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Research Paper

Herbaceous plant species diversity in communal agro-pastoral and conservation areas in western Serengeti, Tanzania

Diversidad de especies herbáceas en áreas de uso agropastoril comunal y protegidas en Serengeti occidental, Tanzania

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Abstract

Agro-pastoralism involves the growing of crops and keeping of livestock as a livelihood strategy practiced by communities in rural areas in Africa and is highly dependent on environmental factors including rainfall, soil and vegetation. Agro-pastoral activities, e.g. livestock grazing and land clearing for crop cultivation, impact on environmental condition. This study evaluated the impacts of agro-pastoral activities on herbaceous plant species diversity and abundance in western Serengeti relative to conservation (protected) areas. A vegetation survey was conducted along the grazing gradients of ten 4 km transects from within village lands to protected areas. A total of 123 herbaceous species belonging to 20 families were identified. Higher herbaceous species diversity and richness were found in protected areas than in communal grazing lands. Similarly, the number of perennial herbaceous species was higher in the former than the latter, while occurrence of annuals was higher in the village areas. This observation indicates poor rangeland condition in village communal grazing lands as compared with protected areas. It is obvious that current agro-pastoral activities have contributed to a reduction in herbaceous species diversity in village lands in western Serengeti. However, the array of pasture species, especially desirable perennial species, still present in communal grazing areas, suggests that rejuvenation of these areas is possible. Resting of grazing land is recommended to reverse the trend towards diversity reduction and ensure future availability of feed resources for grazing animals in village lands.

Keywords: Ground cover, land use type, pasture condition, species composition.

Resumen

El sistema de uso agropastoril de la tierra se define como la combinación de cultivos con la producción de ganado y es una estrategia de producción y sustento practicada por las comunidades en las zonas rurales de África que depende, en gran medida, de factores ambientales como la precipitación, el tipo de suelo y la vegetación. Actividades agropastoriles, tales como el pastoreo de ganado y la preparación del suelo para cultivos, impactan en el medioambiente, sobre todo en la composición florística. En este estudio se evaluaron los impactos de las actividades agropastoriles en la diversidad y abundancia de especies de plantas herbáceas, en comparación con áreas de conservación (áreas protegidas), en la región del Serengeti occidental, Tanzania. Para el efecto se hizo un levantamiento de la vegetación a lo largo de gradientes de pastoreo en 10 transectos de 4 km cada uno, desde áreas de uso comunal hasta áreas protegidas. Se identificaron un total

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de 123 especies herbáceas pertenecientes a 20 familias. Se encontró mayor diversidad y riqueza de especies en áreas protegidas que en áreas de pastoreo comunal. Del mismo modo, el número de especies herbáceas perennes fue mayor en áreas protegidas que en áreas comunales, mientras que en estas últimas la presencia de plantas anuales fue mayor. Estos resultados indican un estado deteriorado de las áreas para pastoreo en las tierras comunales en comparación con las áreas protegidas. Es obvio que en el Serengeti occidental las actuales actividades agropastoriles han contribuido a una reducción de la diversidad de especies herbáceas en las áreas comunales. Sin embargo, la variedad de especies útiles para pastoreo, especialmente especies perennes deseables, todavía presentes en áreas de pastoreo comunales, indica que la rehabilitación de estas áreas es posible. Se sugiere permitir periodos de descanso adecuados en estas áreas con el fin de revertir la tendencia hacia la reducción de la diversidad de especies y asegurar la disponibilidad futura de recursos forrajeros para los animales en pastoreo en las tierras comunales.

Palabras clave: Cobertura del suelo, composición botánica, manejo de pastoreo, uso de tierra.

Introduction

Agro-pastoralism is a combination of cropping and keeping of livestock as a livelihood strategy practiced by communities in rural areas. Local communities perceive that their survival is dependent on having sufficient cropland and pastureland, while they derive no benefit from biodiversity conservation (Kaltenborn et al. 2003; Kideghesho 2008). Agricultural production involves land clearing, which impacts negatively on vegetation structure and species composition. Grace et al. (2010) found a strong interaction between agro-pastoralism and plant biodiversity showing that agro-pastoralism and biodiversity conservation have conflicting goals, which poses a challenge in managing plant resources in the ecosystem.

The success of agro-pastoralism in western Serengeti is heavily reliant on environmental factors including rainfall, soil and vegetation (Salami et al. 2010). Crops grown by agro-pastoralists during 4–8 years include food crops such as maize (*Zea mays*), cassava (*Manihot esculenta*), sorghum (*Sorghum vulgare*) and finger millet (*Eleusine coracana*); cotton (*Gossypium hirsutum*) as a cash crop; and other food crops such as sweet potatoes (*Ipomoea batatas*), beans (*Phaseolus vulgaris*) and a variety of vegetables (Mfunda and Røskaft 2011). Subsequently land is left fallow for 4–5 years. Livestock grazing is normally conducted in communal grazing lands and abandoned or fallow lands (Kavana et al. 2017).

Annual rainfall affects plant growth, vegetation type and hence the feed resource base for both wildlife and domestic animals in eastern and western Serengeti. Muchane et al. (2013) conducted a biodiversity study in 4 parts of north-eastern Serengeti (Ololosokwan, Loliondo, Machokwe and Nyansurura), aiming to identify optimal land use and management practices, which would favor biodiversity while still providing livelihoods for the pastoralists. Their results for plant diversity were based on a rapid vegetation survey conducted from July 2009 to December 2010 covering only a small patch of the ecosystem that differs from western Serengeti in terms of mean annual rainfall (550 vs. 1,050 mm, respectively). Generally, previous studies on agro-pastoralism have been limited in coverage and time. Here we conducted a study on the effects of agro-pastoralism on herbaceous plant diversity over a period of 2 years covering 2 wet seasons in western Serengeti to determine the influence of agro-pastoralism on herbaceous plant composition and diversity, especially the effects of livestock and wildlife grazing, following a grazing gradient in 3 areas: communal lands with livestock grazing; areas with mixed livestock and wildlife grazing; and protected areas with wildlife grazing only. In addition, fallow lands were included in the study to reflect the impact of cultivation and grazing as part of the combined effects of agro-pastoral activities on the diversity of herbaceous plant species.

Materials and Methods

Study sites

Western Serengeti is part of the Serengeti ecosystem and is wooded savanna grassland, which is situated in agro-ecological zone III characterized by intensive agriculture and the keeping of cattle, goats, sheep and poultry (NBS 2015). It encompasses Serengeti, Bunda, Busega, Magu, Meatu and Bariadi districts. While this zone has low agricultural potential and is only marginally suitable for arable agriculture, it is occupied by agro-pastoralists. Average annual rainfall ranges between 500 and 1,200 mm, declining towards the Serengeti National Park boundary and increasing towards Lake Victoria (Sinclair et al. 2000). The area is highly diverse in terms of ethnicity, including more than 20 ethnic groups, and is among the most densely settled parts of the Greater Serengeti ecosystem with population growth rates exceeding those to the north, east and south of the National Park (Kideghesho 2010).

The study was conducted in 4 districts with respective villages shown in brackets (Figure 1): Serengeti (Park Nyigoti), Bunda (Nyamatoke), Meatu (Makao) and Bariadi (Mwantimba and Mwashibaba).

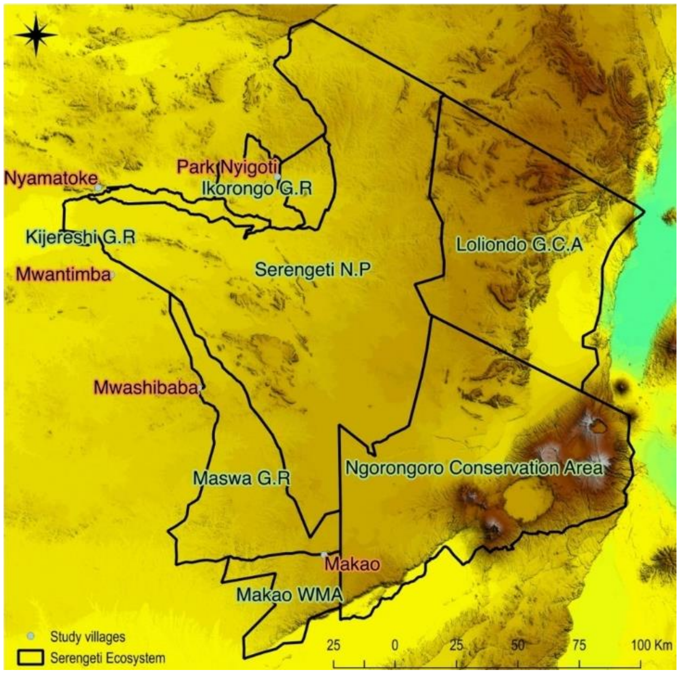

Figure 1. Map of Serengeti ecosystem showing the study sites in western Serengeti.

