INFLUENCE OF GEOMORPHOLOGY ON THE PHYSIOGNOMY OF *COLOPHOSPERMUM MOPANE* AND ITS EFFECT ON BROWSING IN CENTRAL NAMIBIA

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ABSTRACT *Colophospermum mopane* is a characteristic tree species indigenous to Southern Africa, where it forms 'mopane vegetation.' Mopane plays an important role in livestock farming, and the physiognomy of mopane influences the availability of feed. This study clarified the relationship between the difference in mopane physiognomy and the browsing activity of goats with reference to geomorphology. The physiognomy of mopane corresponded to geomorphological characteristics of surface structures and soil layer thickness. Consequently, the landscape based on the physiognomy of mopane was more diverse in the mountainous study area. Short, multi-stemmed mopane dominated the pediment and crest surface, while tall, single-stemmed mopane trees dominated the flood plain and ephemeral river bed. We determined that people recognize the differences in vegetation and geomorphology and use this knowledge to ensure good browsing for their goats. Most browsing occurred on pediment, where many short, multi-stemmed mopane plants, an important browsing resource for goats, can be found. The physiognomy of mopane at the study site corresponded to geomorphology and was related to browsing activity.

Key Words: *Colophospermum mopane*; Tree shape; Land unit; Browsing activity; Feed resource; Namibia.

INTRODUCTION

Indigenous tree species have important roles as a resource for livestock browsing in communal farming areas of semi-arid Southern Africa (Sibanda & Ndlovu, 1992). *Colophospermum mopane* Kirk ex J. Leonard (Kirk ex Benth) is a characteristic indigenous tree distributed widely in Southern Africa, where it dominates in most areas (White, 1983). This mopane-dominated zone is called 'mopane vegetation.' The local inhabitants regard mopane as a resource for livestock farming (van Wyk & Gericke, 2000).

Mopane vegetation is generally viewed as homogeneous on a wide spatial scale (Timberlake, 1996). Nevertheless, the geomorphological environment may influence patterns of dry land vegetation (Wu & Archer, 2005). Further studies need to examine mopane vegetation relative to geomorphological features, and how they relate to inhabitants' knowledge of the environment.

Some studies of mopane vegetation have reported that vegetation patterns, such as tree shape or tree species composition, may indicate vegetation degradation in densely populated areas (Strohbach, 2000). By contrast, for areas with low population densities, such as the southern Kunene Region, little is known about the relationship between the vegetation pattern and vegetation degradation for diverse geomorphological environments (Sullivan, 1999). Nevertheless, a research indicates that an understanding of vegetation patterns is reflected in the inhabitants' way of life.

In mopane-dominated zones, the grass biomass is reduced because of root competition between mopane and grass in the shallow soil layer (White, 1983). Consequently, tree species, especially mopane, are more important than other forms of vegetation as feed resources. Differences in the physiognomy of mopane restrict access to important feeding resources for animals. Especially for goats which are mixed feeders that feed mainly on trees (Hofmann & Stewart, 1972), the position of the edible parts of the plant, such as the leaves and pods, regulates the amount of feed available.

Mopane has different physiognomic forms, occurring both as a tree and a shrub (e.g., Styles & Skinner, 2000), and mopane vegetation is classified into two corresponding types. There are two hypotheses to explain the existence of these two forms of mopane: the disturbance and abiotic hypotheses. Regarding disturbance, Styles & Skinner (2000) reported that hedging of mopane was caused by excessive browsing pressure by elephants. In addition, Mlambo & Mapaure (2006) reported that in response to wildfires mopane trees resprout and growth are restricted. Alternatively, abiotic factors may also affect the physiognomy of mopane. For instance, the shrub form of mopane is more stressed by water than the tree form (Hempson et al., 2007). Mlambo (2007) reported that soil fertility, especially phosphorus, was strongly related to the physiognomy of mopane.

The present study examined geomorphology (e.g., land units) to understand the spatial distribution of the different physiognomic forms of mopane. Other studies have indicated that geomorphology restricts vegetation, because different land units have different water conditions (Briault et al., 1963), and water is thought to be a major factor affecting the shape of mopane (February et al., 2007).

Mopane is an important feeding resource for domestic animals such as goats. Therefore, environmental factors that affect the physiognomy of mopane are important elements characterizing this area. Consequently, we examined the spatial distribution of forms of mopane to determine the relationship between tree shape and browsing activity of goats, with special reference to geomorphology.

