More woody plants? the status of bush encroachment in Botswana's grazing areas

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Foci points, which are currently intensified by increased anthropogenic activities, have resulted in vegetation changes in the cattle-dominated grazing areas of Botswana. Bush encroachment species – for instance Acacia tortilis, A. erubescens, A. mellifera, Dichrostachys cinerea, Grewia flava, *and* Terminalia sericea *– are increasing in cover and density around foci points (e.g. water points and kraals) at the expense of the grass cover. A number of factors have the effect of encouraging the germination and survival of bush encroachment species. The practice of cattle husbandry and continual shifting of foci points within grazing areas have resulted in the spread of the distribution of bush encroachment species across the country. This is evidenced by the potential extent of 37 000 km^2 (6·4% of Botswana) of darkened and near infrared (NIR) reflective bush encroached areas in 1994. This paper suggests that specific management strategies should be adopted to help overcome the bush encroachment problem, which is causing a significant reduction in the extent of Botswana's high quality rangeland. These strategies may vary from the enforced reduction of grazing intensity in areas identified as being heavily bush encroached to the selective management of opportunistic (communal) grazing in better quality predominantly grassland areas. Further work is however required to update this analysis and especially to consider trends since 1994–1995. While some work on the extent of woody cover and the further causes of bush encroachment is being undertaken under the SAFARI2000 project, more research is needed in specific areas to pinpoint causes and responses to the bush encroachment problem.*

Keywords: Botswana; bush encroachment; foci points; management options.

Introduction

Increases in woody plant species cover (bush encroachment) have been documented in Botswana (Campbell and Child, 1971; Van Vegten, 1981, 1983; Skarpe and Bergstrom, 1986; Tolsma *et al*., 1987; Skarpe, 1990a,b; Perkins and Thomas, 1993; Ringrose *et al*., 1996a,b, 1998; Moleele and Perkins, 1998). This phenomenon is infact common in other semi-arid savannas and grasslands of the world (Buffington and Herbel, 1965; Blackburn and Tueller, 1970; Barnes, 1979; Bucher, 1987; Harrington *et al*., 1984; Archer, 1989; Matheson and Ringrose, 1994). These increases are accompanied by decreases in herbaceous production (APRU, 1980; Abel, 1997) and undesirable shifts in herbaceous composition (Archer, 1990) as noted in Botswana and drier parts of America, respectively.

In Botswana most of these major woody plant species that are reported to have increased in density are thorny although some broad-leaved encroachers for instance *Terminalia sericea* are also known cases. The driving factor behind the shift in vegetation in grasslands and semi-arid savannas is a subject of some controversy. In southern Africa, the shift is associated with anthropogenic activities, especially high cattle densities

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(Van Vegten, 1981; Skarpe and Bergstrom, 1986; Skarpe, 1991; Ringrose *et al*., 1996a). Elsewhere, explanations for these changes are debated to be either natural or human-induced or a combination of the two (Verstraete, 1986). Even though it is now accepted that increases in CO_2 levels in the atmosphere contribute towards global warming (Hanson *et al*., 1989; Kiehl and Briegleb, 1993; Christy and McNider, 1994; Mitchell *et al*., 1995), the debate still continues on whether and where C3 plants (including woody plant species) will respond with a burst of photosynthesis and growth (Culotta, 1995; Midgely *et al*., 2000).

Few previous attempts have been made to map the extent of bush encroached rangeland in Botswana using multi-spectral techniques. Most studies done in this respect involve mapping degradation features and other associated aspects of the vegetation cover (Ringrose and Matheson, 1991 Vanderpost *et al*., 1998, Ringrose *et al*., 1999 and 2000). The major reason behind this can be explained by the literature that suggests that bush encroachment is a negative aspect of range degradation (e.g. Ringrose *et al*., 1990a,b, 1997b), mostly because the thickness of the cover locally precludes grass formation and cattle entering thickets. However this is not always the case on the ground (Moleele, 1998).