Study design

The study was designed to sample vegetation and assess soil texture along 4 km transects that traversed across different land use types including: domestic livestock grazing; mixed grazing by domestic livestock and wildlife; and wildlife grazing. This method was chosen because it can be easily applied in rapid vegetation surveys when funds and time are limited. Two transects separated by 5 km were established for each of the 5 villages. Each transect started in village land traversing 0 to 1.5 km in grazing land dominated by livestock grazing followed by 1.5 to 2.5 km crossing the border between village land and protected area which was dominated by mixed grazing, and the rest 2.5 to 4.0 km was in protected area dominated by wildlife grazing. The starting and end points of each transect were established by recording GPS readings. In addition to the two 4 km transects, for each village a separate 1 km transect was established in grazed fallow land, with up to 4–5 year-old vegetation. This sampling transect separation was necessary because crop/fallow land is usually not in proximity to grazing lands.

Vegetation sampling

Vegetation sampling for determination of plant species diversity was done at the peak blooming period of herbaceous plants during April and May 2016 and 2017. At the same time, soil cover by plants was determined by visual estimation. Herbaceous plant species were recorded within 0.25 m^2 quadrats at every 0.1 km along each transect. Plants were identified by following plant nomenclature according to Agnew and Agnew (1994). Each species encountered was categorized in terms of functional attributes, e.g. life form (grass, forb and small shrub), life span (annual and perennial), feeding merit (edible and inedible) and desirability for grazing animals (undesirable, slightly desirable, moderately desirable and highly desirable). The desirability of the identified species was based on experience of research workers, subjective opinion of the rangers and livestock keepers as well as support from literature.

Expected number of herbaceous plant species in land types

Expected number of species encountered in each land use type was estimated by using species accumulation curves according to Bunge and Fitzpatrick (1993) so as to ascertain the possibility of encountering all herbaceous plant species that exist in the study area. To establish the species accumulation curves the 'Vegan' R package (Oksanen et al. 2013) was used and the curves were fitted using the Michaelis-Menten function as follows:

$$S = (b_0 \times A_b)/(b_1 + A)$$

where:

S is the number of species (the dependent variable); A is the sampling unit (the independent variable); and b_0 and b_1 are the 2 (estimated) parameters. The best function for each land use type was chosen based on the lowest corrected Akaike Information Criterion (AICc) of the fitted model (Grueber et al. 2011).

Soil sampling

Soil samples, 0–30 cm horizon, were taken at the central point of every fourth quadrat after clipping of plants (10 samples per transect) for determination of soil texture according to the standard procedure described by Brady (1974).

Statistical analyses

Analysis of data was done using R software version 3.5.0. Shapiro test was used for testing normality of data collected. Log-transformation was applied to the data that did not conform to normal distribution so as to enable application of normally distributed analysis of data. The herbaceous plant species composition in land use types was ordinated by PCA according to Legendre and Legendre (2012). An ordination diagram was developed in order to assess species composition in relation to land use type. Pearson correlation coefficients were established among the soil texture and herbaceous species variables. One variable was chosen from highly correlated variables for inclusion in a model. Then, stepwise elimination of variables in a model was used to find out their contribution to variance observed in species ground cover across land use types.

Herbaceous plant species diversity

The plant species diversity among different land use types was determined in terms of Shannon-Wiener diversity index according to the following formula:

$$\text{Diversity Index (H)} = -\sum p_i \ln p_i$$

where:

$p_i = n_{i/N}$ is the proportion of the total number of all species in a quadrat and ln = natural logarithm to base e.

Herbaceous plant species ground cover modelling

Collinearity analysis was conducted by construction of Spearman's correlation matrix for each dataset, and if 2 variables had correlations >0.60, one variable was deleted from the model selection stage in accordance with the procedure of Zuur et al. (2009). A global mixed effects model using lmer package of R statistical software (Kuznetsova et al. 2017) was used where herbaceous species ground cover was considered as the response variable. Ground cover is an important parameter in determination of rangeland degradation due to soil erosion. The predictor variables included number of species (species richness), inedible species, edible species, undesirable species, slightly desirable species, moderately desirable species, highly desirable species, perennial species, annual species, grass species and forbs, while land use type (livestock, mixed and wildlife) was defined as a random effect. The input variables were standardized using Gelman's approach (Gelman 2008) and the dredge function in package MuMIn (Barton 2009) was used to perform automated model selection with subsets for each of the standardized global models. The best fitting model procedure was used to select the most accurate model. Model averaging was used to calculate model averaged parameters and used the second-order Akaike information criterion (AICc) (Burnham and Anderson 2002) to obtain the top model based on variables with highest relative importance.

Results

Herbaceous plant species composition across land use types

A total number of 123 herbaceous plant species from 20 families were recorded in the vegetation survey (Appendix 1). Species accumulation curves (Figure 2) indicated the highest species richness occurred in protected areas and the lowest in fallow. Results from Figure 2 further indicated that species richness reached an asymptote within sample size from different land use types. Maximum herbaceous plant species richness in different land use types fell in the ranges: 80–100, 50–60, 40–50, 15–20 and 10–15 for protected areas (Wildlife), livestock and wildlife (Mixed), continuous livestock grazing (Livestock) and Fallow respectively.

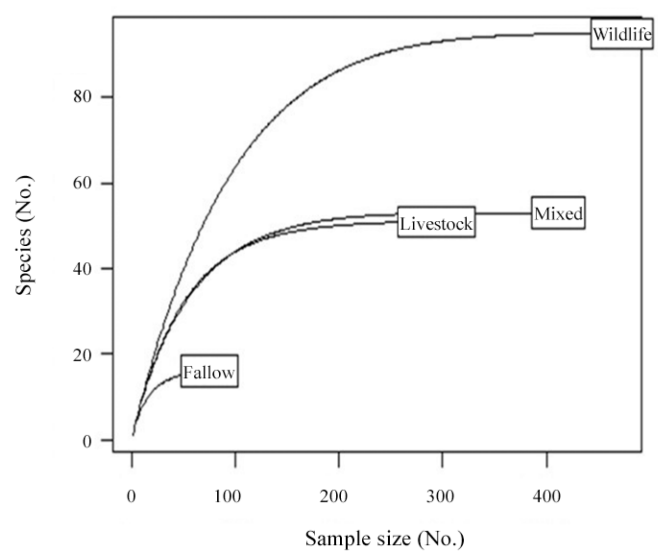

Figure 2. Herbaceous plant species accumulation curves in different land use types in western Serengeti, Tanzania.

Ordination (Figure 3) indicated shift of herbaceous species composition towards *Themeda triandra* in Wildlife grazing areas, *Cynodon dactylon* in Livestock grazing areas and *Chloris pycnothrix* in the Mixed grazing sites. Fallowing of cultivated lands developed herbaceous species composition rich in *Sphaeranthus suaveolens*.

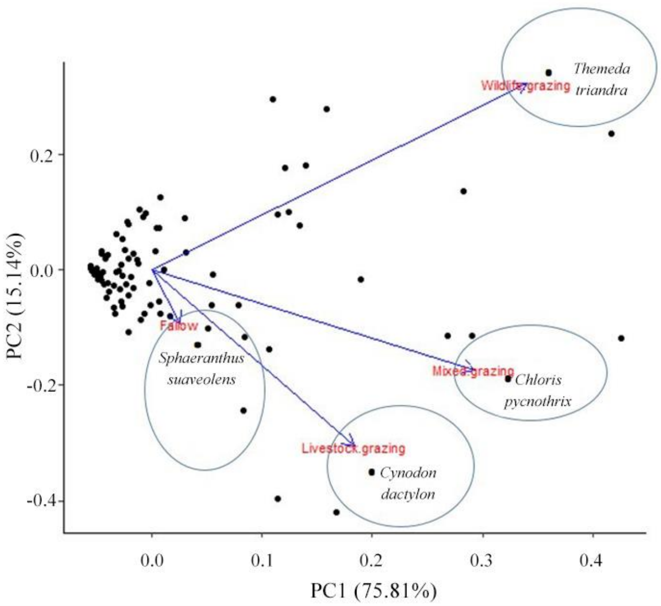

Figure 3. Ordination of plant species composition based on land use type.

