient without confounding soil effects. The significance of the Kalahari transect is well known and acknowledged since it has been designated as one of the International Geosphere–Biosphere Program (IGBP) transects designed to address the global change questions at the regional scale (Koch *et al.* 1995; Scholes and Parsons 1997; Privette *et al.* 2004). The present study analysed the trends of encroacher species on Kalahari sands in central Namibia by exploring five sites, namely Mile 46, Sonop, Waterberg, Sandveld and Ebenhaezer. All the study sites fall within the extensive Kalahari sands and are dominated by the surface sediment of aeolian origin (Thomas and Shaw 1991). However, the study sites have different climatic conditions (Table 1).

1.2. Demarcation of plots and sampling

Data used in the present study was collected from February until April 2016. The demarcation of plots was done using measuring tapes, and the GPS recording of each plot was taken. The study employed quantitative research design. Ten 50 m by 20 m plots were randomly demarcated using stratified random sampling design at Waterberg and Ebenhaezer. For Mile 46, Sonop and Sandveld, sampling was done on Biodiversity Observation Network (BIOTA) plots (50 m by 20 m), which were also selected on a stratified random manner (Jürgens et al. 2010). According to Barbour *et al.* (1980) and Barbour *et al.* (1987), stratified random design allows the fieldworker to locate the samples randomly within each homogeneous region by subdividing the survey area or any given stand into several homogeneous regions known as strata. Barbour *et al.* (1980) stated that this design ensures that samples are dispersed throughout the entire surveyed area thus capturing key population

Table 1: Main characteristics of the five selected study sites along an aridity gradient

Study sites	Latitude	Longitude	Altitude (m)	Mean annual rainfall (mm)	Mean annual temperature (°C)	Habitant type
Mile 46	18.301826 S	19.247311 E	1180	540	22.6	dry woodland savanna
Sonop	19.073818 S	18.903897 E	1236	500	23.1	dry woodland savanna
Waterberg	20.461330 S	17.208133 E	1550	450	18	Tree and Kalahari woodland savanna
Sandveld	22.043351 S	19.133903 E	1523	400	19.4	Camelthorn savanna
Ebenhaezer	23.216666 S	18.400000 E	1340	280	21.7	grassland and *Acacia* dominated savanna

characteristics in the sample. Another advantage of stratified random sampling is that it does not compromise the concept of random sampling (Barbour *et al.* 1980).

In each plot at each site, encroacher species were identified and counted. From each plot, a composite sample of surface soil was collected from a depth of 0–3 cm (Belsky *et al.* 1989, Collins *et al.* 1989, Stohlgren *et al.* 1998). This was done after the surface litter was removed. The composite sample was prepared by combining soil samples taken from the corners and in the central point of the plot. The latter procedure was adapted in order to get soil sample that is a representative of the whole plot, hence accounting for short range spatial variability (Collins *et al.* 1989). Top soil (4 kg) was collected from each plot using a garden shovel and placed in a Ziploc bag that was labelled accordingly. Samples were then sun-dried to halt biological activities and subjected to analysis at the Ministry of Agriculture Water and Forestry (MAWF) laboratory. The analysis focused on soil pH, texture, organic matter and electrical conductivity. Soil samples were also tested for important macro elements, such as potassium, phosphorus, calcium, magnesium and sodium.

2. DATA ANALYSIS

A Nonmetric Multidimensional Scaling (NMS) ordination using PC-Ord 6 (McCune *et al.* 2002; Hoand 2008) was used to determine the main environmental factors influencing the distribution of encroacher species on Kalahari sands. The environmental data was overlaid as a biplot to indicate the environmental gradients of interest. The environmental factors used consisted of the following variables: mean annual rainfall, annual minimum temperature, annual maximum temperature, humidity, pH, electrical conductivity, organic matter, phosphorus, potassium, calcium, sodium, % sand, % clay and % silt.

Encroacher species density was calculated based on a formula: D = N/A, where *D* is the density, *N* is the number of sampled encroacher species and *A* is the size of the plot from which encroacher species were sampled (Pielou 1975; Gotelli and Colwell 2011). Density of encroacher species was expressed in number per hectare.