RESEARCH AREA

The research area was the settlement of Renosterkop, in the southern Kunene Region (Fig. 1). Renosterkop is 50km southeast of Khorixas, the main town in the Kunene Region. A previous study defined the vegetation around this settlement as mopane savanna dominated by mopane trees (Giess, 1971). The area is characterized by high relief, ranging from about 900 to 1,500m above sea level. The geology of the area is complicated because it is located at the edge

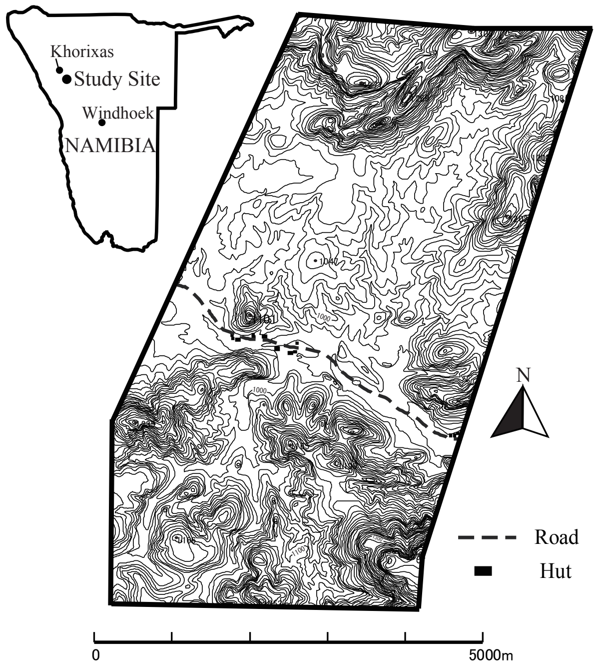

Fig. 1. Map of the study site.
Map source: South West Africa 1:50,000 2015AD Bertram.

of the Damara complex (Schneider, 2004).

The mean annual precipitation (for the 46 years from 1958 to 2004) at Khorixas is 220mm/year, with large fluctuations, according to data from the Namibia Meteorological Service. For example, precipitation totaled only 60mm in 1995, but 359mm in 2004. These large fluctuations may affect livestock farming by influencing the availability of feed, such as grasses and trees.

The Damara people who live in this mountainous settlement raise goats and some cattle. In December 2006, the population of Renosterkop was about 40 people, in 11 households. The population and livestock densities are lower than the national averages for Namibia. For instance, population density is 0.6/km^2 in the settlement and 2.1/km^2 in average of Namibia (Republic of Namibia, 2003). Hence, the effects of people and livestock on the physiognomy of mopane should not be extreme in this settlement. In addition, the density of wild animals in the area is low; thus their browsing pressure is also relatively low. Interviews with the villagers revealed that no large wild fires that would affect the shape of mopane have occurred in a long time.

The main livelihoods of the residents are livestock farming and migrant labor. Livestock farming is the most important activity for obtaining food and cash. In addition, some people engage in labor in the town. Pension and remittance money are also important. Domestic animals in the settlement include goats, cattle, and a few donkeys. Almost every household has goats, which are a source of meat and milk and can be used as gifts or exchanged for resources. The number of goats is different by each household: some household have more than one hundreds while others hold only around ten of them. Only two households kept cattle for milk, meat, and sale. Some people owned donkeys for transport, and donkeys were sometimes eaten.

RESEARCH METHODS

Fieldwork was conducted from August 2006 to March 2007. Firstly, a geomorphological map of the area was prepared from field observations. Secondly, 77 quadrats (20 × 20m) were defined, and tree height and the number of stems of each mopane plant in all quadrats containing mopane were measured, which was used to classify the physiognomy of mopane. The species composition in each quadrat was also examined. In addition, the land surface structure and soil were observed in each quadrat. The land surface structure was divided into the following five types: silt and sand (matrix) (≤ 2mm), gravel (2–64mm), boulders (≥ 64mm), exposed bedrock, and unknown (Hubbard & Glasser, 2005). Small holes were dug to observe soil sections.

Browsing activity was investigated by interviewing herders and observing the feeding of goats from three households in the settlement. The routes followed during browsing were observed by travelling with the herders, and recorded with a global positioning satellite (GPS) unit, as well as by interviewing the herders. The interviews referred to topographical features in the browsing area known to the herders.

