INFLUENCE OF AGRO-PASTORALISM ON HERBACEOUS PLANTS DIVERSITY AND LIVELIHOOD OF COMMUNITIES IN WESTERN SERENGETI

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EXTENDED ABSTRACT

The study was undertaken to assess the influence of agro-pastoralism on diversity of herbaceous plants and its contribution to the livelihood of people in western Serengeti. Agro-pastoralism is an integrated practice of growing crops and keeping of livestock as a livelihood strategy practiced by communities in rural areas and relies on environmental factors including rainfall, soil and vegetation. It is practiced in western Serengeti and other parts of Tanzania with an aim of increasing household food security and income. The Serengeti ecosystem contains biodiversity of natural biological resources of which human depend on for livelihood, survival and development. Local communities in Serengeti ecosystem perceive that cropland and pastureland provide immediate benefits than conservation of natural resources biodiversity. The agro-pastoral activities involve land clearing that consequently impact negatively on vegetation structure and plant species composition. This implies conflicting goals between agro-pastoralism and biodiversity conservation as a tendency to maximize services from agro-pastoralism results in overutilization and removal of plants that consequently affect plant diversity.

This thesis investigates the ecological outcomes of agro-pastoral practices applied adjacent to protected areas in western Serengeti and their potential impacts on herbaceous plant species diversity, aiming at identifying agro-pastoral activities that affect negatively species diversity. An interdisciplinary methodological approach was applied combining conventional analytical frameworks used in biological conservation science i.e., direct measures of diversity such as species composition, richness and social analytical tools. First, through a review of the literature of the agro-pastoralists' livelihood. This study examined agro-pastoral production and its contribution to the livelihood of communities in western Serengeti. This research explored the effectiveness of protected areas on conserving herbaceous plant species diversity compared to traditional agro-pastoral

management system practiced in village lands. Data on botanical inventories as well as edaphic and anthropogenic impacts were collected along established transects.

For the first objective, secondary data was used to evaluate contribution of agro-pastoralism on livelihood of people in western Serengeti. The data were collected from published and unpublished reports on agro-pastoralism, socio-economic, national, regional, districts and area-specific issues to synthesize information that depicted agro-pastoralism in western Serengeti. This was done by using various search engines and data sources to establish the body of knowledge concerning the subject. The review involved a pre-defined search protocol using filters for keywords to audit search relevance and relevant literature was searched with Google Scholar.

The data for second, third and the fourth objectives were obtained from randomized design with 4 factors and 2 replications. The factors included (1) village land that included communal and private grazing lands that were within villages; (2) protected area that include Serengeti National Park, Maswa and Ikorongo Game Reserves and Makao Wildlife Management Area (WMA). Replications involved two 4000 m transects that extended from village land to protected land. Response variables were considered in each block that included plant species and soil properties.

The results shown in the first study revealed that the human population in western Serengeti increased from 400 000 people in 1967 to 1 400 000 people in 2016. Increase in human population triggered the need for food sufficiency that in turn stimulated increase in cultivated land from 400 000 ha in 2006 to 800 000 ha in 2009. Food production increased from 200 000 tonnes in 2006 to 480 000 tonnes in 2010 that signified the importance of agriculture for people’s livelihood in western Serengeti. Results indicated that livestock is

equally important in supplying animal protein required by the growing human population. There was an increase in animal protein availability from 25 g/person/day in 2002 to 42 g/person/day in 2012 which was rather related to an increase in livestock population from 1 200 000 TLU in 2002 to 1 400 000 in 2008. Results showed an overall increase in monetary value of agro-pastoralism from 58 billion TZS in 2008 to 110 billion TZS in 2015 that signifies the contribution of agro-pastoralism to the livelihood of people in western Serengeti.

The second study determined that a total of 123 herbaceous plant species belonging to 20 families in a vegetation survey. The results indicated that higher herbaceous plant species diversity indices were found in protected areas (≥ 1.2) than in communal grazing lands (≤ 0.8). Similarly, the number of perennial herbaceous plant species was higher in the protected areas (≥ 5 species/0.25 m^2 quadrat) than the communal grazing lands (≤ 4 species/0.25 m^2 quadrat). The average density of grazing animals which exert grazing pressure in different land use types were 160 TLU/km^2 on transects within livestock-dominated grazing lands, 129 TLU/km^2 for mixed grazing and 83 TLU/ km^2 for wildlife grazing only. The study found that current agro-pastoral activities contributed to a reduction in herbaceous plant species diversity in village lands. However, the array of pasture species, especially desirable perennial species, still present in communal grazing areas suggest the possibility of rejuvenation of degraded areas. Resting of grazing land was recommended to reverse the trend towards diversity reduction and ensure future availability of feed resources for grazing animals in village lands.