Encroacher species were categorised into three different life forms depending on their height and plotted. Growth forms used in the study were defined as follows: mesophanerophytes defined as all perennial woody plants with a height from 8 m to 30 m, and microphanerophytes defined as all perennial woody plants with a height from 2 m to 8 m as well as nanophanerophytes defined as all perennial woody plants with a height between 25 cm and 2 m (Esten 1932; Raunkiaer 1934; Skarpe 1996).

3. RESULTS

Acacia erioloba E.Mey., *Acacia mellifera (Vahl) Benth. ssp. dentines (Burch.) Brenan, Combretum collinum Fresen., Terminalia sericea Burch. Ex DC., Grewia spp., Bauhinia petersiana Bolle ssp. macrantha (Oliv.) Brummitt & J.H. Ross* were identified to be the main encroacher species at the five study sites along the aridity gradient (nomenclature used in the present study followed Klaassen and Kwembeya [2013]). Infraspecific taxa and author citations were not repeated in the text.

3.1. Environmental factors

Multivariate statistics specifically Nonmetric Multidimensional Scaling (NMS) was used to determine the encroacher species-environment relationship. NMS ordination procedure was done using Sørensen (Bray-Curtis) distance measure. Number of runs used with real data was 200. After 500 number of iterations, a final solution was reached with a stress of 11.320 and a final instability of 0.000001. A varimax Rotation of the results was requested. The resulting ordination graph was overlaid as a biplot (Figure 1). The present study revealed that mean annual rainfall was the main environmental factor influencing the distribution of encroacher species (Figure 1) on Kalahari sands. *G. bicolor, G. flava, A. mellifera* and *A. erioloba* were also correlated with minimum annual temperature.

3.2. Density of main encroacher species

Density per hectare of each of the main encroacher species was calculated and plotted to indicate their response to change in mean annual rainfall (Figure 2). According to Figure 2, *A. mellifera* and *A. erioloba* showed overall similar trends of decreasing species density with increasing mean annual rainfall. Slightly higher than expected *A. mellifera* density was recorded at 500 mm mean annual rainfall (Sonop). Furthermore, similar

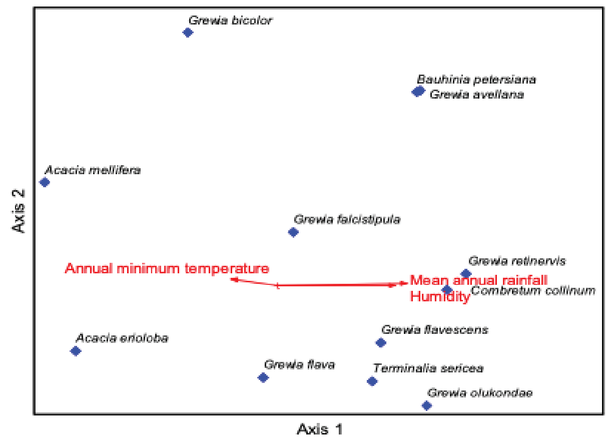

Figure 1: NMS result of main encroacher species illustrating a biplot overlaid with environmental factors

trends of increasing species density with increasing mean annual rainfall were recorded for *C. collinum*, *Grewia spp* and *T. sericea.* However, *Grewia spp* increase with mean annual rainfall up to 500 mm and drops drastically, while *T. sericea* increase with mean annual rainfall up to 450 mm and decrease gradually with mean annual rainfall. The density of *B. petersiana* fluctuated with increasing mean annual rainfall (Figure 2).

3.3. Encroacher species life form

Encroacher species life forms were plotted. According to Figure 3, a high number of nanophanerophytes from different encroacher species were recorded between 400 mm and 500 mm mean annual rainfall. *B. petersiana* had the highest nanophanerophytes at 540 mm and 450 mm respectively. Microphanerophytes were widely distributed over the rainfall gradient. The highest number of microphanerophytes recorded belonged to *A. mellifera* at 280 mm followed by *T. sericea* at 450 mm. Mesophanerophytes of encroacher species were only

