Bush encroachment in relation to rangeland management systems and environmental conditions in Kalahari ecosystem of Botswana

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Bush encroachment is an environmental problem in savanna ecosystems, but it is not yet clear whether it is more prevalent in communal or ranching grazing lands. This study investigates bush encroachment dynamics in relation to two rangeland management systems under different environmental conditions in Botswana. Woody vegetation cover (WC) was measured in 10 × 10 m quadrants at 100, 200 and 300 m along 23 transect located in both communal and ranching lands. Woody plant cover and diversity were not strongly influenced by rangeland management systems (P>0.05), but were highly dependent on site effects. The encroached rangelands (WC>40%) particularly, at Matlolahokgang site and also had high woody species diversity. Woody cover and diversity increased with decreasing soil clay content, but not in a linear way. The lack of variability of bush encroachment between management systems has implications for rangeland management policy in Botswana and other sandveld regions of sub-Saharan Africa.

Key words: Communal grazing, diversity, ranching, rangeland degradation, soil clay, savanna ecosystems.

INTRODUCTION

Bush encroachment, increase in woody vegetation density, cover and biomass in rangelands (Tews et al., 2004; van Auken, 2009) has been widely reported in Southern Africa (Moleele et al., 2002; Joubert et al., 2008; Wigley et al., 2009). The driving factors of bush encroachment in savanna ecosystems are not well understood (Moleele et al., 2002; Ward, 2005; Wiegand et al., 2005), but is often associated with overgrazing (van Vegten, 1984; Skarpe, 1990a) because a positive correlation between grazing pressure and woody cover has been observed in other studies (Oba et al., 2000). Other possible drivers of bush encroachment are increased rainfall (Joubert et al., 2008), fire suppression (Oba et al., 2000; van Langevelde et al., 2003) and soil characteristics (Wilson and Bowman, 1994; Mourik et al., 2007; Sankaran et al., 2008).

The dominance of herbaceous vegetation and patchy distribution of woody plants in savanna ecosystems is essential for livestock production and conservation of rangelands (Bond and Midgley, 2000) in developing countries such as Botswana. The increase of busy cover suppresses the productivity of herbaceous plant species (Hagos and Smit, 2005; Ward, 2005) and negatively affects the use of rangelands and conservation of biodiversity (Skarpe,1990a; Wigley et al., 2010) and eventually reduces their carrying capacity (Ward, 2005; Wiegand et al., 2006). This in turn threatens livestock production particularly, grazers (Kraaij and Ward, 2006; Angassa and Oba, 2008) and livelihood of pastoral communities. Therefore, the increase in woody plants cover in savanna ecosystems is an indication that the rangelands are being degraded (Oba et al., 2000).

In Botswana, rangeland degradation affected 25% of the rangeland in 1980 (Vanderpost et al., 2011) and an

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estimated 37,000 km² (6.4%) of land especially, around livestock watering points (for example, boreholes) and kraals, was encroached by woody vegetation in 1994 (Moleele et al., 2002). Rangeland degradation in Botswana communal grazing lands was occurring at an alarming rate as suggested by the “Tragedy of commons” (Hardin, 1968). As a result, the Government of Botswana introduced the Tribal Grazing Land Policy (TGLP) in 1975 to address the perceived land degradation in communal grazing areas through establishment of privately owned ranches to facilitate the control of grazing pressure and ensure sustainable use of rangelands (Botswana Government, 1975; Tsimako, 1991).

However, there is limited evidence to suggest that land use change through TGLP has achieved its intended goals (for example, Frimpong, 1995) especially, that the relevance of the equilibrium model which is the basis for ranch management is highly debatable in arid environments (Vetter, 2005). Understanding the dynamics of bush encroachment in relation to rangeland management systems over a broad range of environments is thus, essential for sustainable management of savanna ecosystems (Milchunas and Lauenroth, 1993). The aim of the present study was to investigate bush encroachment dynamics in relation to rangeland management systems under different environmental conditions in Botswana. The specific objectives were to determine the (i) woody vegetation cover in relation to rangeland management systems, (ii) diversity of woody plants in relation to rangeland management systems and (iii) relationships between woody vegetation dynamics and environmental variables.