The present paper brings together scattered information into a single model that condenses some of the wider issues related to the origin and distribution of bush encroachment in semi-arid rangeland as typified by Botswana. The overall goal is to establish the nature and distribution of bush encroached browse in a predominately cattle economy such as Botswana, specifically:

(1) To consider various hypotheses (brought into a single model) pertaining to the origin and distribution of bush encroachment species.
(2) To review the results of image processing with the aim of understanding the extent of the bush encroached areas.

Origin of bush encroachment in Botswana

Initially, the two main gradients determining natural woody vegetation distribution (i.e. species and structure) in Botswana are rainfall and soil type (Walker, 1980; Scholes and Walker, 1993). The natural vegetation cover, which is assumed to be largely open savanna and grasslands, has largely adapted to climatic and soil variations over the southwest to northeast gradient. Currently, human disturbance mostly cuts across the natural factors resulting in totally different vegetation types under otherwise similar natural conditions (Dahlberg, 1994). The following are general hypotheses to account for bush encroachment in relation to foci points (e.g. boreholes, wells, kraals and to some extent settlements) in the communal rangelands of Botswana. The hypotheses are aggregated in Figure 1, which combines four major factors that are dependent upon anthropogenic activities: soil moisture (related to cattle density); cattle selectivity; soil nutrient concentration and fire frequency. A detailed discussion of the phases of bush encroachment with distance from major foci points (e.g. boreholes, kraals, rivers, pans etc), as influenced by the four factors, follows.

(1) Grazing and trampling at water-points by cattle and pressure from both livestock and people around settlements are held responsible for opening up the herbaceous (grass) sward resulting in bare soil patches (Ringrose *et al*., 1996b; Moleele and Perkins, 1998), with the situation being extreme in the 'sacrificial' zone, where there is almost permanent total vegetation destruction (Figure 1). In the bush encroachment zone, within the bare patches, moisture competition can be sufficiently lenient to allow woody invaders to establish themselves as seedlings and grow to maturity (Van Vegten, 1981, 1983; Moleele and Perkins, 1998). The process is well accounted for by the two-layer soil moisture model (Walter, 1964; Tinley, 1982; Walker and Noy-Meir, 1982) and results in bush encroachment. Some of the following woody species have been identified as bush encroachment species in this context: *Acacia tortilis, Acacia erubescens, Acacia fleckii, Acacia mellifera, Dichrostachys cinerea, Grewia flava, Euclea undulata, Maytenus heterophylla* and *Ziziphus mucronata* (Van Vegten, 1981; Skarpe, 1990a; Moleele and Perkins, 1998). As one moves beyond the bush encroachment zone (see Figure 1), the area available for grazing increases and the livestock are generally too widely dispersed over most of the range to cause any significant shift in the balance between the herbaceous and the woody layers. This is probably the limit zone where major grazing effects are experienced, and other woody species (non-encroachers) start dominating in the 'mixed' and the 'non-encroachment' zones.
(2) Selectivity of cattle on the range can result in changes in structure and composition of vegetation, especially close or next to foci points (e.g.