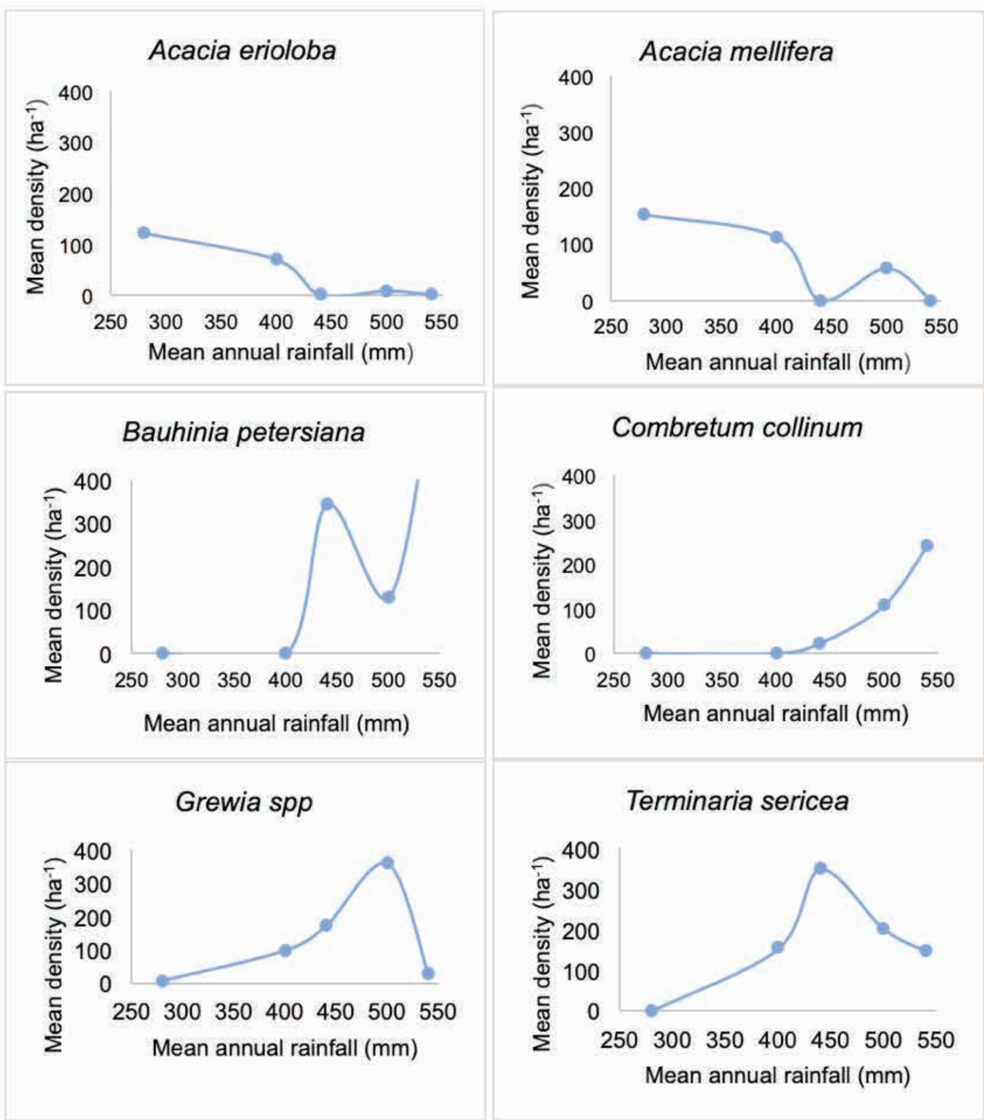

Figure 2: Change in encroacher species density along an aridity gradient on Kalahari sands

recorded from 280 mm to 450 mm, out of which *T. sericea* had the highest mesophanerophyte individuals (Figure 3).