GEOMORPHOLOGICAL FEATURES

Renosterkop is located in an area of high relief (Fig. 1) and diverse geomorphology because of an ephemeral river and complex geology. Based on observations, the land units were classified into the following seven types: crest surface, scarp, pediment, debris slope, flood plain, ephemeral river bed, and concave valley head. Figure 2 shows the geomorphological map of the distribution of land units at the study site. The features of each land unit were affected by the surface structure and matrix layer (Table 1). The proportion of exposed bedrock on the surfaces of crests, scarps, and pediment was larger than for the other land units, and the proportion of boulders was also higher. The soil in these units consisted mainly of silt or clay, and the average thickness of the soil in each land unit was less than 50cm (Fig. 3). The major surface matrix of crest surface, scarp, and pediment units was silt. By contrast, the flood plain and ephemeral river bed featured surfaces that were 50–60% sand, which is more than twice the proportion of matrix found in the other land units. In the flood plain and ephemeral river bed, the sand layer was more than 1 m thick.

PHYSIOGNOMY OF MOPANE AND VEGETATION FEATURES

I. Tree Species Composition

The vegetation survey identified 23 tree species at the study site. The domi-

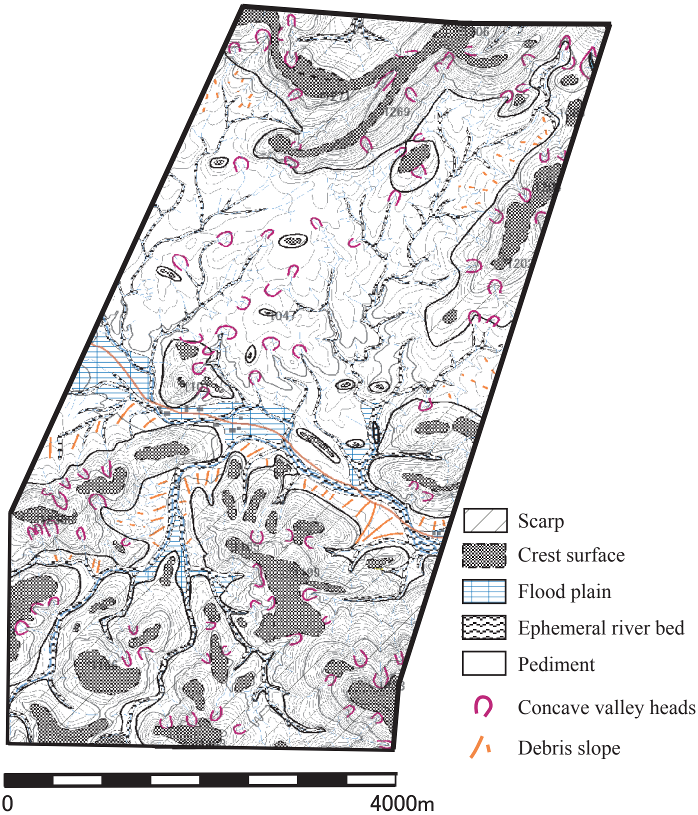

Fig. 2. Geomorphological map of the study site.
This figure was drawn using the results of the field survey.
In the study site, linear erosion of pediment was a noticeable feature.

Table 1. The features of each land unit.

	Land Unit						
	Concave valley head	Debris slope	Pediment	Flood plain	River bed	Scarp	Crest surface
Soil layer thickness (cm)	40–100	50<	20–100	100<	100<	20–100	20–100
Proportion of exposed bedrock (%)	30	0	20	0	0	40	30
Proportion of boulders (%)	40	40	40	40	30	40	40
Proportion of matrix (%)	20	20	20	50	60	0	10
Major component of the matrix	Sand	Sand & Silt	Silt	Sand	Sand	Silt	Silt

The thickness of the soil layer is the thickness of the soil from the surface to bedrock based on 2–5 soil sections dug in each land unit.
The proportions of bedrock exposure, boulders, and matrix are rounded-off averages for the surface structures on each land unit. These proportions are based on 77 quadrats; the surface structure was classified as bedrock, boulders, gravel, matrix, and unknown.