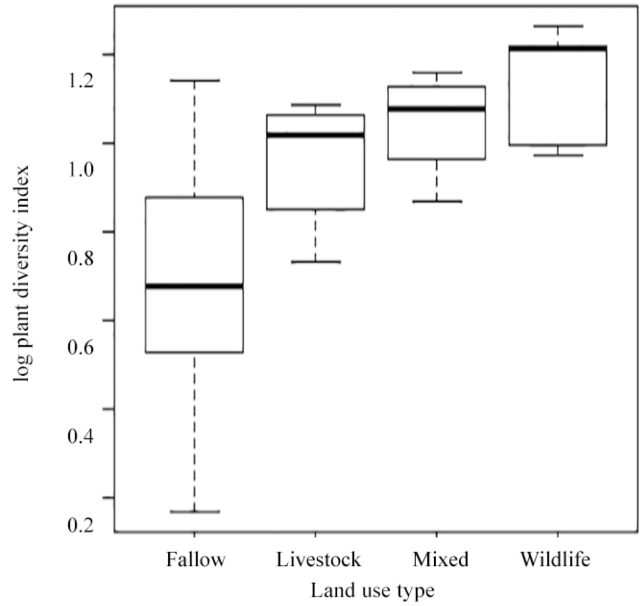

Figure 5. Comparison of herbaceous plant diversity among different land use types.

The dendrogram (Figure 4) grouped species composition into 3 clusters. Communal Livestock grazing and Mixed grazing were closely related, while plant species composition under Fallow land and Wildlife grazing were not closely related, i.e. they were rather separated from the Livestock and Mixed clusters.

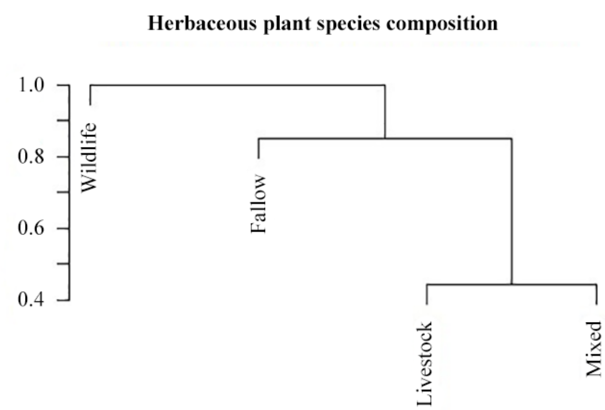

Figure 4. Cluster analysis of herbaceous plant species composition for different land uses.

Herbaceous plant species diversity

Results (Figure 5) indicated highest plant diversity in protected areas (Wildlife) and lowest in fallow lands (Fallow).

Influence of agro-pastoral activities on availability of herbaceous plant species

Figure 6a indicates that the number of species increased along transects from communal grazing lands towards protected areas as did the number of grass species (Figure 6b).

While the number of perennial species increased from communal lands (Livestock grazing) into the protected area (Wildlife grazing), the reverse was true for annual species (Figures 7a and 7b).

This indicated that annual species contributed significantly as a feed resource for livestock grazing in communal grazing lands. Plants highly desired for grazing animals were less available in communal lands than in protected areas, presumably because they were reduced by heavy grazing (Figure 8).

Availability of herbaceous plants in different land use types contributed to different patterns of ground cover. Results indicated an increase in ground cover along transects from communal grazing lands to protected areas (Figure 9). Vegetation gradients observed along transects from communal lands into protected areas indicated variation in coverage of ground by different forms of herbaceous plants.

Numbers of undesirable herbaceous plant species were higher in communal grazing lands and declined towards the protected area (Figure 10).

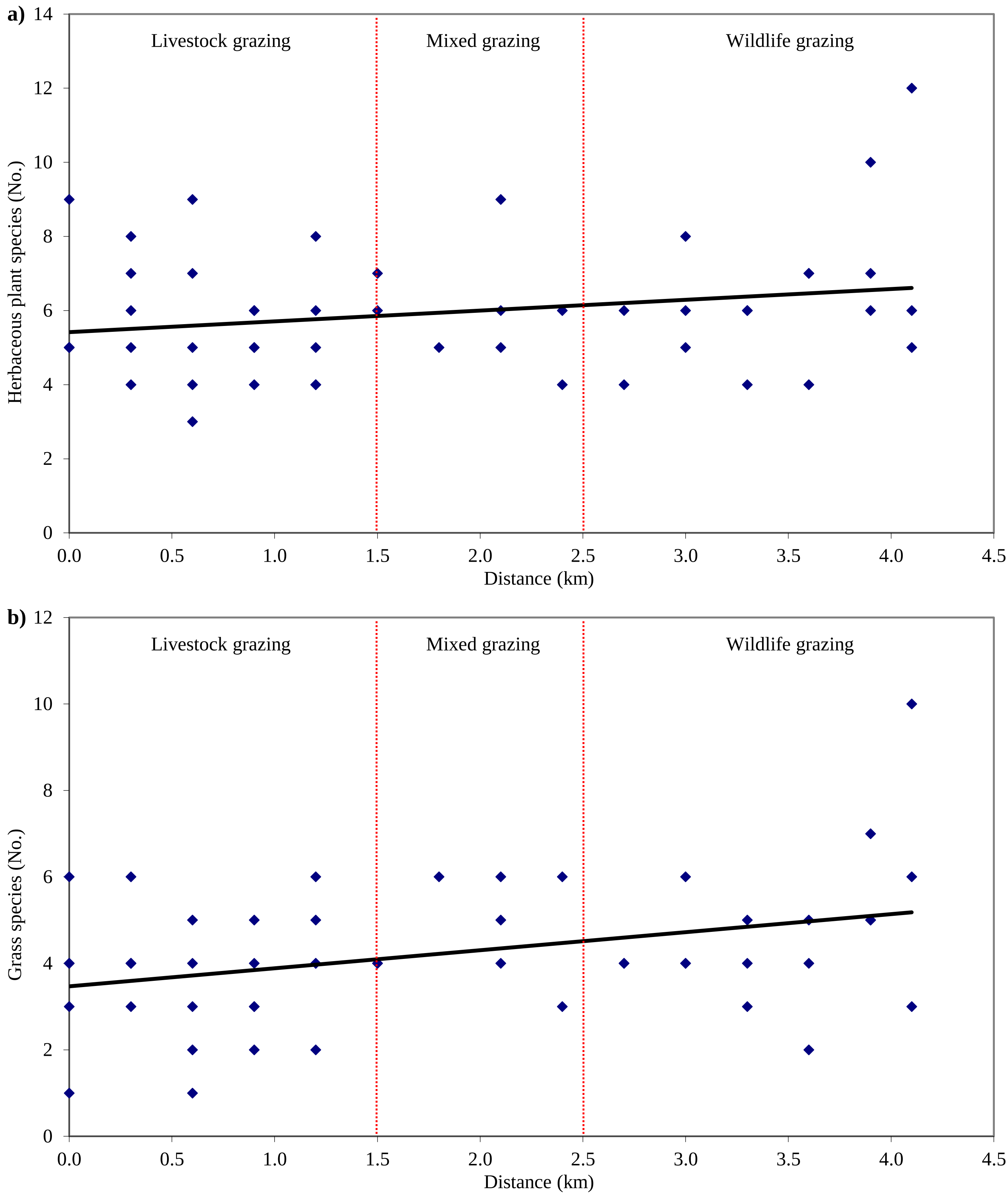

Figure 6. Availability of herbaceous plant species in western Serengeti as a function of location (distance from village to protected areas) and grazing strategy: a) all species; b) grasses only.