The third study investigated the nutritive values of herbaceous plants in different land use types. Results indicated that ADF, IVDMD, IVOMD, ME and TDN were significantly ($P \leq 0.05$) affected by land use types but CP, NDF and ADL were not affected. Land use

types affected significantly (P≤0.05) soil pH, OC, CEC, P, C:N ratio and Ca^{2+} contents in the soil as well. An overall evaluation indicated that regardless of climatic conditions, successful herbaceous plants production in western Serengeti is determined by intensity of grazing, soil C:N ratio, Ca^{2+} and P concentration in the soil. The results showed that agro-pastoral practices conducted in western Serengeti affected negatively residual standing biomass of herbaceous plants while improving the nutritive value of herbaceous plants. Reduction of grazing pressure by either reducing the number of animals or duration of grazing on communal grazing lands was recommended. Specific studies are also required to establish appropriate stocking rates and grazing patterns for specific communal grazing lands in villages.

The fourth study elucidated how agro-pastoral activities contributed to deterioration of soil properties in western Serengeti. Results indicated that soil pH was not significantly different (p≥0.05) although it was relatively low in fallow and communal grazing lands. Clay content in soils was not affected by land use types whereas sand and silt contents were significantly different (p≤0.05) among land use types. In terms of soil nutrients, OC, CEC and soil P showed a significant difference (p≤0.05) among land use types but land use did not affect TN and Ca^{2+} contents in the soil. Bare land was highest in communal grazing lands (1233 cm^2/quadrat) and lowest in wildlife dominated grazing lands (906 cm^2/quadrat). Protected areas represented by wildlife grazing sites had the highest soil stability expressed in terms of soil structure stability index. Soil quality decreased with increase in bare land. The current practices of livestock grazing and cultivation had, however, higher negative effects on soil properties than the other land use types. Long term monitoring of impacts of agro-pastoralism on soil properties was recommended so as to establish proper stocking rates and proper cultivation techniques to avoid reaching an irreversible deterioration situation of soil properties.

Generally, it is concluded that agro-pastoralism is an important economic activity for the livelihood of the people. In western Serengeti it has been demonstrated that human population in rely on local crops and livestock products as the main income for their households. The current agro-pastoral activities carried out in western Serengeti, however, affected availability of feed resources in communal grazing and fallow lands evidenced by proliferation of undesirable herbaceous plant species. Diversity of herbaceous plant species in western Serengeti is also negatively affected by continuous livestock grazing and cultivation. The study demonstrated that agro-pastoral practices conducted in western Serengeti were detrimental to standing biomass of herbaceous plants at a given point in time. The study showed further that rejuvenation of desirable and highly desirable plant species is possible due to presence of pasture species array in communal grazing lands. It is recommended that grazing pressure in communal grazing lands should be reduced by either reducing the number of grazing animals or duration of grazing to improve herbaceous plants diversity and sustain livelihood of people. Specific studies should be conducted by respective local government authorities to establish appropriate stocking rates and grazing patterns of different communal grazing lands in villages. New strategies that involve resting of grazing lands should also be developed with the aim of making livestock grazing sustainable and productive in communal grazing lands. The better condition of pastures in wildlife areas with greater species diversity indicates that managing village grazing lands in a similar way could improve the condition of pastures.

DECLARATION

I, Pius Yoram Kavana, do hereby declare to the Senate of Sokoine University of Agriculture that this thesis is my own original work and that it has neither been nor concurrently being submitted for a degree award in any other institution.