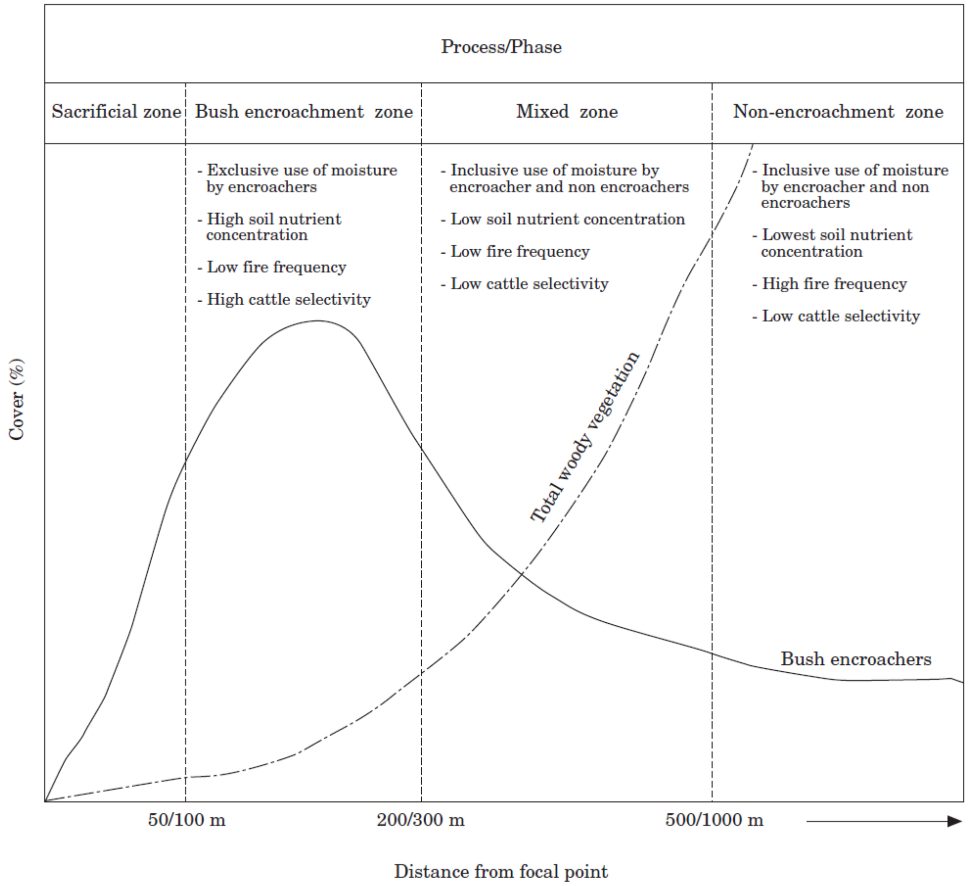

Figure 1. Four general phases related to bush encroachment around foci points in communal grazing pastures in south-eastern Botswana (assuming homogeneous topography and no overlapping phases/distances between foci points). The effect of the four interacting factors on each phase is also depicted.

the 'sacrificial' and 'bush encroachment' zones) where the area available for grazing is too small (Figure 1). Squires (1981) classifies cattle as selective browsers, while Moleele (1998) and Scholte (1992) working in the semi-arid rangelands of Botswana and Kenya, respectively, find that cattle rely heavily on browse even when grass is plentiful. This is because at certain times of the year, browse is more nutritious than grasses. Although there may be many woody species on offer during the dry and wet seasons, it is not unusual for a limited number of them to form a significant proportion of the cattle's diet (Moleele, 1998). The palatability of leaves, presence of thorns, nutrient levels in leaves and presence of chemical deterrents affects the establishment and survival of woody plants (Wilson, 1969; Woodward and Reed, 1989). Palatable species with high levels of nutrients therefore are not able to survive heavy browsing pressure within the zones next to foci sites (e.g. 'sacrificial, and 'bush encroachment' zones of Figure 1) unless they have thorns. Leaves of *Acacia tortilis, Acacia erubescens, Acacia karoo, Dichrostachys cinerea* and other thorny woody species have been found to be very nutritious (Tolsma *et al.*, 1987; Moleele, 1998), but are not easily browsed by cattle since they have thorns. Therefore, species that are avoided by cattle become abundant, since they survive where animal densities are high e.g. the 'bush encroachment' zone (Figure 1). Moleele and Perkins (1998) found that thorny and palatable species were more frequent closer to foci-points, while non-thorny species like *Burkea africana, Boscia albitrunca,* *Combretum apiculatum* (easily browsed) were more common further away, where cattle pressure is lower (e.g. in the 'mixed' and 'non-encroachment' zones).