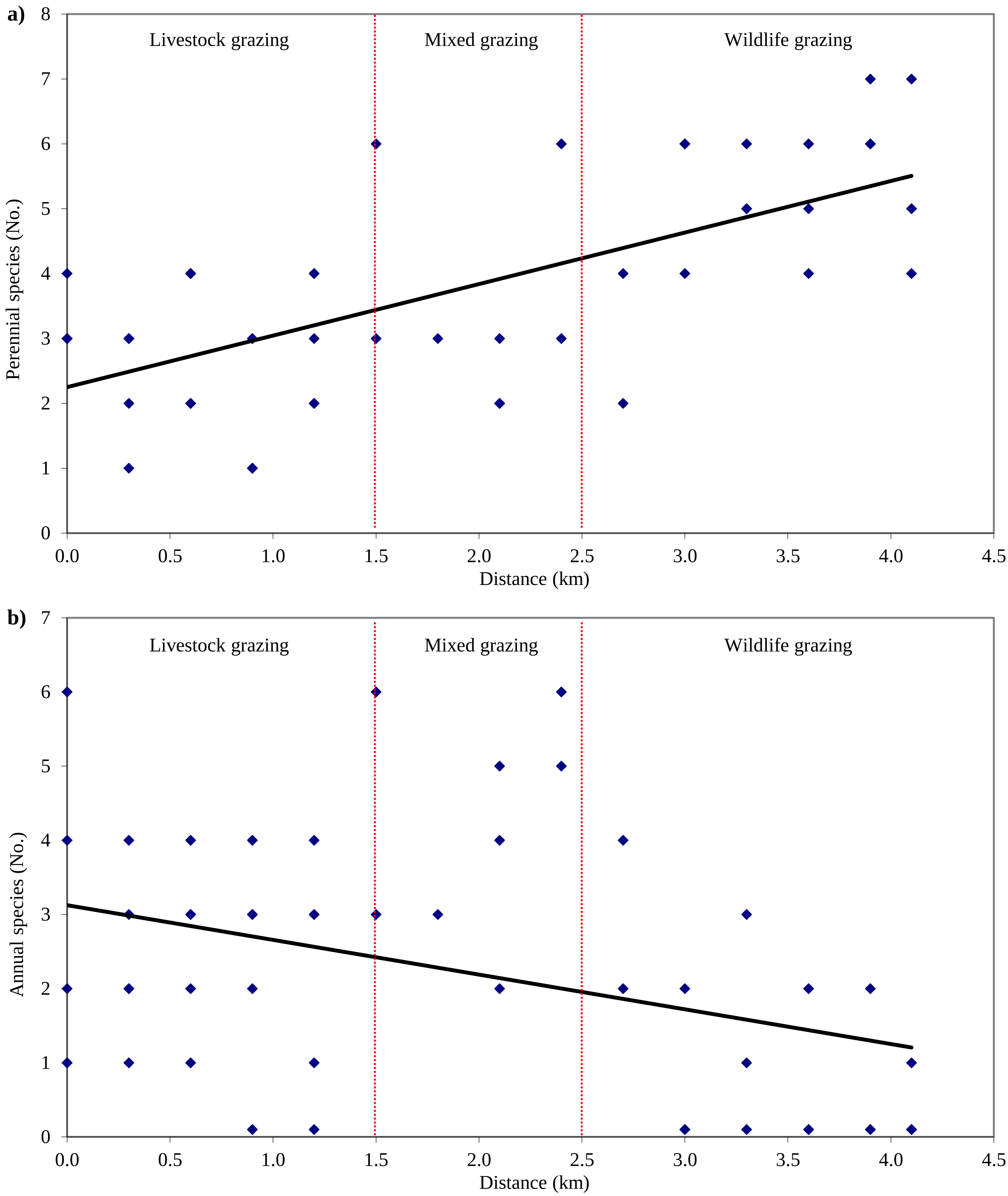

Figure 7. Availability of perennial (a) and annual (b) species as a function of location (distance from village to protected areas) and grazing strategy.

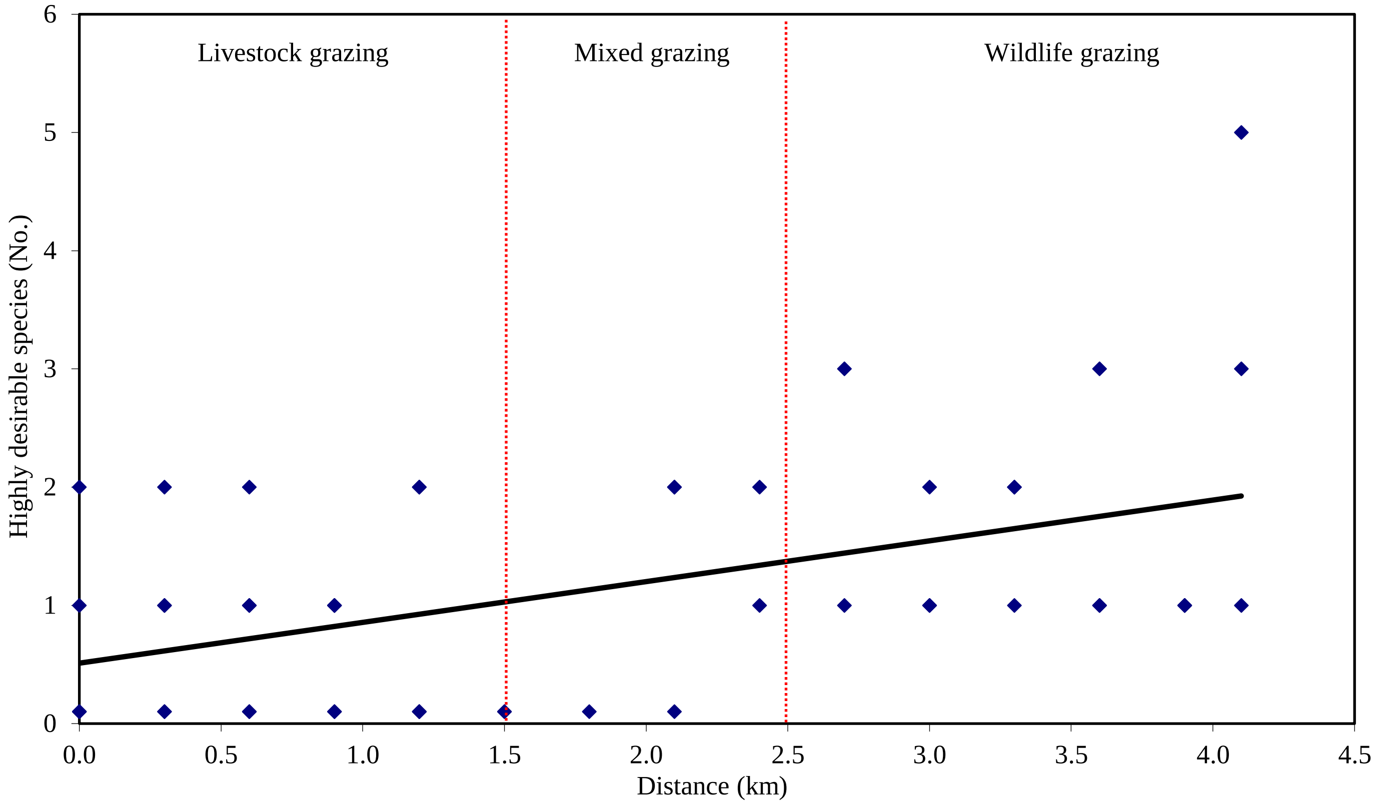

Figure 8. Availability of highly desirable herbaceous plants as a function of location (distance from village to protected areas) and grazing strategy.