_____ _____

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The above declaration is confirmed by;

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(Supervisor)

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LIST OF ABBREVIATIONS

AD	Animal Density
ADF	Acid Detergent Fibre
ADL	Acid Detergent Lignin
ANOVA	Analysis of Variance
AP	Available Phosphorus
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
CEC	Cation Exchange Capacity
CLA	Conjugated Linoleic Acid
CP	Crude Protein
CV	Coefficient of Variation
GIS	Geographic Information System
GPS	Geographic Positioning System
IVDMD	In-Vitro Dry Matter Digestibility
IVOMD	In-Vitro Organic Matter Digestibility
LG	Livestock Grazing
LGP	Length of Growing Period
ME	Metabolisable Energy
MG	Mixed Grazing
NDF	Neutral Detergent Fibre
OC	Organic Carbon
P	Phosphorus
PCA	Principal Component Analysis
SOC	Soil Organic Carbon
SSSI	Soil Structural Stability Index

TALIRI	Tanzania Livestock Research Institute
TAWIRI	Tanzania Wildlife Research Institute
TLU	Tropical Livestock Unit
TN	Total Nitrogen
TP	Total Phosphorus
VIF	Variance Inflation Factor
WG	Wildlife Grazing

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background Information

1.1.1 Agro-pastoralism

Agro-pastoralism is a joint practice of agriculture and livestock keeping and constitutes one of the strategies which different agrarian groups utilize to live and produce in a precarious and unstable social and economic context (Bonfiglioli, 1993). Climate and the ecological aspects of plants that include crops cast the performance of livestock and consequence livelihood of agro-pastoralists. Agro-pastoralists' livelihood strategies are based on livestock husbandry and crop farming (Goldman and Riosmena, 2013). World-wide agro-pastoralism is practiced in almost all continents with differences in the level of integration, crop types and types of animals kept by agro-pastoralists. Agro-pastoralism does not exist as a single, standard mode of production; rather, there are many kinds of agro-pastoralism graded according to degree of crop or livestock practice integration in a given community (Lane, 2006).

Agro-pastoralism is hinged on livestock herding and crop production in such a way that it encompasses two groups of different economic activity background. The first group is the one with livestock keeping background that due to various reasons such as climatic variability compel them to diversify economic activities by engaging in crop production. The second group is the one with farming background that find easier to expand their crop farming by using draught power in that manner livestock keeping become true livelihood integrated for production purposes. Agro-pastoralism therefore corresponds to a form of transformation and evolution of pastoral and agrarian societies (UNESCO, 1981). It is considered that agricultural practices and pastoral practices never reach a state of true

integration, but they, however, remain simply associated, even placed side by side (Bonfiglioli, 1993).

Agro-pastoralism is practiced differently among continents basing on the level of integration between crops and livestock types as well as use of technology. In American continent, the North American agro-pastoralism integrates cattle with cereal crops (Maughan *et al*., 2009; Tanaka *et al*., 2005; Sulc and tracy, 2007) and in some cases cattle is integrated with cotton (Acosta-Martinez *et al*., 2004; Hill *et al*., 2004; Allen *et al*., 2005). The salient feature of agro-pastoralism in North America involves high level of mechanization and monocropping with private land ownership. In South America cattle is integrated with cereal crops and pulses mainly soy bean (Agostini *et al*., 2012; Assmann *et al*., 2003; Lang *et al*., 2011; Modolo *et al*., 2013; Trogello *et al*., 2012; Assmann *et al*., 2014; Carvalho *et al*., 2018, Debiasi, 2012; Ferreira *et al*., 2015; Franchini *et al*., 2015; Nicoloso *et al*., 2006; Taffarel *et al*., 2016). In particular sheep is integrated with corn and beans (Carvalho *et al*., 2018; Novakowiski *et al*., 2013).

In Australia, agro-pastoralism involves integration of cereal crops and sheep (Harrison *et al*., 2011; Lenssen *et al*., 2013; Proffitt *et al*., 1995; Virgona *et al*., 2006) while beef cattle is integrated with sorghum (Radford *et al*., 2008). In Asia, agro-pastoralism involves integration of crops mainly rice, livestock and aquaculture (Phong *et al*., 2008). Agro-pastoralism in central Asia is practiced in mountainous areas in form of transhumance. This strategy has been pursued from prehistoric times where agro-pastoralists spend part of each year in the mountains when environmental conditions are optimal and the rest of each year somewhere else either in adjacent lower valleys but sometimes in very distant plains, or even in towns or cities (Kerven *et al*., 2011). The authors narrated further that mountain or altitudinal transhumance is still widely practiced in every continent including in

Mediterranean Europe, the Andes of Latin America, western rangelands of USA, Iran, Afghanistan, Turkey, North Africa, the Himalayas and Hindu Kush of Pakistan, India, Nepal and Bhutan, and in western China.