(3) In the rangelands of Botswana, foci points experience high grazing and trampling pressure since cattle are constrained by their physiology to graze within several kilometres of drinking water. On the other hand however, large quantities of nutrients are imported through dung and urine from distant pasture (Weir, 1971; Moleele and Perkins, 1998; Perkins and Thomas, 1993) i.e. from the 'mixed' and 'non-encroachment' zones towards the 'sacrificial' and 'bush encroachment' zones (Figure 1). The relative increase in nutrients next to boreholes is dependent on cattle density and borehole age (Tolsma *et al*., 1987). Moleele (1998) established that the woody species composition along grazing gradients (zones) from foci points was significantly influenced by nutrient concentration.

(4) Fire frequency was very high in historical times as compared to today in all types of rangeland ecosystems (Bailey, 1988). In savanna rangelands' ecosystems, due to the expanding human pressure, herbivores (cattle) have eaten and depleted most of the fuel source (herbaceous layer) for fires at the 'sacrificial' and 'bush encroachment' zones. Fires are therefore non-existent at these zones while being irregular and random at the 'mixed' zone due to the patchiness of fire fuel load. However, fire and fuel loads are relatively high and reliable within the 'non-encroachment' zone, where disturbance in the form of grazing is minimal (Moleele and Perkins, 1998).

The removal of fire in vegetation communities that evolved with fire can be both positive and negative (Noble, 1989; Bailey, 1988; Hodgkinson, 1991). Fire enhanced the germination of two of the seven principal shrub species in a semi-arid shrub-invaded woodland in eastern Australia (Hodgkinson, 1991). In semi-arid rangelands where rainfall is very variable in time and space, it is likely that fire fuel availability will differ from patch to patch. Patches that are less impacted by humans (e.g. the 'non-encroachment' and 'mixed' zones) and those that receive more rainfall will have more fuel load, hence more chances of being burned. Patches that are burnt periodically (e.g. the 'non-encroachment' zone) will harbour vegetation that is favoured by fire (probably herbaceous), while patches that stay unburned should be dominated by shrubby woody encroachers (e.g. the 'bush encroachment' zone, Figure 1).

Present status of bush encroachment in Botswana

Mapping was undertaken on the vegetation cover of Botswana on the woody forest cover in 1994 (Ringrose *et al*., 1997a). The digital map used in this exercise was a mosaic of images comprising forty Landsat Thematic Mapper (TM) scenes taken from the wet season, 1994–1995. The data comprised a fully processed 800 Mb file projected to the UTM co-ordinate system (Zone 35) using the Clarke 1880 spheroid. Pixel size was degraded to 75 m. The TM data comprised one visible band (TM3 centred on 0·660 μm), one near infrared band (TM4 centred on 0·830 μm) and one mid infrared band (TM5 centred on 1·650 μm). Fieldwork involved collecting woody species data from 180 sites using access afforded by the road network based on a stratified random sampling approach across all of Botswana. The fieldwork was undertaken firstly to establish a field database of woodland cover and other vegetative components to form a basis for woody cover change. Each site was located using a Magellan 7000AX Global Positioning System. Fieldwork consisted of pacing 90 $\times$ 90 m transects along which all species were identified and their canopy cover assessed (Ringrose and Matheson, 1991). The vegetation cover components comprised woody vegetation cover (WVC) and live herbaceous cover (AHC). Other measured components include dead herbaceous cover (DHC) and plant litter. The 1994-1995 wet season was a year of average to low rainfall (Republic of Botswana, 1995).