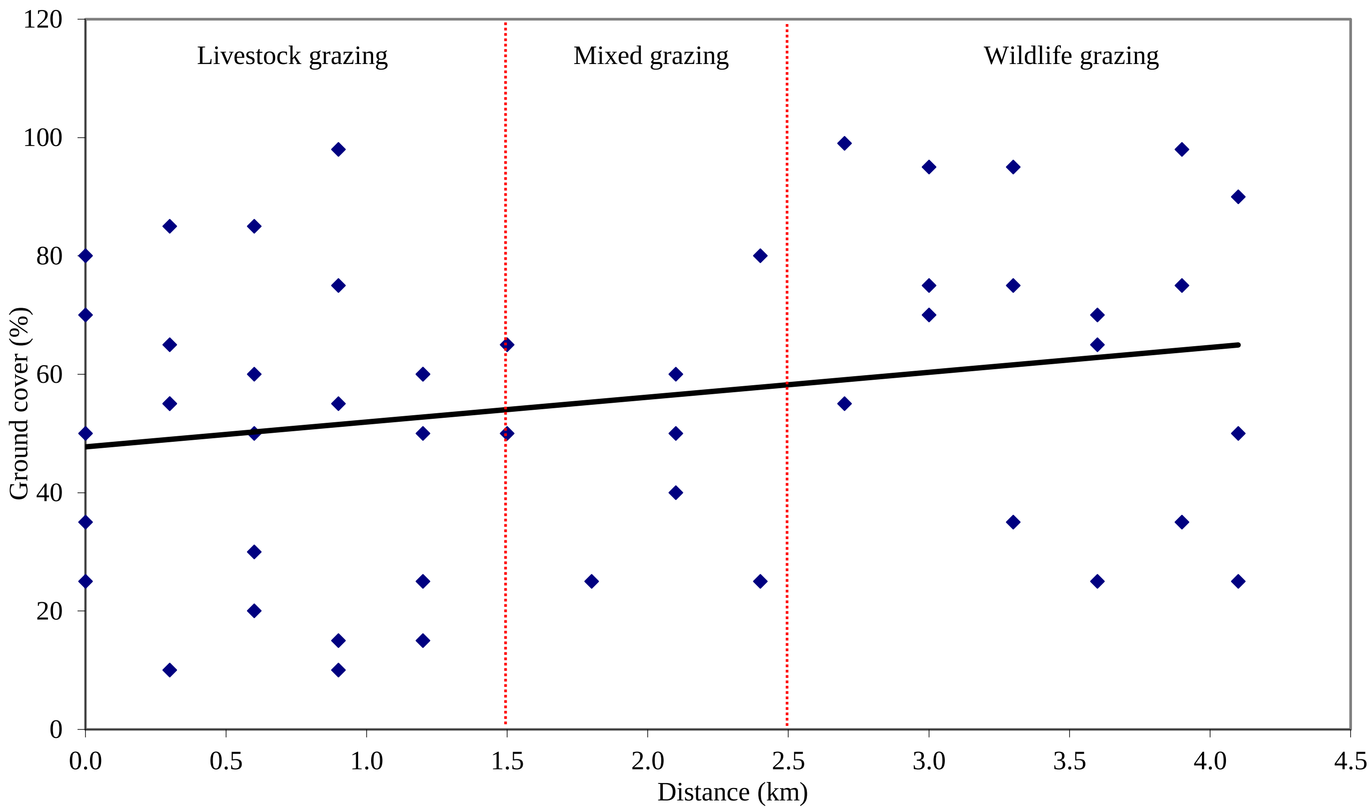

Figure 9. Ground cover of herbaceous plants as a function of location (distance from village to protected areas) and grazing strategy.

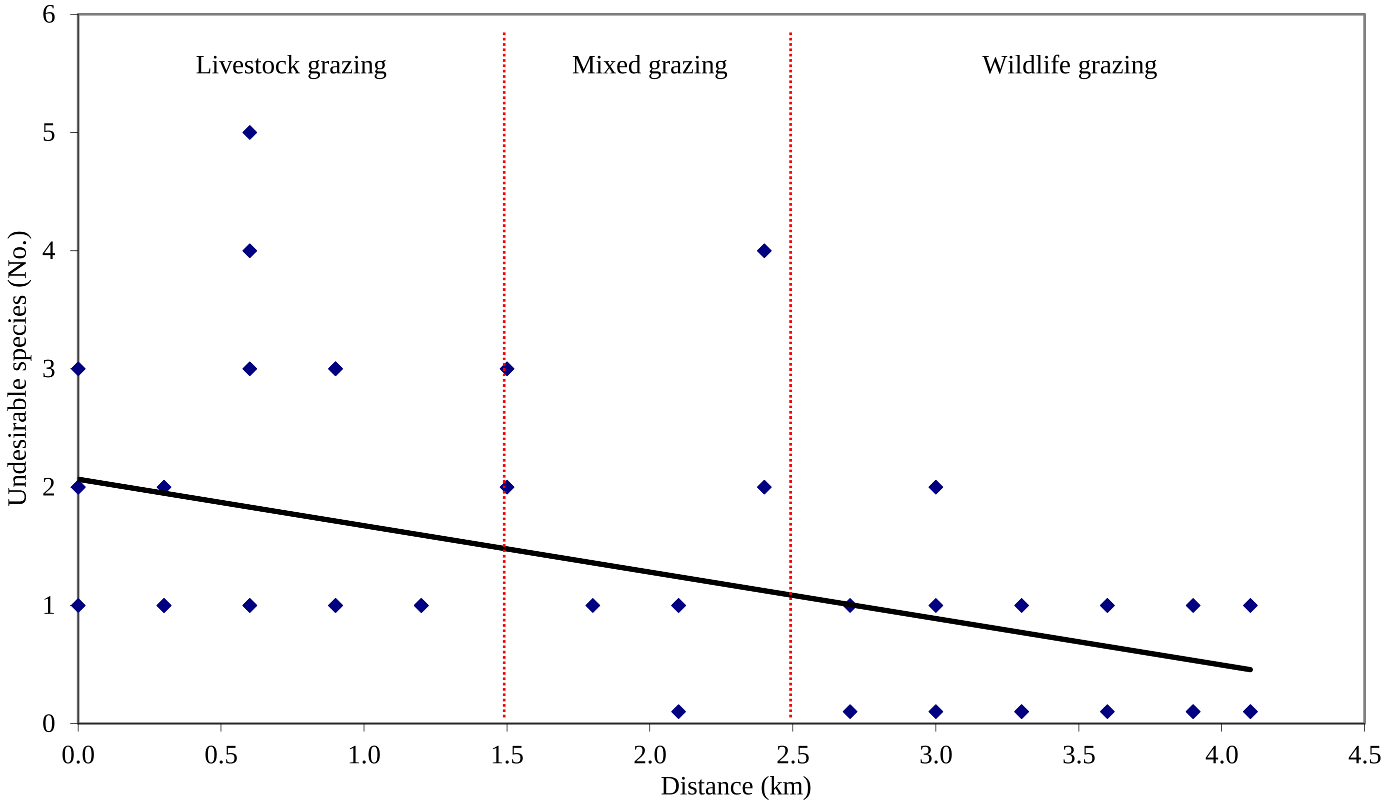

Figure 10. Undesirable herbaceous plants as a function of location (distance from village to protected areas) and grazing strategy.

Herbaceous plant ground cover model

Top model variables are shown in Table 1 along with their rankings that were used for selection of variables for the final model.

Contributions by variables, such as soil texture (clay, sand and silt), life span (perennial and annual species), desirability for grazing animals (undesirable, slightly desirable, moderately desirable and highly desirable), species richness and land use type, to the variance observed in herbaceous plant species ground cover were evaluated by coefficient of determination (R^2) of the model formed by exclusion of either a group or a single variable (Table 2).

Land use type was included in Model 1 as a random effect that encompassed: high grazing pressure in communal lands due to continuous livestock grazing; intermediate grazing pressure on borders between communal and protected lands due to mixed grazing of livestock and wildlife; and low grazing pressure due to wildlife grazing on large protected areas. Coefficient of determination in Model 1 indicated that almost 68% of the variance in herbaceous plant species ground cover was attributed to other factors not considered in the model. The difference in terms of coefficients of determination between Model 1 and Model 2 indicated that land use type contributed <1% of the variance observed in herbaceous plant ground cover. Differences in coefficients of determination among Models 2, 3, 4 and 5 indicated the contributions of desirability of plant species, species richness, plant life span and soil texture to variance in herbaceous plant ground cover were 6.8, 5.7, 6.6 and 12.6%, respectively. This shows little contribution of soil texture to establishment of herbaceous species under grazing pressure in the western Serengeti. The model shows also little influence of soil texture (clay, silt and sand), plant life span (annual or perennial), plant desirability for grazing animals (undesirable, slightly desirable, moderately desirable and highly desirable) and plant species richness on ground cover under grazing in western Serengeti.