Agro-pastoralism in Europe is historically the extensive breeding of mostly sheep, goats and cattle associated to farming activities in marginal area of Mediterranean Europe (Nori and Farinella, 2020). Pardini and Nori (2011) showed that agro-pastoralism in Europe involves integration of fruit trees associated with vegetable crops and small animals, cover crops with sheep, vineyards and olive groves, thinned out forests, sown firebreaks with native cattle, sheep or cattle with chestnut and forage trees planted in rows with pasture integrated with cattle or sheep. Agro-pastoralism is strategic for Euro-Mediterranean countries, where extensive livestock breeding is a main economic activity in the mountainous territories, inner regions, and islands that are not suited to intensive agriculture. However, market competition with specialized intensive farms from other parts of Europe caused many agro-pastoral farms to either close or restructure their farms by expanding their herd and labour resources in order to adjust cost-benefit ratios (Hadjigeorgiou, 2011; Ragkos and Nori, 2016; Mattalia *et al*., 2018; Farinella, 2019).

Agro-pastoralism is an economic activity for over 200 million agro-pastoralists in Sub-Saharan Africa (SNV, 2012). This population rely on mixed crop–livestock production systems for their livelihood. However, integration of crops and livestock in Sub-Saharan Africa and African continent at large is contrary to integration practiced in Asia and Europe (McIntire *et al*., 1993). In Africa, cereal crops are mainly integrated with cattle and small ruminants. In Sub-Saharan Africa Agro-pastoralism is found in the arid, semiarid, sub-humid and humid tropics and in tropical highland areas (Sere and Steinfeld, 1996). Winrock (1992) classifies sub-Saharan Africa into five agro-ecological zones (AEZs): arid,

semi-arid, sub humid, humid and highlands. The basis of the classification is the amount and distribution of rainfall, the altitude (which affects temperature) and the length of growing period (Winrock, 1992; McIntire *et al*., 1992).

The arid zone, which is the largest, covers 38.2% of sub-Saharan Africa. It receives between 0 and 500 mm of rainfall per year and has a length of growing period (LGP) of less than 90 days (Otte and Chilonda, 2002). A characteristic of the arid zone is the high variability of its rainfall, which has a coefficient of variation of 25 to 35%, according to Wilson (1986), making it unsuitable for crop production and thus, in principle, exploitable only through livestock keeping.

The semi-arid zone covers about 18.1% of sub-Saharan Africa, receives 500 to 1 000 mm of rainfall per year and has an LGP between 90 and 180 days followed by a 7- to 9-month dry period. The coefficient of variation of rainfall is generally in the region of 20 to 25% (Wilson, 1986). The main crops are millet, sorghum, groundnut, maize and cowpea (Otte and Chilonda, 2002).

The sub-humid zone covers 21.2% of sub-Saharan Africa, extending through the centre of West Africa to parts of East and southern Africa (Kurukulasuriya and Mendelsohn, 2008). It receives between 1 000 and 1 500 mm of rainfall per year (Otte and Chilonda, 2002). Rainfall is less variable than in the arid or semi-arid zones, making crop production less risky and pastures more productive. A wide variety of crops is grown in the sub-humid zone, including cassava, yam, maize, fruit and vegetables, rice, millet, groundnut and cowpea (AGRA, 2014).

The humid zone covers 17.9% of sub-Saharan Africa and stretches along the coast of West and Central Africa and into the central Congo basin (Otte and Chilonda, 2002). The humid

zone receives in excess of 1 500 mm of rainfall per year, has an LGP of 270 to 365 days and consists of rain forests and derived savannah (FAO, 1999). The highland zone is defined as the area in which the mean daily temperature is less than 20°C (Winrock, 1992). The highlands occupy about 4.7% of sub-Saharan Africa. Approximately 75% lie in Ethiopia and Kenya and the remainder in other East African countries and sub regions (FAO, 1999). Rainfall is at least bimodal. The cool climate, relatively few diseases and pest problems, and high productive potential have led to high human population densities and favourable environment for livestock production (Otte and Chilonda, 2002). Livestock are kept as main source of income and depend on natural forage while cropping is important for provision of food. This system is particularly well developed in densely inhabited areas of eastern and southern Africa (Greiner *et al*., 2013).

Agro-pastoralism in Tanzania is mainly practiced in Shinyanga, Tabora, and Mara regions in western Tanzania, the Dodoma and Singida regions in central Tanzania and the Kilimanjaro, Arusha, and Manyara regions in northern Tanzania where shifting cultivation of sorghum and millet is practiced (Sewando *et al*., 2016). The same authors explained that diversification of livestock with crop farming and off-farm activities are the common feature in agro-pastoral systems in Tanzania. Cattle, goats, and sheep are integrated with sorghum, finger millet, groundnuts, Bambara nuts, cassava, and grapes, while off-farm activities include the sale of forest products, weaving, knitting, pottery, small businesses, and wage employment (Food Studies Group, 1992; Mnenwa and Maliti, 2010).