4. DISCUSSION

Acacia mellifera and *A. erioloba* generally showed similar trends of decreasing species density with increasing mean annual rainfall. The low rainfall in the study was coupled with annual minimum temperature, which limits the colonisation of these study areas by many woody plant species and other encroacher species. This significantly reduces the competition resulting in *A. mellifera* and *A. erioloba* species dominating owing to their adaptability to harsh conditions. Another factor that presumably contributed to the low density of *C. collinum, T. sericea, Grewia spp.* and *B. petersiana,* and a high density of *A. erioloba* and *A. mellifera* in low rainfall areas is frost. According to Mendelson *et al.* (2009), the studied low rainfall areas (Sandveld and Ebenhaezer) receive on average about 20 to 30 days of frost in a year, whereas high rainfall areas (Mile 46, Sonop and Waterberg) receive less than 5 days of frost in a year. Skarpe (1996) and Wakeling *et al.* (2012) stated that juveniles, short shrubs and broad-leaved species cannot survive many days of frost.

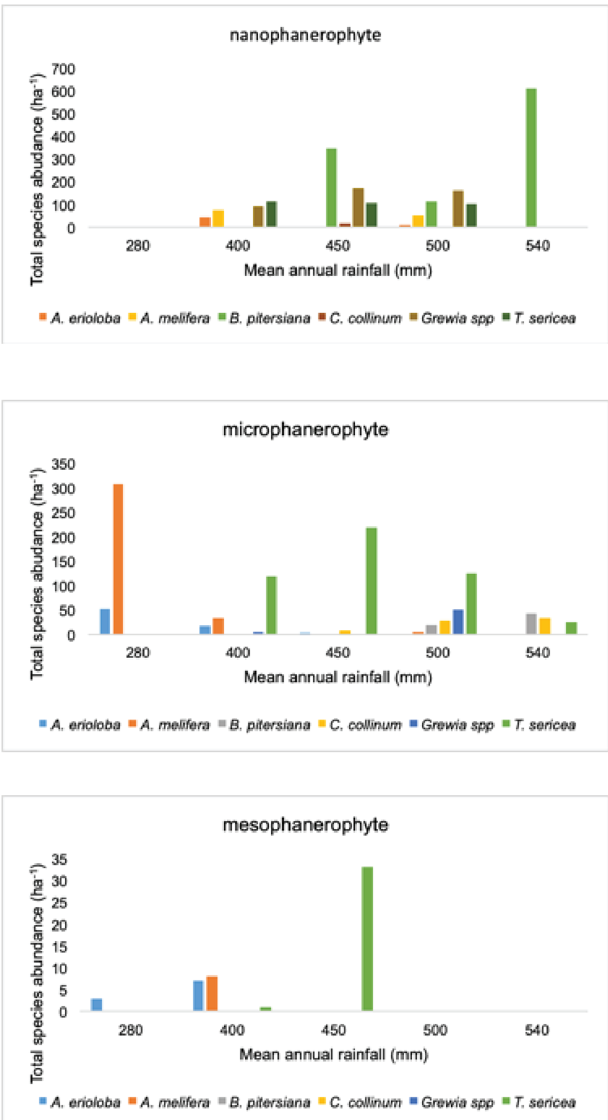

Figure 3: Change in encroacher species growth form along an aridity gradient

Rainfall has also been identified in other studies to be the main environmental factor influencing the recruitment of *A. mellifera* and *A. erioloba* (Ernst *et al.* 1990; Barnes 1999; Joubert *et al.* 2017). The present study indicated that the studied low rainfall areas are not bush encroached. This can be attributed to the high mortality rate of species in low rainfall areas. As stated by Barnes (1999), recruitment of seedlings can take place during an average rainfall year, however, mortality of seedlings mostly reach 100% before the next rain season; hence, recruitment and survival of seedlings and saplings is more likely to be successful in years with above average rainfall. In addition, under low rainfall conditions, species grow much slower. Joubert *et al.* (2017) claimed that *A. mellifera* individuals are only likely to reach a height of approximately two meters at about 65 years. However, this growth rate can be improved under better environmental conditions such as mean annual rainfall above 400 mm. The annual minimum temperature associated with the low rainfall areas in the present study ostensibly contributed to the low recruitment and slow growth rate in low rainfall areas. This corroborates with Wakeling *et al.* (2012) who stated that savanna trees grow more slowly in cooler sites compared to warmer sites.