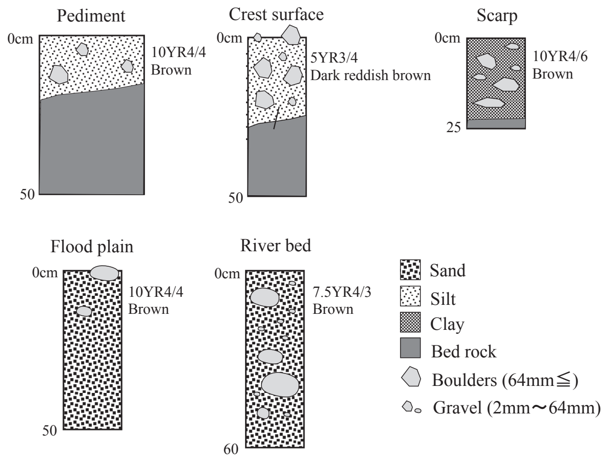

Fig. 3. Typical characteristics of soil cross-sections for each land unit.

nant species in this area was mopane, which occurred in 75 of 77 quadrats. Other species that were common and had high coverage included *Acacia reficiens*, *Boscia albitrunca*, *Catophractes alexandri*, *Combretum collinum*, *Combretum imberbe*, *Myrothamnus flabellifolius*, and *Terminalia prunioides*. The remaining species were infrequent and had less than 5% of total coverage. Consequently, mopane and the seven other species listed above could be treated as key species for classifying the vegetation. Although differences in tree species composition did alter the landscape at the study site, mopane was still the most important factor affecting the landscape because of its abundance.

II. Spatial Distribution of the Physiognomy of Mopane

The number of mopane trees and coverage in each quadrat differed according to the type of land unit. On pediment and crest surface, there were many individuals and the coverage rate was high. Although there were fewer individual mopane on the flood plain and the ephemeral river bed, mopane still covered a large area. Fewer mopane were present on scarp and concave valley heads and the coverage rate was low.

Figure 4 is a box and whisker plot of tree height for each land unit. Tree height varied greatly with land unit type. The tallest trees grew on the ephemeral river bed, which had the highest median tree height. The flood plain had the second highest median value. On the flood plain and the ephemeral river bed, the average tree height was about 5m, but height varied widely. By contrast, tree height was similar for pediment, scarp, and crest surface land units, with median values of about 2m, a maximum of less than 5m, and little individual variation.

According to the number of mopane stems per individual, there were more multi-stemmed individuals on pediment, crest surfaces, and debris slopes, while there were more single-stemmed individuals on flood plain, ephemeral river bed,

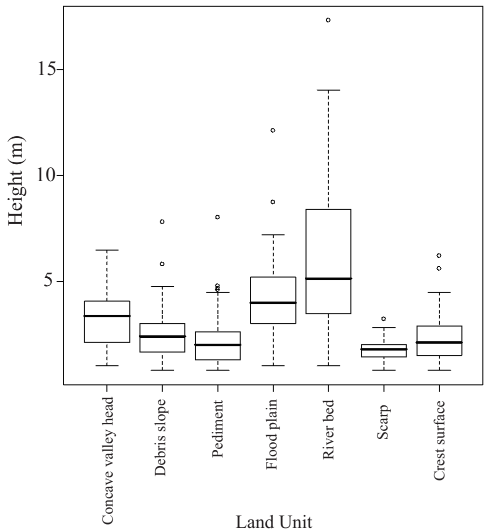

Fig. 4. Box and whisker plot of mopane tree height for each land unit.
The boxes indicate the first and third quartiles of the tree height for each land unit. The horizontal line within each box shows the median value. The ends of the whiskers denote the maximum and minimum. Circles indicate outliers that are more than 1.5 times the inter-quartile range between the first and third quartiles.

scarp, and concave valley heads (Table 2).

The Kruskal-Wallis test revealed that the physiognomy of mopane varied significantly at the 1% level with land unit. In other words, the characteristic shape of mopane was uniquely different for every land unit. This implies that the physiognomy of mopane tends to correspond to the land unit type at the study site. Crest surfaces, pediment, and scarp were dominated by short, multi-stemmed mopane, although scarp had a high proportion of single-stemmed individuals. Conversely, tall, single-stemmed mopane dominated the flood plain and ephemeral river bed. The mopane on the concave valley head and debris slopes had characteristics intermediate between these two types.

III. Factors Causing the Physiognomic Differences

Abiotic factors were likely the primary cause of the different shapes of mopane at the study site. This echoes the findings of February et al. (2007), who found that plants on the ephemeral river bed could access underground water. The thick soil layer of the flood plain also retains soil moisture after rain. In this study, plants on these two land units were able to access water relatively easily in comparison to plants on the other land units.