1.1.2 Herbaceous plants diversity

Biodiversity conservation refers to management of human use of the biosphere that may yield greatest sustainable benefit to present generation while maintaining its potential to meet the needs and aspirations of the future generation (IUCN, 1980). It is clarified further

that biodiversity conservation is a wise use of the biosphere and encompassing three levels namely, design of production and sustainable land use systems, the preservation of species with actual or potential benefits to humanity, and conservation for non-economic reasons. To achieve those objectives, the world has come up with the World Conservation Strategy (IUCN, 1980; 1987, 1991) aimed at maintaining essential ecological processes and life supporting systems that human survival and development depend on. The Tanzania State of the Environment Report (URT, 2014) lists biodiversity loss as one of the six key national environmental challenges in the country.

Key drivers of biodiversity loss in Tanzania include: wide spread poverty covering 28.2% of the country's population, high population growth at 3.2% per year, cropland expansion, tree cutting for wood-fuel; global trade in plant and animal species, Climate Change and invasive and alien species. High rates of biodiversity loss are responsible for low provision of ecosystem services (URT, 2014). Importance of plant biodiversity is traditionally recognised by agro-pastoralists particularly for livestock production and other uses such as medicinal values. Plants are used for a variety of purposes including, providing building materials, fodder, weapons, and medicines. For this reason plants have become the most revered, and treasured friends in the agro-pastoral systems. Because of this intimate relationship agro-pastoralists have developed thorough and complex knowledge systems on plants.

Plant species diversity has functional consequences because the number and kinds of species present determine the organism traits that influence ecosystem process (Lundholm, 2015). Plant species traits may mediate energy and material fluxes directly or may alter abiotic conditions such as limited resources, disturbance and climate that regulate process rates. The components of plant species diversity include number of plant species (species

richness), their relative abundances (species evenness) and the particular species present (species composition).

Herbaceous plant species composition and productivity influence the quality and quantity of forage in rangeland (Butt and Turner, 2012). There is a global perception that heavy livestock grazing reduces biodiversity and that biodiversity is maximized in primary vegetation (Alkemade et al. 2000). A well-known contemporary grazing-diversity model indicates a decline in diversity with heavy grazing intensity, at least outside areas of high resources (Cingolani et al., 2005). The decline in the proportion of herbaceous species abundance due to the effect of grazing pressure is consistent with other studies (Angassa and Oba 2010; Sisay and Baars 2002; Terefe *et al*., 2010). Under continuous and increased grazing pressure, palatable plants (decreasers) would die and with the death of decreasers less palatable plants (increasers) become dominant (Mengistu *et al.,* 2015). This may be related to the presence of high animal grazing pressures due to the presence of a high number of livestock and human activities which damage palatable herbaceous species.

Cultivation affects herbaceous plants due to removal of non-crop species by considering them as weeds. Higher farming intensity is associated with a number of factors that can affect herbaceous species diversity. These include a greater reliance of herbicides that reduces biodiversity (Romero *et al.,* 2008; Petit *et al.*, 2015), and more fertilizer increases levels of nitrogen which is associated with decrease in diversity of herbaceous plants. This happens as only a few species do well in such high nutrient environments, outcompeting and eventually excluding the other species (Crawley *et al.,* 2005; Bobbink *et al.,* 2010). Higher farming intensity thus may be associated with decreases in native, rare plants that are not tolerant of agricultural practices (Storkey *et al.,* 2010). Therefore, determination of herbaceous plant species diversity indicates the status of agro-pastoral land in supporting domestic and wild grazing animals.

1.2 Problem Statement and Justification of the Study

1.2.1 Problem statement

Studies have focused on the impact of agro-pastoralism on environmental processes in different areas at regional and global scales (Basamba *et al*., 2016). It is widely acknowledged that agro-pastoralism contributes to the wellbeing of people in rural areas and the economy of the country (Ibrahim *et al*., 2021). The livelihoods of poor rural people are particularly vulnerable to the establishment of protected areas (PA), particularly in developing countries, because their livelihoods are mainly dependent on agro-pastoralism and on the available natural resources (Young and Goldman, 2015). The impact of PAs on local livelihood has been widely studied (Roe, 2008; West et al., 2006). Benefits gained and costs paid by local people as a result of the presence of PAs in their vicinities can encourage positive or negative attitudes toward conservation activities (Clements et al., 2014; Kideghesho et al., 2007; Røskaft et al., 2007). Currently, balancing the conservation goals and needs of local people is particularly challenging (Bennett and Dearden, 2014; Clements et al., 2014).