MATERIALS AND METHODS

Study sites

The study sites are located in ranches and surrounding communal grazing lands in different regions of Botswana (Figure 1) at Goodhope, Matlolakgang and Xanagas. Ranches refers to fenced grazing lands that are privately grazed and owned by individuals or group of farmers, while communal grazing system is the shared use
of rangeland in tribal lands by pastoral community (Masike and Urich, 2008). Communal grazing system largely reflects traditional subsistence farming in which a diverse livestock species such as goats and cattle are reared (Wigley et al., 2010). On the contrary, ranching is a commercial oriented production system and is mostly focused on one or few livestock species. Subsequently, communal and ranching grazing systems are expected to have different impact on bush cover because of differences on grazing pressure, the browser/grazer ratio, and fire management practices (Wigley et al., 2010). The three sites are characterised by semi-arid climatic conditions and differ in rainfall, soil characteristics and vegetation (Table 1). The rainfall is erratic and concentrated between October and April (Weare and Yalala, 1971; APRU, 1979). Livestock production is a major livelihood strategy for local communities at all sites because of low rainfall, though, at Goodhope, arable farming is also widely practiced. Woody plants are also used as firewood and building material.

Data collection

Woody cover and diversity was determined towards the end of the growing season (April to May) in 2009. The woody vegetation data was collected along 300 m transects located randomly in selected paddocks within ranches and in communal grazing land. At each site, four transects were established in both the ranch and communal grazing land, with the exception of Goodhope communal land, where the fourth transect was abandoned to avoid the confounding effects of arable farming. Transects were well spaced (at least 1 km) to account for spatial variability in vegetation and avoid pseudo-replication (Waite, 2000). Collecting samples in 69 quadrants ensured that the data were representatives of different management systems within and between sites and also of the area as a whole (Bonham, 1989).

The woody vegetation was measured in 10 ×10 m quadrats located at 100, 200 and 300 m distance along transect such that, each transect had a total sampling area of 300 m². In each quadrat, individual woody plant species were identified and classified into height classes and then counted. They were classified into seedlings (<0.5 m), small shrubs (≥0.5 but ≤1.0 m), shrubs (>1 but ≤2.0 m), and tall shrubs/trees (>2.0 m) (Angassa and Baars, 2000; Dahlberg, 2000; Angassa and Oba, 2008). The plant height was measured to the highest leaning part using a 2 m long rod. For each height class, three woody plants were selected at random and their crown diameter measured to calculate the crown area as follows:

\[ n \times (D/2)^2 \]

Where \( n = 3.14 \) and \( D \) is mean diameter (m) of woody plants (Bonham, 1989). The tree/shrub density per transect was then multiplied by the crown area to calculate woody vegetation cover (%) (van de Vijver et al., 1999).

The diversity of woody plant species was estimated using the species richness (R) and Shannon-Weiner diversity index (H'). The species richness measures the total number of plant species present in a habitat and is also referred to as \( \alpha \) richness (Weare et al., 2008). Species richness measures the total number of plant species present in a habitat and is also referred to as \( \alpha \) richness (Weare et al., 2008). The Shannon-Wiener index was also used to estimate the woody vegetation heterogeneity per transect and was calculated as:

\[ H' = -\sum p_i \ln p_i \]

Where \( p_i \) (n/N) is the proportion of each species in the sample (Reyes et al., 2010). High value of \( H' \) reflects high heterogeneity or uncertainty that a randomly selected individual from a community of \( N \) individuals will be a similar species as the previous one (Smith and Smith, 2001). In addition to the woody plant species data, environmental factors (rainfall and soil characteristics) were also quantified at each site. Mean annual rainfall from 1988 to 2008 obtained from the Department of Agricultural Research was used for each study area. Soil samples of (69) were collected using a manual auger along similar transects in 2010 for soil texture analysis using pipette method (Marzaioli et al., 2010).

Statistical analysis

The general linear model (GLM) was used to compare the effects of multiple categorical factors such as rangeland management systems and rainfall on woody vegetation cover and diversity across sites. Comparisons of effects of rangeland management systems on woody vegetation cover and diversity at each site were done using a one-way analysis of variance (ANOVA). Stepwise regression analysis was also used to identify the best relationship between woody plant cover and other multiple environmental variables such as rainfall and soil properties. All statistical analyses were run in Minitab 15 and for each test, normality of data was tested through histogram and normal probability plot (Hair et al., 1998). All differences were considered significant at \( P<0.05 \), unless otherwise stated.

RESULTS

Woody plants cover in relation to rangeland management systems

The woody vegetation cover differed significantly between all three sites (\( P<0.001 \)), but not between ranches and the communal grazing land in a particular site (\( P>0.05 \)). The highest woody vegetation cover in both the communal grazing land and ranches was observed at Matlolakgang rangelands and the lowest at Goodhope (Figure 2).