The plants on the other land units had severely limited access to water. On the crest surface, scarp, and pediment, there are many surface outcrops and a shallow silt or clay-rich soil layer, which soaks up only a small amount of rainfall. Following a rain event, water is retained for a much shorter period than on the ephemeral river bed. The debris slope had a relatively thick soil layer that could retain moisture despite the high gravel content. The concave valley head soil contained a high proportion of sand in the surface matrix, which would draw small amounts of precipitation underground, facilitating access by plants relative to the crest surface or pediment soils.

Mopane may adapt to variation in water conditions by changing its shape. On the ephemeral river bed and flood plain, where access to water is better than on the other land units, mopane can grow vertically and tall. With better

Table 2. The frequency (%) of the number of stems per individual mopane on each land unit.

Number of stems	Land Unit						
	Concave valley head	Debris slope	Pediment	Flood plain	River bed	Scarp	Crest surface
1	57.1	35.9	16.2	51.7	59.2	55.6	25.3
2	14.3	18.4	11.7	34.5	19.4	14.8	13.8
≥3	28.6	45.6	72.1	13.8	21.4	29.6	60.9
Total number of individuals	n=42	n=103	n=376	n=58	n=98	n=27	n=225

access to light, mopane can outgrow competing species. By contrast, on the crest surface, scarp, and pediment, where bedrock underlies a shallow soil layer, the amount of available water depends largely on the infrequent precipitation. Under such severe water conditions, water stress hinders upward growth and the number of stems is increased to improve survival rate (Macgregor & O'Connor, 2002; Okitsu, 2007). Nevertheless, the number of stems is also related to disturbance (Smallie & O'Connor, 2000; Kennedy & Potgieter, 2003; Donald & Isaac, 2006), more researches are needed on that.

THE RELATIONSHIP BETWEEN BROWSING BY GOATS AND THE SHAPE OF MOPANE

I. The Browsing Activity of Goats

Goats were allowed to browse during day-trip herding. They were taken out of the kraal at about 09:00 every day and brought by the herder to a field to browse. The goats were only occasionally milked in the morning before browsing. The small goats were kept near the huts. Before or after browsing activity, the goats drank at the well located at the center of the settlement. Each herder traveled about 10km with the goats every day, and returned to the settlement at about 16:00. The goats fed mainly during the middle of the day. Consequently, the areas subject to high feeding pressure are far from the settlement. Near the settlement, they fed little.

From December to February, the goats mainly browsed trees (Fig. 5). Regarding the diet of the goats, one herder stated, "they eat a lot of mopane, just like we humans eat porridge, while they eat other plant species in the same way that we eat meat (porridge is the staple food for Damara people, but they eat meat only occasionally)." The interviews and observations of grazing activity suggested that the goats found *Catophractes alexandri* and *Combretum collinum* the most palatable species, although they mostly ate mopane. On observing the stomach contents of adult female goats after grazing, mopane constituted about 60% of the total contents. Therefore, mopane is the most important food resource for goats during this season at the study site.

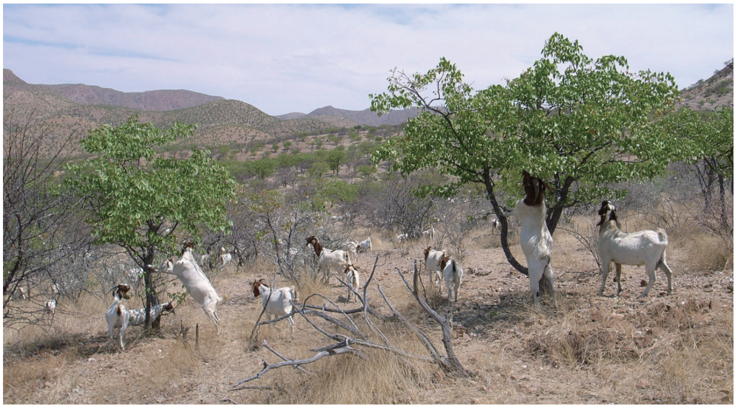

Fig. 5. Goats browsing on mopane (February 2007).