Income for livelihood of people in Serengeti ecosystem relies on agro-pastoralism by 64% (Jiao, *et al*., 2019) and the rest of the income is obtained from environmental products. Restrictions from accessing environments products from PAs cause conflicts as agro-pastoralists trespass into PAs. Little is known about the effect of trespassing of agro-pastoralists in PAs in western Serengeti. Mfunda and Røskaft (2011) tried to quantify contribution of agro-pastoralism to the food security and livelihood of people in western Serengeti. The authors considered mainly the importance of crop production, farm size, crop raiding by wildlife and other factors influencing crop loss to households in Western Serengeti. Agro-pastoralists trespass into PAs in search of pastures and bush meat.

The prevalence of illegal bushmeat hunting has been exacerbated by an expanding population, weak government policy and most importantly poverty (Ceppi and Nielsen, 2014). Illegal hunting is common inside and outside the park as a source of protein to put on the table. Approximately 500,000 people live in western Serengeti, and pressure for food and resources continues to grow with increasing human population at a rate of 2.9% annually (Loibooki et al., 2002). However, little is known on the impact of agro-pastoral activities and trespassing in PAs of western Serengeti on vegetation and soil properties. The relationship between vegetation and soils in Serengeti has been studied to some extent by Lyaruu (2010) while Mligo (2015) studied plant species composition and distribution in relation to land uses in Northern Serengeti. Both studies covered small patch of Serengeti ecosystem without inclusion of socio-economic and agro-pastoralism practiced in Serengeti ecosystem. Muchane et al. (2013) conducted biodiversity study under ASARECA agro-biodiversity project in North-eastern Serengeti. The study aimed at identifying best land use and management practices that favour biodiversity while providing livelihood. It covered villages namely Ololosokwan, Loliondo, Machokwe and Nyansurura. The results on plants biodiversity were based on rapid vegetation survey conducted from July 2009 to December 2010.

The study covered a small patch of Serengeti ecosystem mainly North-Eastern Serengeti that differs with western Serengeti in terms of annual rainfall 550 versus 1,050 mm (Sinclair et al., 2000). This affects vegetation types, growth and hence feed resource base for both wildlife and domestic animals between Eastern and Western Serengeti. Therefore, the current study aimed at establishing the influence of agro-pastoralism on herbaceous plants diversity, soil properties and its contribution to the livelihood of communities residing adjacent to the protected areas in western Serengeti.

1.2.2 Problem tree for effect of agro-pastoralism

The problems of decline in ecosystem services due to agro-pastoral activities are entangled on decline of herbaceous plants diversity as shown in Figure 1.1.