Woody vegetation diversity in relation to rangeland management systems

The woody plant species richness differed significantly

<table>
<thead>
<tr>
<th>Site name</th>
<th>District</th>
<th>Mean annual precipitation (mm) (1988−2009)</th>
<th>Soils</th>
<th>Main vegetation type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodhope</td>
<td>Southern</td>
<td>475</td>
<td>Non-calcareous loam</td>
<td>Acacia giraffae tree savanna</td>
</tr>
<tr>
<td>Matlolakgang</td>
<td>Kweneng</td>
<td>434</td>
<td>Non-calcareous sand</td>
<td>Central Kalahari bush savanna</td>
</tr>
<tr>
<td>Xanagas</td>
<td>Gantsi</td>
<td>368</td>
<td>Calcareous</td>
<td>Northern Kalahari tree and bush savanna</td>
</tr>
</tbody>
</table>
Table 2. Mean (± SE) woody species richness across the semi-arid savannas of Botswana.

<table>
<thead>
<tr>
<th>Site name</th>
<th>Management systems</th>
<th>Communal</th>
<th>Ranch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodhope</td>
<td>4.00 ± 0.58</td>
<td>5.00 ± 0.58</td>
<td></td>
</tr>
<tr>
<td>Matlolakgang</td>
<td>8.00 ± 1.08 *</td>
<td>12.00 ± 0.85 *</td>
<td></td>
</tr>
<tr>
<td>Xanagas</td>
<td>8.00 ± 1.22</td>
<td>7.00 ± 0.75</td>
<td></td>
</tr>
</tbody>
</table>

*indicate significant differences (P <0.05) between management systems.

between sites (F=13.97, P<0.001), but not between the communal grazing land and ranches (P>0.05). Matlolakgang rangelands had the highest woody plant species richness (10.00 ± 0.95), followed by Xanagas (8.00 ± 0.68), while the lowest was observed at Goodhope (5.00 ± 0.43). There were significant differences in woody plant species richness between the communal grazing land and ranch at Matlolakgang (P<0.05), but not at other sites (P>0.05, Table 2). The Shannon-Wiener index showed no significant difference in woody plant diversity between sites and rangeland management systems (all P>0.05). However, Matlolakgang had slightly higher overall woody plant species diversity than other sites (Figure 3).

DISCUSSION

Woody plant cover in relation to rangeland management systems

The results of the present study exhibited heterogeneity in woody vegetation cover in communal grazing land and ranches at each site and between sites. Patches with high woody plant cover were observed along some transects, which was consistent with the savanna patch dynamics theory (Meyer et al., 2007, 2009). Goodhope rangelands had the lowest woody plant cover, suggesting that bush encroachment is not an environmental problem. The low woody plant cover at Goodhope rangelands could be due to local environmental conditions such as high rainfall and good soil fertility, which promotes high
herbaceous plant growth and limits the establishment of woody vegetation. Previous studies have shown that high growth rates of grasses limit the germination of woody plant seeds, establishment and seedling survival by out competing them for resources (Hagenah et al., 2009). It is also possible that the lower woody plant density at Goodhope could be due to high utilization of woody plants for fuel-wood and construction material by the local
community (Nkambwe and Sekhwela, 2006) since the site is closer to a major populated village than other sites.

The woody vegetation cover observed at Matlolakgang communal grazing land and ranch was significantly higher than the 40% considered as an equilibrium between encroached and non-encroached rangeland condition (Roques et al., 2001; Dalle et al., 2006). The results of the present study therefore, indicated that both the communal grazing land and ranch at Matlolakgang were encroached by woody plants such as *Terminalia sericea* and *Dichrostachys cineraria*, which was consistent with previous studies in other parts of Botswana (van Vegten, 1984). Woody plant cover observed within Xanagas rangelands was within the threshold (40%) between encroached and non-encroached rangeland condition and was lower than 50% and 70% as reported for nearby overgrazed areas at Noojane and Gantsi respectively (Skarpe, 1990a). However, a high woody plant cover of 89% was observed along one transect in a communal grazing land at Xanagas, which could indicate that bush proliferation is occurring and may be more widespread in this region in the near future.