Table 1. Products of automated model selection of different soil texture and vegetation variables.

Parameter	Coefficient	s.e.	z Value	Pr (>z)	Significance	Relative importance of variable
Intercept	-2104.9	722.6	2.717	0.00409	**	
Clay	21.450	7.251	2.916	0.00355	**	1.00
Slightly desirable species	-4.167	2.136	1.922	0.05465	NS	0.68
Perennial species	2.302	1.229	1.845	0.06499	NS	0.66
Sand	21.514	7.222	7.327	0.00332	**	1.00
Silt	20.568	7.316	2.771	0.00558	**	1.00
Species richness	3.238	1.260	2.533	0.01131	*	1.00
Undesirable species	4.284	2.349	1.687	0.09155	NS	0.54
Forbs	2.111	1.765	1.178	0.23881	NS	0.09

Table 2. Herbaceous plant ground cover variation attributed to different variables.

Model	R^2 (%)
Model 1: GrC = Clay+Sand+Silt+ASp+PSp+SR+MDS+SDS+MDS+HDS+UDS+LTYP	31.9
Model 2: GrC = Clay+Sand+Silt+ASp+SDS+PSp+SR+MDS+HDS+UDS	31.6
Model 3: GrC = Clay+Sand+Silt+ASp+PSp+ SR	24. 9
Model 4: GrC = Clay+Sand+Silt+ASp+PSp	19.2
Model 5: GrC = Clay+Sand+Silt	12.6

GrC = Ground cover; ASp = Annual species; PSp = Perennial species; SR = Species richness; SDS = Slightly desirable species; MDS = Moderately desirable species; HDS = Highly desirable species; UDS = Undesirable species; and LTYP = Land use type.

Discussion

This study has highlighted the relationships among agro-pastoral activities, herbaceous plant attributes, wildlife conservation and soil texture in western Serengeti, contributing to our knowledge of how these factors impact on the prevalence and sustainability of herbaceous plants in the ecosystem.

Plant species diversity is commonly used as one of the important indices of determining ecosystem status, i.e. the health of the system (Sharafatmandrad et al. 2014), and species diversity, richness and composition present in an ecosystem determine organismal traits that influence ecosystem processes (Chapin III et al. 2000). Diversity of plant species plays an important role in water purification, climate mitigation, air quality improvement and prevention of soil erosion (Pyne 1997). The lower numbers of herbaceous species (10–50 species) in areas highly involved in agro-pastoral activities (Figure 2), i.e. Fallow, Livestock and Mixed land use types, than in protected Wildlife areas (80–100 species) is not surprising. It is in agreement with findings by Luna-Jorquera et al. (2011), who described level of human impact as the main variable that explained variation in species composition of vegetation in British Columbia's southern Gulf Islands. Figure 4 in our study shows that the Fallow cluster (rested cultivated areas) was separate from the Livestock and Mixed clusters implying that the effect of cultivation on herbaceous plant species composition is different from the effect caused by grazing animals.

Results from this study agree with research conducted by Buba (2016) in Nigeria that showed a decrease in species composition following cultivation. After repeated cultivation, land that is fallowed to allow it to recover could not be expected to display a wide array of species as seed supplies of many plant species would be depleted over time. A similar situation, but possibly to a lesser degree, could be expected on areas grazed continuously by livestock. Poor management practices such as keeping of large herds of livestock within a small grazing area or grazing continuously on the same range area for the whole year exert pressure on edible herbaceous species, especially highly palatable ones, limiting recovery of grazed plants. Unlimited expansion of cultivated land involving land clearing and weeding reduces the array of herbaceous species on cropped areas and fallow lands. Studies conducted in different ecosystems by Johnstone et al. (2016) showed that disturbance altered the state of ecosystems, making them prone to degradation: large areas of protected pastures and restriction of human activities resulted in low pressure on herbaceous plants and consequently more diverse species composition.

The increase in herbaceous species richness from village land towards protected areas (Figure 7a) indicates that agro-pastoral activities conducted in the village caused a decline in number of perennial herbaceous species and an increase in annual species. Bare areas within village lands started at about 600 m from the village-protected area boundary, occurring in overgrazed areas, crop farms and settlements. Analogous to this study, Coppolillo (2000) reported from the Sukuma agro-pastoral system in Rukwa Valley, Tanzania, that more settlements (and more cattle) depleted grazing resources and forced herds to travel farther away from the settlements to find suitable and palatable forage.

As well as providing the feed resource base for ruminants, the herbaceous plants particularly grasses serve other important roles including water retention, biodiversity reserves, cultural and recreational needs and potentially a carbon sink to reduce greenhouse gas emissions (Boval and Dixon 2012). The number of grass species, especially perennials, increased along transects from communal grazing lands towards protected areas as also reported by Sabo et al. (2009) and Pour et al. (2012). Perennial grasses are very important in rangeland health as they are usually more productive than annuals, allow extended grazing periods and improve soil quality as their extended root zones enable recapture of leached nutrients and water (Manahan 2007). Unavailability of perennial grasses in communal grazing lands reduces forage availability within village lands, increasing intrusion of livestock into protected areas and resulting in border disputes. Land clearing for crop farming involves uprooting of perennial grasses, which are considered as notorious weeds in crops, and continuous heavy grazing limits the ability of perennial grasses to set seed for perpetuation of the species. While fallowing of crop farms could possibly increase availability of perennial grasses in communal lands, cultivation in village lands usually opens up new niches and encourages the proliferation of annual forbs (Davis et al. 2000).

Vegetation is usually considered a good indicator of rangeland condition with poor condition described as low grass cover, preponderance of grasses of low palatability, change in species composition where annuals replace perennials as the dominant herbaceous species, and increase in bush encroachment (Bayene 2003). Results from this study (Figure 8b) support this hypothesis, suggesting the current agro-pastoral practices in villages of western Serengeti contribute significantly to rangeland deterioration. Highly desirable herbaceous species, such as the grasses *Brachiaria semiundulata*, *Digitaria milanjiana*, *Cenchrus ciliaris* and *Panicum coloratum*, were more plentiful in protected areas than in communal grazing lands (Figure 9). In contrast, undesirable herbaceous species were more plentiful in communal grazing land than in protected areas (Figure 10).

Changes in species composition are central to grazing land management for sustainable production and conservation of plant species diversity. According to Crawley (1997) grazing-sensitive or highly desirable species decline in abundance, while undesirable plant species become more abundant under high grazing pressure. The decline in highly desirable and increase in undesirable herbaceous species in communal grazing lands as observed in this study indicate existence of high grazing pressure.

According to Naylor et al. (2002) the major effects of vegetation on soil are bio-protection and bio-construction. Plant cover protects soil against erosion by reducing water runoff (Rey 2003; Puigdefábregas 2005; Durán Zuazo et al. 2006, 2008) and by increasing water infiltration into the soil matrix (Ziegler and Giambelluca 1998; Wainwright et al. 2002). Herbaceous plant ground cover increased from communal grazing lands to protected areas in our study. Communal grazing lands with limited plant cover, especially of perennial species, are vulnerable to soil erosion, leading to poor soil condition and consequently low plant productivity, if the situation is not reversed.

While there were suggestions that soil type affects the range of species present in different locations (Cottle 2004), the overall absence of significant relationships between soil texture and species composition observed in this study indicated that other factors like grazing pressure had the major influence on pasture species growing at different locations. The model developed in the present study indicated that plants and soil texture had small influence on ground cover of herbaceous plants in western Serengeti. This supports other studies that showed rainfall as a major factor influencing ground cover in Sub-Saharan Africa (Ellis and Swift 1988; Oba et al. 2000). It implies that linkage of climatic variables, plants and grazing could provide better understanding of dynamics of herbaceous plant ground cover in western Serengeti. Oba et al. (2000) emphasized that climate is the principal driver of ground cover and biomass dynamics, while grazing influences biomass, species diversity and the efficiency with which plants use rainwater.