The present study recorded a low density of *A. erioloba* compared to the density of *A. mellifera* in low rainfall areas. According to Seymour and Milton (2003), *A. erioloba* is less likely to be a primary encroacher species at any given area because it lacks the characteristics of a bush encroaching species. The predictions of a decrease in rainfall due to climate change (Midgley *et al.* 2005; Dirkx *et al.* 2008) suggests that the low rainfall areas are less likely to be bush encroached. Bush encroachment in low rainfall areas will be a highly slow process that can easily be detected and controlled before it threatens herbage production. Majority of encroacher species at low rainfall areas are microphanerophyte at 280 mm (Ebenhaezer) and mesophanerophyte at 400 mm, evidencing the slow recruitment rate and high mortality rate in low rainfall areas. The present study recorded a high abundance of nanophanerophyte of most encroacher species between 400 mm and 500 mm suggesting that areas that receives between 400 mm and 500 mm are more likely to experience bush encroachment.

Trends of increasing species density with increasing mean annual rainfall were recorded for *C. collinum*, *Grewia spp* and *T. sericea* while *B. petersiana* density fluctuated with mean annual rainfall. This highlights the importance of rainfall in the distribution of plants on Kalahari sands as shown by Scholes *et al.* (2002). Encroacher species in high rainfall areas and in deeper soils areas are likely to have a significantly higher recruitment, survival and growth rate, which makes high rainfall areas susceptible to bush encroachment. *Terminalia sericea*, *C. collinum* and *B. petersiana* species give a definite preference to deep Kalahari sand soils, and severe encroachment occurs locally under these habitat conditions. The highest density of *T. sericea* was recorded at 440 mm, primarily due to poor rangeland management and especially due to fire suppression that has been ongoing at that particular study site (Waterberg) since the 1980s (MET 2016).

The result of this study suggests that under long time fire suppression, *T. sericea* and *B. petersiana* are the most dominant encroacher species. *Terminalia sericea* gains its competitive advantage from its ability to depict different rooting systems depending on the climatic conditions (Hipondoka and Versfeld 2006). Its tendency for deploying its roots near the surface effectively enables it to compete for available soil water and nutrients with all other shallow rooted plants, such as grasses (Hipondoka and Versfeld 2006). This suggests that some *T. sericea* species with tap roots are able to utilise deep water, while some with shallow roots utilise water on and close to the surface. These give *T. sericea* an advantage to outcompete grasses and other phanerophytes. Conferring to Ferrar (1980), *T. sericea* species have developed morphological and physiological features resulting in low rates of transpiration even under non-stress condition. The high density of *B. petersiana* at 440 mm was mostly nanophanerophyte. Hence, it is logical to deduce that fire exclusion has significantly reduced the density of grasses at 440 mm, consequently reducing competition on seedlings and saplings.

5. CONCLUSION AND RECOMMENDATIONS

The findings of the present study led to the conclusions that mean annual rainfall is the main environmental factor influencing colonisation and distribution of main encroacher species on Kalahari sands in central Namibia, primarily owed to its role in plant establishment, growth and survival. Poor rangeland management such as fire suppression is one of the causative factors of bush encroachment. It is therefore recommended that fire suppression on savannas should be limited, and information from this study should be used as a baseline for conservation and restoration attempts towards the savanna rangelands.

Acknowledgement: We thank Dr. Wanke through OPTIMASS (Options for sustainable geo-biosphere feedback management in Savanna systems under regional and global change) and the German Federal Ministry of Education and Research for funding this research, SASSCAL (Southern African Science Service Centre for Climate Change and Adaptive Land Management) for transport provision. We acknowledge Leena Naftal, Emma Shidolo and Sherline Mukatu for the help rendered during data collection.

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APPENDIX 1

Table 2: Soil analysis results from the five selected study sites (M = Mile 46, S = Sonop, W = Waterberg, V = Sandveld and E = Ebenhaezer). For weather data please consult www.sasscalweathernet.org