Image processing was undertaken to transform the original three-band image into a thematically mapped product. Such processing techniques enable the user to manipulate pixel values in the individual bands so that specific aspects of the imagery can be enhanced. In this case image processing included haze correction, to try and minimise variation in illumination (or brightness) of the pixels across all the mosaiced images and supervised classification. Steps in the supervised classification process ensure that specific training areas (with known pixel values and field based attributes) can be used to identify similar pixel areas across an image (Erdas, 1998). The supervised classification process was used as this procedure was thought to be the most appropriate for isolating differing densities of natural vegetation cover and thereby focusing in on denser bush encroached area. One hundred and ten training sites were developed in 3-dimensional (TM) space based on a number of locations known to represent specific forest cover categories in the field. Once these locations were identified and enlarged, enclosing polygons were drawn interactively using AOI (area of interest) tools directly in a magnified viewer to ensure homogeneity of included pixels. The pixels within the polygons were saved, along with their initial interpretation, as signature files. The training signatures were evaluated using comparative histograms and the contingency matrix to ensure that:

(1) All portions of the available feature space were considered.
(2) No excessive overlap of the potential classes took place.

Once the data had been past through a contingency matrix, 12 classes were merged and deleted, initially resulting in 91 classes. This process was repeated until the feature space was clearly defined and 39 signatures were used for the final classification analysis. Classification analysis was run by first passing the data through a Feature Space Ellipsoid, then the data were run through two parametric rules to define overlapping pixel classes and finally ascribed to specific classes using probability analysis in the form of the Maximum Likelihood classification algorithm (Erdas, 1998). The Maximum Likelihood classifier has frequently been found to be most useful in areas of complex terrain or diverse environments (Ringrose and Matheson, 1987; Matheson, 1994).

The results of supervised classification analysis were evaluated by:

(1) Comparing the classified image to the original image by overlying the two images.
(2) Naming the classes to the prescribed forest type.
(3) Grouping the forest areas into classes based on cover density.

General statistics for vegetative components across Botswana indicated that the average woody cover of all types is around 16%, alive herbaceous cover 14%, while dead herbaceous cover and litter are around 6% each (Ringrose *et al*., 1997a, Vanderpost *et al*., 1998). The results of the classification are shown in Table 1. In the classification, the terms dense refer to woodland/shrubland cover in excess of 35% (including most of the bush encroachment areas); moderate = 25–35% woodland/shrubland; sparse = 15–25% mainly shrubland and very sparse = less than 15%, usually shrubland.

The dense category is subdivided into two sub-categories, which are mainly differentiated spectrally based on differing vegetation spectral characteristics. In terms of spectral response patterns, the two main vegetation types found in Botswana are mostly darkened vegetation (i.e. low infrared reflectance) and to a lesser extent near infrared (NIR) reflective vegetation (i.e. high NIR reflectance). Most of the bush encroachment species are found in the darkened category. These include for instance *Acacia erubescens, A. luederitzii, A. mellifera, A. senegal, A. tortilis, A. karoo, A. erioloba, Dicrostachys cinerea, Acacia nigrescens, Ziziphus mucronata* and *Maytenus senegalensis*. These occur in this category because they mainly have a microphyllous leaf structure (cf. Ringrose *et al*., 1989). Other species such as *Ehretia rigida, Boscia albitrunca, Terminalia sericea, Peltophorum africanum* and *Commiphora spp*. may be NIR reflective after early rains and become darkened with increasing desiccation as the season progresses. Bush encroachment species that are mostly NIR reflective include the *Grewia spp*. and *Combretum spp*. (Ringrose *et al*., 1989). While the identification of darkened and NIR reflective vegetation spectral response patterns is typical of semi-arid areas worldwide, the realisation of these two types has only been fully acknowledged relatively recently (Fiorella and Ripple, 1993; Chavez and McKinnon, 1994; Ringrose *et al*., 2000). The high near infrared reflectance

Table 1. Results of supervised classification analysis for forest cover over Botswana (after Ringrose *et al*., 1997a)

Class	Area (km^2)	Interpretation
1	114 477	Dense mainly broadleaved/Acacia savanna woodland
2	207 302	Moderate mainly broadleaved/Acacia savanna woodland
3	85 728	Sparse mixed savanna woodland and grassland
4	35 159	Floodplains and bare soils
5	37 141	Dense mixed savanna, including bush encroachment
6	26 277	Dark soils including pan grasslands
7	28 592	Very sparsely vegetated and bare soil areas including burn scars
8	1 337	Fields (Lands areas)
9	17 089	Flooded areas, hills and dark soils

patterns in vegetation cover have been well documented since the 1970s (e.g. Tucker and Sellars, 1986).