In general, there was no significant difference in woody plant cover between the communal grazing land and ranches which was consistent with other studies (Smet and Ward, 2005; Tefera et al., 2008). However, these results contradicted the observations in South Africa (Wigley et al., 2010) which reported lower woody plant cover in communal rangelands than the ranch probably due to high utilisation of woody plants for firewood and construction material by local communities (Wigley et al., 2009; Wessels et al., 2011). The result of the present study suggests that bush encroachment is a common environmental problem in both the communal grazing lands and ranches. This contradicts the TGLP, which assumed that bush encroachment occurred mostly in communal grazing land due to overstocking and poor rangeland management (Botswana Government, 1975; Moleele and Perkins, 1998) and that ranches would promote sustainable utilisation of rangeland resources and minimise land degradation (Botswana Government, 1975). Contrary to the TGLP, Vanderpost et al. (2011) reported higher land degradation in ranches than communal grazing land.

**Woody vegetation diversity in relation to rangeland management systems**

In this study, highest woody plant species diversity was observed at overgrazed Matlolakgang rangelands. However, the woody species richness observed at Matlolakgang was lower when compared to neighbouring rangelands of Letlhakeng (Ringrose and Matheson, 1991). The high woody plant species richness at Matlolakgang rangelands could be attributed to overgrazing that reduces competition from herbaceous plants species (Jacobs and Naiman, 2008) and provided a suitable environment for different woody plant seeds deposited through animal faeces to germinate and establish especially, after the above average high rainfall (Kraaij and Ward, 2006). High browsing pressure in overstocked rangelands could also increase the mortality of dominant woody plant species and reduce interspecific...
competition, thus, allowing less dominant woody plant species to be established, which could eventually lead to increase in woody plant species diversity (Reyes et al., 2010) as observed at Matlolakgang. The lowest woody species richness was observed at Goodhope, despite having the highest mean annual rainfall and therefore, contradicts other studies which reported a positive influence of precipitation on woody plant species richness (Speziale et al., 2010).

The lack of a significant difference in species richness between the communal grazing lands and ranches at Goodhope and Xanagas probably indicated that both rangeland management systems have limited influence on woody plant diversity. It is possible that local environmental conditions such as soil and rainfall at each site have strong influence on seed germination and establishment of woody plants (Wiegand et al., 2005) and their response to browsing pressure. These results are in agreement with other authors (for example, Dahlberg, 2000), who reported no significant difference in woody plant species diversity between the communal grazing land and ranches in North-eastern part of Botswana. The Shannon-Weiner index showed no significant differences in woody plant species diversity between the communal grazing lands and ranches, which was generally low probably because rangelands were dominated by few and unevenly distributed woody plant species (Waite, 2000).

Relationships between woody vegetation dynamics and environmental variables

A multiple factor analysis showed that clay content was the most important factor influencing woody vegetation cover and diversity in a non-linear model. Matlolakgang and Xanagas rangelands located in the Kalahari sandveld had higher woody vegetation cover and diversity than Goodhope located in the hardveld. Sankaran et al. (2008) also reported on a negative relationship between woody plant cover and soil clay content in other African savannas, which is consistent with results of the present study. Water infiltration in sandy soils is higher compared to clay soils even in the absence of vegetation because they absorb rain water well (Rietkerk et al., 1997). In semi-arid environments, where soil moisture limits plant growth, good infiltration therefore, enhances the development of a continuous vegetation cover during good rainfall years (Rietkerk et al., 1997). Other authors, Sankaran et al. (2005) suggested that the Kalahari sandy soils sustained a higher woody plant cover which was consistent with the findings of this study.

Conclusion

The proliferation of bush thickets differed between sites, but not between grazing management systems at local scale. The bush encroached rangelands at Matlolakgang also exhibited the highest diversity in woody species composition. In all sites, the communal and ranching systems showed no significant differences in both woody plant cover and diversity, which contradicts the assumptions of Botswana grazing policy (TGLP). Therefore, it is highly possible that bush encroachment is largely dependent on site-specific conditions and our results showed that both strong bush cover and diversity were strongly associated with edaphic properties. The increase in soil clay content led to a decrease in woody plant cover and diversity and therefore, we concluded that bush encroachment is likely to be an environmental problem in both ranches and communal grazing lands located in Sandveld regions. Future research should therefore, be focused on measures to control bush encroachment and mitigate its impact on livestock production and pastoralists’ livelihood.

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REFERENCES


Hagos MG, Smit GN (2005). Soil enrichment by Acacia mellifera subsp