Plots-	PHw	Ecw uS/cm	OM %	P ppm	K ppm	Ca ppm	Mg ppm	Na ppm	Sand %	Silt %	Clay %
M1	6.25	212	1.1	0.6	38	339	57	0	96.2	2	1.8
M2	6.2	169	0.36	0.4	0	81	21	0	96.9	1.8	1.3
M3	6.35	226	1.08	1.5	77	595	82	0	94.3	3.6	2.1
M4	6.07	144	0.36	0.9	0	85	27	0	95.9	2.9	1.2
M5	6.32	218	1.16	0.6	0	25	14	0	93.6	2.7	3.7
M6	6.51	103	0.44	0	34	376	76	0	96.6	1.4	2
M7	6.22	182	0.95	1	29	525	76	0	96.3	2.3	1.4
M8	6.46	160	0.99	0.1	0	119	39	0	96.7	2.1	1.2
M9	6.05	142	0.5	0.3	0	90	30	0	96.8	2.3	0.9
M10	6.23	177	0.56	3.5	0	127	15	0	96.6	1.7	1.7
S1	5.65	232	0.78	3.6	21	179	32	0	95.6	3.5	0.9
S2	6.53	198	1.05	2.5	28	359	78	0	97.1	1.1	1.8
S3	5.98	127	0.35	0	21	57	14	0	96.7	1.3	2
S4	6.32	228	0.88	2.8	0	20	11	0	89.9	5.3	5
S5	6.69	215	0.78	5.2	38	489	82	0	97.2	1.6	1.2
S6	6.82	150	0.51	3.2	0	508	29	0	97.6	1.9	0.5
S7	5.76	200	0.45	0.3	30	201	43	0	93.8	4.6	1.6
S8	5.91	230	0.69	0.9	60	607	83	0	96.6	2.3	1.1
S9	6.86	217	0.41	0	55	642	91	0	97.5	1.3	1.2
S10	6.15	151	0.42	0.1	0	25	10	0	97.1	1.7	1.2
W1	5.33	337	2.76	37.2	262	3149	342	0	79.1	13.2	7.7
W2	5.26	182	1.72	16	15	331	69	0	91.6	4.7	3.7
W3	4.97	105	0.61	0	0	36	8	0	95.4	2.6	2
W4	5.32	283	0.75	0	20	39	10	0	93.9	5.1	1
W5	5.97	996	1	0	6	22	26	0	94.9	2.6	2.5
W6	5.06	167	1.13	0	2	14	22	0	94.5	4.3	1.2
W7	5.06	167	1.13	0	2	19	25	0	95.3	4	0.7
W8	4.5	135	0.76	21	44	29	6	0	92.8	6.1	1.1
W9	4.72	101	0.82	0	13	325	38	0	94.6	3.5	1.9
W10	5.39	620	1.92	30	163	675	322	0	95.2	4.1	0.7
V1	6.25	212	1.1	0.6	38	339	57	0	89.6	7.2	3.2
V2	6.76	236	0.76	0.5	43	201	60	0	90	6.9	3.1
V3	5.98	127	0.35	0	21	57	14	0	94.3	3.6	2.1
V4	5.81	169	0.36	0.4	0	81	21	0	94.9	4	1.1
V5	6.69	215	0.78	1	38	489	82	0	93.7	4	2.3
V6	6.65	226	1.08	1.5	77	595	82	0	92.8	5	2.3
V7	6.28	230	0.89	0.7	0	29	21	0	91.9	6.9	1.2
V8	6.36	144	0.63	0.9	0	85	27	0	94.2	2.3	3.3
V9	6.86	217	0.55	0	59	642	91	0	93.5	4.9	1.6
V10	6.53	151	0.42	0.3	0	25	10	0	95.1	3.2	1.7
E1	5.65	220	1.3	0.39	23	130	20	0	94.4	2.3	3.3
E2	6.55	132	1.1	0.9	0	239	63	0	94.8	4.2	1
E3	6.79	180	0.78	0.65	32	260	19	0	94.3	3.1	2.6
E4	6.6	126	1	2.8	40	325	56	0	95.2	2.1	2.7
E5	6.68	134	1.16	0.6	0	264	14	0	95.6	2.6	1.8
E6	6.51	103	0.44	0	34	376	76	0	96.8	2.3	0.9
E7	6.44	122	0.39	0	0	129	46	0	95.1	3.2	1.7
E8	6.46	160	0.99	0.1	0	119	39	0	94.2	4	1.8
E9	6.65	177	0.56	2.3	0	127	30	0	94	2.8	3.2
E10	6.37	100	1.22	0.64	29	300	69	0	93.7	3.3	3