Hence there would appear to be a potential extent of 37 000 km^2 of bush encroached potential browse areas in Botswana (6·4%) in 1994. These occur extensively throughout the country but appear to predominate in the south east and in scattered areas (particularly close to human settlements) in the Kalahari (Figure 2). An additional area where bush encroachment appears particularly pervasive is in the vicinity of the Makgadigadi pans.

Management implications

Evidence from the literature and work within Botswana suggests that bush encroachment takes place as a result of the exclusive use of moisture by encroachers, high soil nutrient concentrations, low fire frequencies and high cattle selectivity. This is based on foci points, which are highly associated with bush encroaching woody plant species, some of which have seedpods that are edible and therefore tend to move centripetal from the surrounding area. Even so, the marked shifts

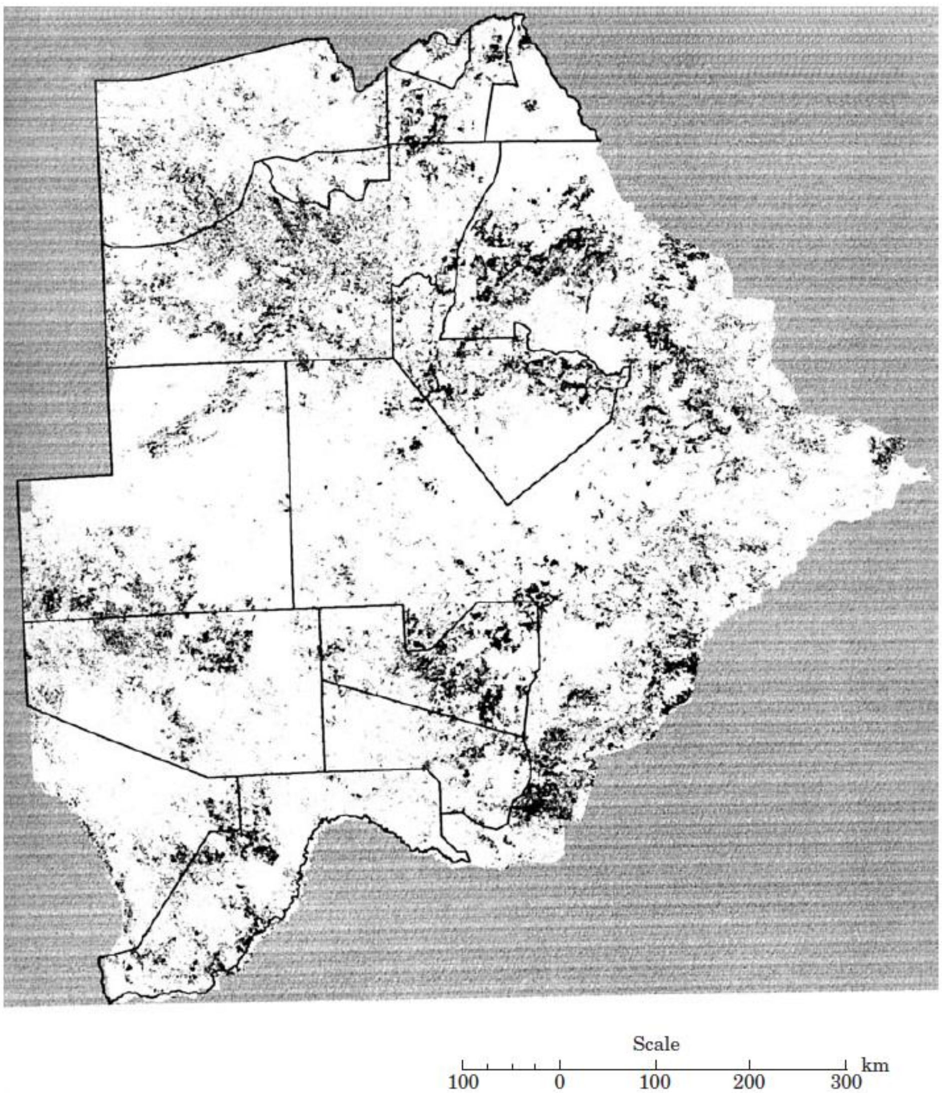

Figure 2. A map showing the extent of bush encroached areas in Botswana (after Ringrose *et al.*, 1997a). Dark black represents the heavily affected areas; white represents those areas that have not yet experienced bush encroachment.

in species dominance in the woody layer that occur around foci points is a topic that is worthy of further study, especially as the browse layer is now a vital supply of forage in some regions of Botswana (Moleele, 1998).

Given that foci points are centers around which bush encroachment takes place, the mapped distribution of bush encroachment in Botswana suggests that:

(1) The foci are concentrated in particular parts of the country, and especially in the southeast and around the Makgadikgadi pans.
(2) The bush encroached zones in these areas have a tendency to coalesce causing relatively extensive areas to have reduced quality in terms of potential grazing.
(3) Specific management strategies should be brought to bear in these areas to minimize or reverse the impact which is assumed to be the result of heavy cattle grazing over decades.
(4) Careful management should take place in the non-encroached areas to prevent or minimize the problem from spreading all over the country.

Management should emphasize that unnecessary shifting of foci points (boreholes, wells, kraals etc) within grazing rangelands is detrimental to livestock grazers, as it subsequently leads to the entire pastures being dominated by bush encroachers, as is now the case in parts of southeast Botswana (especially Kgatleng District grazing areas), parts of the Kalahari and areas around Makgadikgadi pans.