Our study indicated perennial herbaceous species were present in all areas though at a lower frequency in communal areas than in protected areas. This indicates the possibility of rejuvenation of perennial herbaceous plants in presence of rainfall by resting of grazing land as shown by Hughes (2002), where frequency of perennial grasses increased in Arizona after resting from livestock grazing. A study conducted by Oduor et al. (2018) in a semi-arid rangeland in Kenya showed a higher percentage of perennial grasses in enclosures than in open grazing areas supporting the hypothesis that grazing lands can be rejuvenated by restricting livestock grazing. Reece et al.

(2007) showed deferring grazing, when air temperature and soil water were simultaneously favorable, helped to maintain and improve vigor of grasses in grazing lands because rapid growth of grasses could occur under these positive conditions for plant growth. Therefore understanding of how plants grow and how environmental factors affect their growth is critical for planning restoration of herbaceous plants in grazing lands.

Conclusions

- Current agro-pastoral activities carried out in western Serengeti affected herbaceous plant diversity and availability of highly desirable plant species.
- Cultivation, continuous livestock grazing and settlements reduced the diversity of herbaceous species in village lands.
- The array of pasture species still present in communal grazing areas suggests that rejuvenation of these areas could be still possible if different management strategies were adopted.

Recommendations

- Rehabilitation of denuded lands in village areas is imperative if the current trend of declining perennial and highly desirable herbaceous species is to be reversed to ensure future availability of feed resources for grazing animals in village lands.
- New strategies that involve resting of grazing lands should be developed with the aim of making livestock grazing sustainable and productive in communal lands. The better condition of pastures in wildlife areas with greater species diversity indicates that managing village areas in a similar way could improve the condition of pastures in communal areas

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Appendix 1. Plant species encountered during vegetation survey (taxonomy according to the Plant List (theplantlist.org).

	Species	Life form	Life span	Merit	Utilization	Desirability
1	*Abutilon mauritianum* (Jacq.) Medik. (Malvaceae)	Shrub	Annual	Edible	Eaten by livestock and wildlife	Desirable
2	*Achyranthes aspera* L. (Amaranthaceae)	Forb	Annual	Edible	Wildlife (seeds eaten by birds)	Less desirable
3	*Aeschynomene indica* L. (Leguminosae)	Forb	Annual	Edible	Eaten by livestock and wildlife	Less desirable
4	*Albuca kirkii* (Baker) Brenan (Asparagaceae)	Bulb	Perennial	Inedible	None (rodents)	Undesirable
5	*Alternanthera pungens* Kunth (Amaranthaceae)	Forb	Perennial	Inedible	None	Undesirable
6	*Andropogon greenwayi* Napper (Poaceae)	Grass	Perennial	Edible	Wildlife (wildebeest, buffalo, gazelle)	Desirable
7	*Aristida adoensis* Hochst. ex A. Rich. (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Less desirable
8	*Aristida kenyensis* Henrard (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Desirable
9	*Asparagus africanus* Lam. (Asparagaceae)	Forb	Perennial	Edible	Eaten by livestock (especially goats)	Less desirable
10	*Aspilia mossambicensis* (Oliv.) Wild (Compositae)	Shrub	Perennial	Inedible	None (medicinal for chimpanzees)	Undesirable
11	*Bidens schimperi* Sch.Bip. ex Walp. (Compositae)	Forb	Annual	Edible	Eaten by livestock	Less desirable
12	*Blepharis linariifolia* Pers. (Acanthaceae)	Forb	Perennial	Inedible	None (medicinal)	Undesirable
13	*Blepharis maderaspatensis* (L.) B. Heyne ex Roth (Acanthaceae)	Forb	Perennial	Edible	Eaten by livestock (particularly flowers)	Less desirable
14	*Bothriochloa insculpta* (A. Rich.) A. Camus (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Desirable
15	*Brachiaria brizantha* (A. Rich.) Stapf (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Highly desirable
16	*Brachiaria jubata* (Fig. & De Not.) Stapf (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Highly desirable
17	*Brachiaria semiundulata* (Hochst.) Stapf (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Highly desirable
18	*Brachiaria serrata* (Thunb.) Stapf (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Highly desirable
19	*Cenchrus ciliaris* L. (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Highly desirable
20	*Centrapalus pauciflorus* (Willd.) H. Rob. (Compositae)	Forb	Annual	Edible	Eaten by livestock and wildlife	Less desirable
21	*Chamaecrista mimosoides* (L.) Greene (Leguminosae)	Forb	Annual	Inedible	None	Undesirable
22	*Chloris gayana* Kunth (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Highly desirable
23	*Chloris pycnothrix* Trin. (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Desirable
24	*Chloris virgata* Sw. (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Desirable
25	*Chrysochloa orientalis* (C.E. Hubb.) Swallen (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Less desirable
26	*Cleome monophylla* L. (Cleomaceae)	Forb	Annual	Inedible	None	Undesirable
27	*Clitoria ternatea* L. (Leguminosae)	Forb	Perennial	Edible	Eaten by livestock and wildlife	Highly desirable
28	*Commelina africana* L. (Commelinaceae)	Forb	Perennial	Edible	Eaten by livestock and wildlife	Desirable
29	*Commelina aspera* G. Don ex Benth. (Commelinaceae)	Forb	Annual	Edible	Eaten by livestock and wildlife	Desirable
30	*Commelina benghalensis* L. (Commelinaceae)	Forb	Perennial	Edible	Eaten by livestock and wildlife	Desirable
31	*Corchorus aestuans* L. (Malvaceae)	Forb	Annual	Edible	Preferably eaten by rabbits	Desirable
32	*Corchorus trilocularis* L. (Malvaceae)	Forb	Annual	Inedible	None	Undesirable
33	*Craterostigma plantagineum* Hochst. (Linderniaceae)	Forb	Perennial	Inedible	None	Undesirable
34	*Crotalaria spinosa* Benth. (Leguminosae)	Forb	Annual	Inedible	None	Undesirable
35	*Cycnium tubulosum* (L. f.) Engl. (Orobanchaceae)	Forb	Perennial	Inedible	None	Undesirable
36	*Cymbopogon caesius* (Hook. & Arn.) Stapf (Poaceae)	Grass	Perennial	Inedible	None	Undesirable
37	*Cynodon dactylon* (L.) Pers. (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Desirable
38	*Cynodon plectostachyus* (K. Schum.) Pilg. (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Desirable
39	*Cyperus dubius* Rottb. (Cyperaceae)	Sedge	Perennial	Edible	Eaten by livestock and wildlife	Less desirable
40	*Cyperus pulchellus* R. Br. (Cyperaceae)	Sedge	Perennial	Edible	Eaten by livestock and wildlife	Desirable
41	*Cyphostemma serpens* (Hochst. ex A. Rich.) Desc. (Vitaceae)	Forb	Perennial	Inedible	None	Undesirable
42	*Dactyloctenium aegyptium* (L.) Willd. (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Less desirable
43	*Desmodium tortuosum* (Sw.) DC. (Leguminosae)	Forb	Annual	Edible	Eaten by livestock and wildlife	Desirable
44	*Digitaria abyssinica* (A. Rich.) Stapf (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Desirable
45	*Digitaria bicornis* (Lam.) Roem. & Schult. (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Highly desirable
46	*Digitaria eriantha* Steud. (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Highly desirable