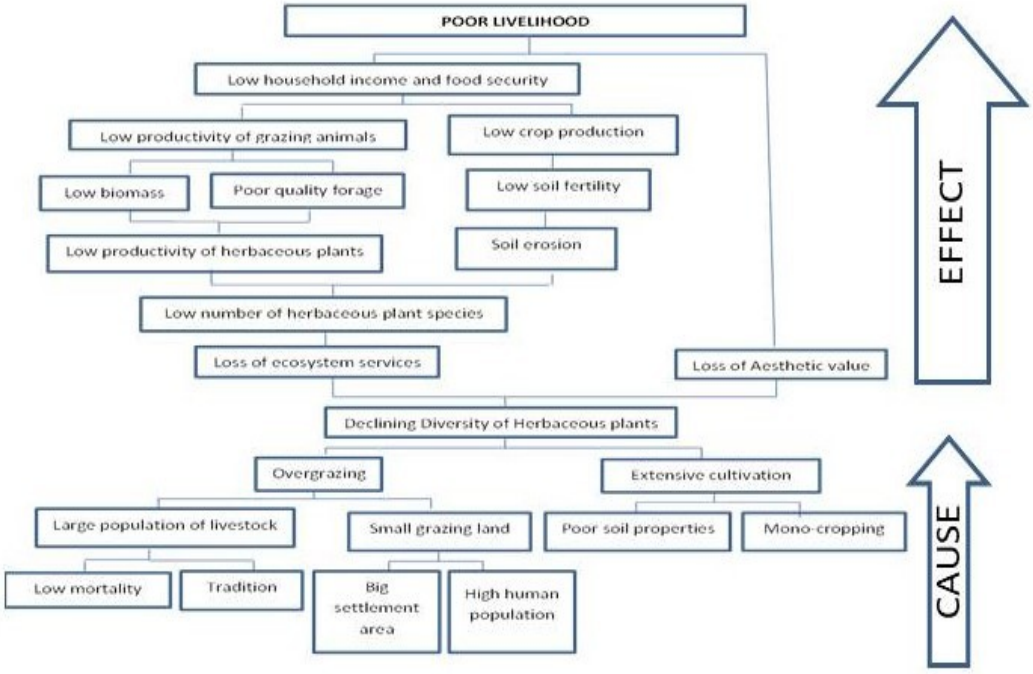

Figure 1.1: Problem tree for effects of agro-pastoral activities on plant diversity and livelihood

Source: Author's opinion 2021

1.2.3 Justification of the study

Wellbeing of agro-pastoralists would decline as a consequence of growing human and livestock populations on limited and often degraded lands leading to increasing imbalances between the demand for and supply of land and water. Therefore, while individual impoverished agro-pastoral households can be helped to gain a viable and sustainable livelihood in agro-pastoral areas, this is no longer true for the agro-pastoral population as a whole. Complementary policies and strategies with the objective to reduce the imbalance between humans, livestock and the environment therefore need to be put in place.

Any attempt to achieve the Millennium Development Goal 2030 of halving extreme poverty needs to include agro-pastoral people who are rather vulnerable to continuing unstable environment. The crucial policy question is whether it would pay off to invest in agro-pastoral development, or whether it would be more appropriate to design diversification strategies in keeping with shrinkage of grazing lands and scarcity of water.

Agro-pastoral populations on decreasing grazing lands require that policy-makers should develop and implement exit and/or diversification strategies. There are, however, good economic reasons for investing in agro-pastoral areas. First, agro-pastoralism is the best, if not the only, means to make productive and sustainable use of natural resources in semi-arid areas that would otherwise remain unexploited. Second, agro-pastoral people produce a large share of the crop and animal products supply in the country.

In the course of centuries agro-pastoralists have developed effective mechanisms to survive in risky environment. Traditional risk-management strategies include diversification of economic activities through livestock keeping and crop cultivation. Agro-pastoralists know suitable crops to grow for particular environmental/climatic condition. They keep traditional crop seeds to sustain crop production in their natural environment. Most agro-pastoralists recognize almost every plant in their range lands and pastures (Ole Lengisugi, 1996). Agro-pastoralists understand the seasonality of plants, their nutrients, toxicity and pharmacological benefits (Bizimana, 1994 and Kilongozi *et al.,* 2005). The knowledge of the nutritive value of plants and its variability is important for agro-pastoralists as it is through them that they are able to undertake biodiversity conservation through management decisions in relation to pastures availability for their animals. Agro-pastoralists demonstrated ability to differentiate good and poor botanical composition of plants in the field (Kilongozi *et al.,* 2005). One of the ways that agro-

pastoralists use to determine and assess the palatability of plants is by monitoring animal behaviour when grazing. Animals tend to be selective on which plants to graze and browse in different seasons of the year. They spend more time on palatable plants and less time on less palatable ones. Agro-pastoralists know that palatable species decreases faster than unpalatable species in the annual grazing cycle so they normally conserve the plant species by restricting animals' access (Kilongozi *et al.*, 2005).

Despite of traditional biodiversity conservation knowledge present in agro-pastoral communities, progressive growth in human population and conversion of natural land to agriculture in western Serengeti as reported by Estes *et al.* (2012) override application of that knowledge to conserve plants. The effect of this situation has been partially assessed in northern Serengeti by Mligo (2015) using rapid vegetation survey. The impact of agro-pastoralism on herbaceous plants diversity which affects ecosystem service of providing feed resources to the grazing animals was not considered by the author.

Furthermore, livestock keepers argue that protected areas are so extensive that the impact of livestock grazing cannot be conspicuous. This perception results in progressive illegal livestock grazing in protected areas of Western Serengeti because of limited number of rangers required to patrol large protected areas. Yet there is no scientific study that has been conducted to evaluate contradicting views between conservationists and livestock keepers on the effect of livestock grazing in protected areas of Western part of Serengeti ecosystem. Therefore, the current study intends to determine the influence of agro-pastoralism on livelihood, herbaceous plants biodiversity, above ground biomass production and nutritive value of forages in village lands and protected areas where livestock grazing is done either legally or illegally in protected areas.