Table 2. Factors that promote the growth and establishment of bush encroachment species around foci points

Cause	Effect in the vicinity of foci points
Soil fertility	Nutrient enrichment (high soil nitrogen)
Moisture availability	Exclusive use by bush encroachment species, due to grazing/browsing exclusion of other species (cattle selectivity)
Fire	Exclusion due to lack/low herbaceous fuel loads
Topographical/ soil texture variation	Light/course grained soils retain less surface moisture and tend to favour woody plants. Heavy soils retain moisture at the surface and favour grasses

Source: Moleele and Perkins (1998).

Conclusions

Foci points-based piospheres, which are today intensified by increased anthropogenic activities, have resulted in vegetation changes in the cattle-dominated grazing areas of Botswana. Bush encroachment species, includings *A. tortilis, A. erubescens, A. mellifera, D. cinerea, G. flava, E. undulata, M. heterophylla and T. sericea* tend to increase in cover and density around foci points at the expense of the grass cover and composition.

All of the factors listed in Table 2 have the effect of encouraging the germination and survival of bush encroachment species. Cattle husbandry and continual shifting of foci points (e. g. kraals and water points) within grazing areas have resulted in the spread of the distribution of bush encroachment species across the country. This is evidenced by the potential extent of 37 000 km^2 (6·4% of Botswana) of darkened and NIR reflective bush encroached areas over the entire country in 1994. Bush encroachment is widespread across the country but appears particularly pervasive in the south east of Botswana, in scattered areas (close to settlements) in the Kalahari and in the vicinity of the Makgadikgadi pans. This paper suggests that specific management strategies should be adopted to help overcome the bush encroachment problem, which is causing a significant reduction in the extent of Botswana's high quality rangeland. These strategies may vary from the enforced reduction of grazing intensity in areas identified as being heavily bush encroached to the selective management of opportunistic (communal) grazing in better quality predominantly grassland areas.

Further work is however required to update this analysis and especially to consider trends since 1994–1995. While some work on the extent of woody cover and the further causes of bush encroachment is being undertaken under the SAFARI2000 project, more research is needed in specific areas to pinpoint causes and responses to the bush encroachment problem.

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