47	*Digitaria longiflora* (Retz.) Pers. (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Highly desirable
48	*Digitaria* macroblephara (Hack.) Paoli (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Highly desirable
49	*Digitaria milanjiana* (Rendle) Stapf (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Highly desirable
50	*Digitaria ternata* (A. Rich.) Stapf (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Less desirable
51	*Dyschoriste radicans* (Hochst. ex A. Rich.) Nees (Acanthaceae)	Forb	Perennial	Inedible	None	Undesirable
52	*Echinochloa pyramidalis* (Lam.) Hitchc. & Chase (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Highly desirable
53	*Eleusine indica* (L.) Gaertn. (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Less desirable
54	*Eragrostis aspera* (Jacq.) Nees (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Desirable
55	*Eragrostis cilianensis* (All.) Janch. (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife (but unpleasant odor when fresh)	Less desirable
56	*Eragrostis patula* (Kunth) Steud. (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Desirable
57	*Eragrostis racemosa* (Thunb.) Steud. (Poaceae)	Grass	Perennial	Edible	Wildlife (buffalo, elephant)	Desirable
58	*Euphorbia inaequilatera* Sond. (Euphorbiaceae)	Forb	Annual	Inedible	None	Undesirable
59	*Eustachys paspaloides* (Vahl) Lanza & Mattei (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Highly desirable
60	*Gomphrena globosa* L. (Amaranthaceae)	Forb	Annual	Edible	Eaten by livestock	Less desirable
61	*Gutenbergia cordifolia* Benth. ex Oliv. (Compositae)	Forb	Annual	Inedible	Pollinators	Undesirable
62	*Gutenbergia petersii* Steetz (Compositae)	Forb	Annual	Inedible	None	Undesirable
63	*Harpachne schimperi* A. Rich. (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Desirable
64	*Heliotropium steudneri* Vatke (Boraginaceae)	Forb	Annual	Edible	Wildlife (tortoise)	Less desirable
65	*Heteropogon contortus* (L.) P. Beauv. ex Roem. & Schult. (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife (when young)	Desirable
66	*Hygrophila auriculata* (Schumach.) Heine (Acanthaceae)	Forb	Annual	Inedible	None	Undesirable
67	*Hyparrhenia hirta* (L.) Stapf (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Less desirable
68	*Hyperthelia dissoluta* (Nees ex Steud.) Clayton (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Less desirable
69	*Hypoxis hirsuta* (L.) Coville (Hypoxidaceae)	Forb	Perennial	Inedible	None	Undesirable
70	*Indigofera basiflora* J.B. Gillett (Leguminosae)	Shrub	Perennial	Inedible	None	Undesirable
71	*Indigofera hochstetteri* Baker (Leguminosae)	Forb	Perennial	Inedible	None	Undesirable
72	*Indigofera spicata* Forssk. (Leguminosae)	Forb	Perennial	Inedible	None	Undesirable
73	*Indigofera volkensii* Taub. (Leguminosae)	Forb	Perennial	Edible	Eaten by livestock (especially sheep)	Less desirable
74	*Ipomoea mombassana* Vatke (Convolvulaceae)	Forb	Perennial	Inedible	None	Undesirable
75	*Justicia betonica* L. (Acanthaceae)	Forb	Perennial	Edible	Eaten by livestock and wildlife	Desirable
76	*Justicia exigua* S. Moore (Acanthaceae)	Forb	Annual	Edible	Eaten by livestock and wildlife	Highly desirable
77	*Justicia glabra* K.D. Koenig ex Roxb. (Acanthaceae)	Forb	Perennial	Inedible	None	Undesirable
78	*Justicia matammensis* (Schweinf.) Oliv. (Acanthaceae)	Forb	Perennial	Inedible	None	Undesirable
79	*Kyllinga nervosa* Steud. (Cyperaceae)	Sedge	Perennial	Edible	Eaten by livestock and wildlife	Desirable
80	*Kyllinga odorata* Vahl (Cyperaceae)	Sedge	Perennial	Edible	Eaten by livestock and wildlife	Desirable
81	*Lactuca inermis* Forssk. (Compositae)	Forb	Perennial	Inedible	None	Undesirable
82	*Lactuca virosa* Habl. (Compositae)	Forb	Annual	Inedible	None	Undesirable
83	*Lepidagathis scabra* C.B. Clarke (Acanthaceae)	Forb	Perennial	Inedible	None	Undesirable
84	*Leucas aspera* (Willd.) Link (Lamiaceae)	Forb	Annual	Inedible	None (medicinal)	Undesirable
85	*Leucas deflexa* Hook. f. (Lamiaceae)	Forb	Perennial	Inedible	None	Undesirable
86	*Leucas martinicensis* (Jacq.) R. Br. (Lamiaceae)	Forb	Perennial	Inedible	None	Undesirable
87	*Macroptilium atropurpureum* (DC.) Urb. (Leguminosae)	Forb	Perennial	Edible	Eaten by livestock and wildlife	Desirable
88	*Melhania ovata* Spreng. (Malvaceae)	Forb	Perennial	Inedible	None	Undesirable
89	*Microchloa kunthii* Desv. (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Less desirable
90	*Mollugo nudicaulis* Lam. (Molluginaceae)	Forb	Annual	Inedible	None	Undesirable
91	*Ocimum basilicum* L. (Lamiaceae)	Shrub	Perennial	Inedible	None	Undesirable
92	*Ocimum gratissimum* L. (Lamiaceae)	Shrub	Perennial	Inedible	None	Undesirable
93	*Ormocarpum kirkii* S. Moore (Leguminosae)	Shrub	Perennial	Inedible	None	Undesirable
94	*Ormocarpum* trichocarpum (Taub.) Engl. (Leguminosae)	Shrub	Perennial	Inedible	None	Undesirable
95	*Oxygonum sinuatum* (Hochst. ex Steud. & Meisn.) Dammer (Polygonaceae)	Forb	Annual	Inedible	None	Undesirable
96	*Panicum coloratum* L. (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Highly desirable
97	*Panicum maximum* Jacq. (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Highly desirable
98	*Pennisetum mezianum* Leeke (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Less desirable
99	*Portulaca oleracea* L. (Portulacaceae)	Forb	Annual	Edible	Eaten by livestock	Less desirable

100	*Portulaca quadrifida* L. (Portulacaceae)	Forb	Annual	Edible	Eaten by livestock (rich in vitamins E, A and C)	Desirable
101	*Rhynchosia minima* (L.) DC. (Leguminosae)	Forb	Perennial	Edible	Eaten by livestock and wildlife	Desirable
102	*Senna occidentalis* (L.) Link (Leguminosae)	Shrub	Annual	Inedible	None (bitter taste)	Undesirable
103	*Sesbania sesban* (L.) Merr. (Leguminosae)	Shrub	Perennial	Edible	Eaten by livestock and wildlife	Desirable
104	*Setaria pumila* (Poir.) Roem. & Schult. (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Desirable
105	*Setaria sphacelata* (Schumach.) Stapf & C.E. Hubb. ex Moss (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Highly desirable
106	*Setaria verticillata* (L.) P. Beauv. (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Desirable
107	*Sida acuta* Burm. f. (Malvaceae)	Forb	Perennial	Edible	Eaten by livestock and wildlife	Desirable
108	*Solanum incanum* L. (Solanaceae)	Shrub	Perennial	Edible	Wildlife (rhino, butterflies)	Less desirable
109	*Sphaeranthus suaveolens* (Forssk.) DC. (Compositae)	Forb	Perennial	Inedible	None	Undesirable
110	*Sporobolus africanus* (Poir.) Robyns & Tournay (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Less desirable
111	*Sporobolus cordofanus* (Hochst. ex Steud.) Hérincq ex Coss. (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Desirable
112	*Sporobolus festivus* Hochst. ex A. Rich. (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Desirable
113	*Sporobolus ioclados* (Trin.) Nees (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Desirable
114	*Sporobolus pyramidalis* P. Beauv. (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Less desirable
115	*Tagetes minuta* L. (Compositae)	Forb	Annual	Inedible	None	Undesirable
116	*Talinum portulacifolium* (Forssk.) Asch. ex Schweinf. (Talinaceae)	Forb	Perennial	Edible	Eaten by livestock	Desirable
117	*Tephrosia pumila* (Lam.) Pers. (Leguminosae)	Forb	Perennial	Inedible	None	Undesirable
118	*Themeda triandra* Forssk. (Poaceae)	Grass	Perennial	Edible	Eaten by livestock and wildlife	Desirable
119	*Tragus berteronianus* Schult. (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Desirable
120	*Tribulus terrestris* L. (Zygophyllaceae)	Forb	Annual	Inedible	None	Undesirable
121	*Triumfetta rhomboidea* Jacq. (Malvaceae)	Forb	Annual	Inedible	None	Undesirable
122	*Urochloa brachyura* (Hack.) Stapf (Poaceae)	Grass	Annual	Edible	Eaten by livestock and wildlife	Desirable
123	*Xanthium strumarium* L. (Compositae)	Shrub	Annual	Inedible	None	Undesirable

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