II. Browsing Route

Figure 6 indicates browsing pressure based on the routes that the goats follow, as determined by interviews between January and February 2007 with three herders living in the settlement. Although the goats frequently passed through sites near the settlement, the browsing pressure there was low, because the animals simply moved through these areas. Each herder followed a different route for browsing that they decided themselves. Topographical accessibility was an important determinant of browsing route. There are some areas that the herders never used for browsing (Fig. 6). For example, they never travelled south of the settlement because the hill was too steep for daily travel, and the herders rarely took their goats to the crest surface or scarp sites. However, the flood plain and ephemeral river bed were not feeding places, despite their topographical accessibility. Therefore, topographical accessibility as well as other factors affect goat browsing routes.

Primarily, the goats browsed in the pediment area. Based on the interviews, all of the herders selected areas with "ample food resources" for browsing. The shape of mopane on pediment, where there was a high proportion of short, multi-stemmed plants, made it suitable for feeding goats; the leaves and pods are more accessible because the trees are short and the crowns low. Goats obtained the greatest total food mass from trees with this shape. Because tall, single-stemmed mopane dominated on the flood plain and ephemeral river bed, it is difficult for goats to feed there because the tree crowns are relatively high. Consequently, the physiognomy of mopane is an important factor affecting the browsing activity of goats.

CONCLUSION

The physiognomy of mopane differed markedly with land unit type and envi-

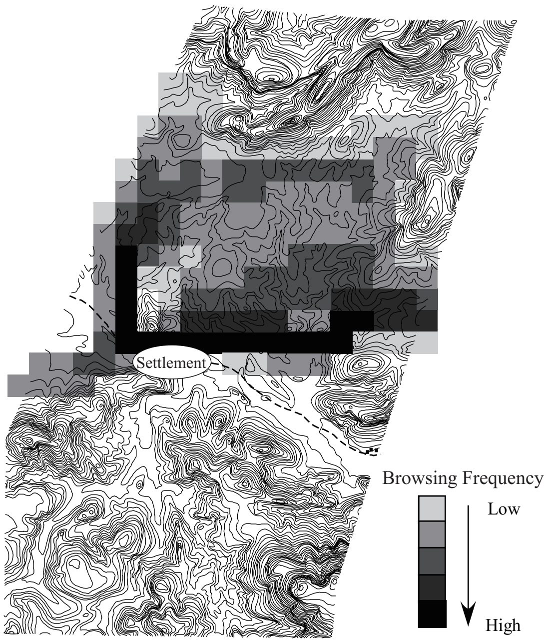

Fig. 6. Distribution of browsing sites at the study site.
This figure is based on interviews with three herders conducted between January and February 2007 (total 30 days) and GPS data.
From the interviews and the number of goats, I estimated how many goats passed through each area per day. A "high" browsing frequency means more than 150 goats passed through that square each day.

ronmental conditions. Short, multi-stemmed mopane dominated on pediment and crest surface, while tall, single-stemmed mopane dominated on the flood plain and ephemeral river bed. Because mopane is an important food resource for goats, its physiognomy strongly affects browsing route. Interviews with herders indicated that there is sufficient food for goats on pediment. This is because the physiognomy of mopane on pediment (e.g., short and multi-stemmed) made it easy for goats to access the edible parts of the plant. By contrast, the tall, single-stemmed mopane dominating the flood plain and ephemeral river bed is not accessible by goats. In addition, the topographical accessibility of pediment was better than that of scarp and crest surface where short, multi-stemmed mopane also grows. This explains why pediment was the primary land unit used for goat browsing. Because mopane is an important food of goats, the physiognomy of mopane, which corresponded to geomorphology, was strongly connected to the inhabitants' subsistence at the study site.

Browsing pressure was not high near the settlement, because there were not many domestic animals present. With intense browsing by domestic animals or game, the abundance of shrubby woody plants increases (Wiegand et al., 2005). This increase in the abundance of shrubby woody plants is commonly referred to as "bush encroachment" and involves invasion of grasslands (Smit, 2005). The grazing capacity of large areas of the South African mopane savanna is reported to have declined due to bush encroachment (Smit, 2005). At the study site, shrub type mopane with its short and multi-stemmed shape is abundant. As this site has not likely experienced bush encroachment, the shrubby shape is derived from the original geomorphology. In addition, this short and multi-stemmed mopane is an important food resource for goats. Consequently, based on the usefulness of short and multi-stemmed mopane, the effect of bush encroachment and mopane vegetation should be reevaluated. Future research should evaluate the potential of mopane vegetation for feeding communal livestock and other human activities.

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