1.3 Objectives and Hypothesis

1.3.1 Overall objective

To determine the influence of agro-pastoralism on herbaceous plants community structure, composition, nutritive value, soil properties and its contribution to agro-pastoral communities' livelihood in Western Serengeti.

1.3.2 Specific objectives

i. To investigate the contribution of agro-pastoralism to the livelihood of agro-pastoral households in Western Serengeti
ii. To evaluate the effect of agro-pastoralism practices on herbaceous plants diversity in village lands and protected areas of Western Serengeti
iii. To investigate the effect of agro-pastoralism practices on quantity and quality of feed resource base in village lands and protected areas
iv. To determine the effect of agro-pastoralism on soil properties in Western Serengeti

1.3.3 Research hypothesis

Ho: Agro-pastoral activities have no effect on herbaceous plants diversity.

Ho: Agro-pastoralism practices have no effect on abundance and quality of herbaceous plants.

Ho: Agro-pastoral activities have no effect on soil properties in grazing and cultivated lands.

Ho: Contribution of agro-pastoralism to the livelihood of communities in western Serengeti is negligible.

1.4 Conceptual Framework

1.4.1 Conceptual framework

This study considers how agro-pastoralism practices affect herbaceous plant diversity and livelihood of agro-pastoralists. Agro-pastoral livelihood encompasses traditional and contemporary practices in order to meet production needs. Choice of any agro-pastoralism practice will affect herbaceous plant diversity and peoples' livelihood. Poor practices such as keeping of large herds of grazing animals within a small grazing area or grazing continuously on the same range area for the whole year causes land degradation by exerting high pressure to plant species and soil properties due to trampling.

Unlimited expansion of cultivated land affects herbaceous plant species due to land clearing thereby reducing feed resource base for grazing animals. Trampling by animals causes compaction of soil that affects bulky density and porosity of the soil leading to poor water infiltration. Removal of plants due to large number of grazing animals causes bare land that in combination with poor water infiltration causes surface water runoff during the rainy season that erodes soil.

Land clearing and cultivation for crop production basically re-structure and disrupts a previously stabilized ecosystem. The disturbed ecosystem due to cultivation immediately begins succession where less desired annual herbaceous and forb plant species adapted to bare land conditions and disturbed soil invade the site and become established. This situation results in changes in plant species composition and consequently plant diversity as some of the herbaceous plant species within the community may become more abundant or new species may invade the community from adjacent ecosystems.

Soil erosion of bare cultivated land during rainy season removes top fertile soil resulting in low soil fertility. Poor soil fertility causes establishment of limited number of plant species

resulting in low herbaceous plant composition. Low herbaceous plant species composition results in low above ground biomass production that causes insufficient feed resource base for grazing animals.

High number of grazing animals in a shrinking grazing land with insufficient feed resource base in terms of quantity and quality results in high utilization pressure by grazing animals. High grazing pressure exerted on palatable herbaceous plant species results in disappearance of palatable plants and consequent loss of herbaceous plant diversity. A series of events explained in this scenario can be termed as ‘herbaceous plant biodiversity detrimental scenario’.

On the other hand, agro-pastoralism as a livelihood strategy encompasses some traditional and contemporary best-bet practices such as deferred grazing (Ngitiri or Alalili), grass band cultivation, rain water spreading furrows and controlled grazing that are based on proper stocking rates. The best-bet agro-pastoralism practices contribute to soil conservation due to minimum disturbance on soil and native plants resulting in availability of diverse plant species that contributes to high primary productivity.

Consistent high primary productivity allows availability of stable feed resource base in terms of quantity and quality for supporting grazing animals. This situation enables grazing animals to remove herbaceous plants through grazing while providing chance for replacement of removed plants by allowing regeneration of plants. This contributes to biodiversity conservation of herbaceous plants. A series of events as explained in this scenario can be termed as ‘herbaceous plant diversity win-win scenario’. Both ‘herbaceous plant diversity detrimental scenario’ and ‘herbaceous plant diversity win-win scenario’

affects livelihood of agro-pastoralists in either negative or positive way respectively. This conceptual framework can be represented by a schematic diagram (Figure 1.2).

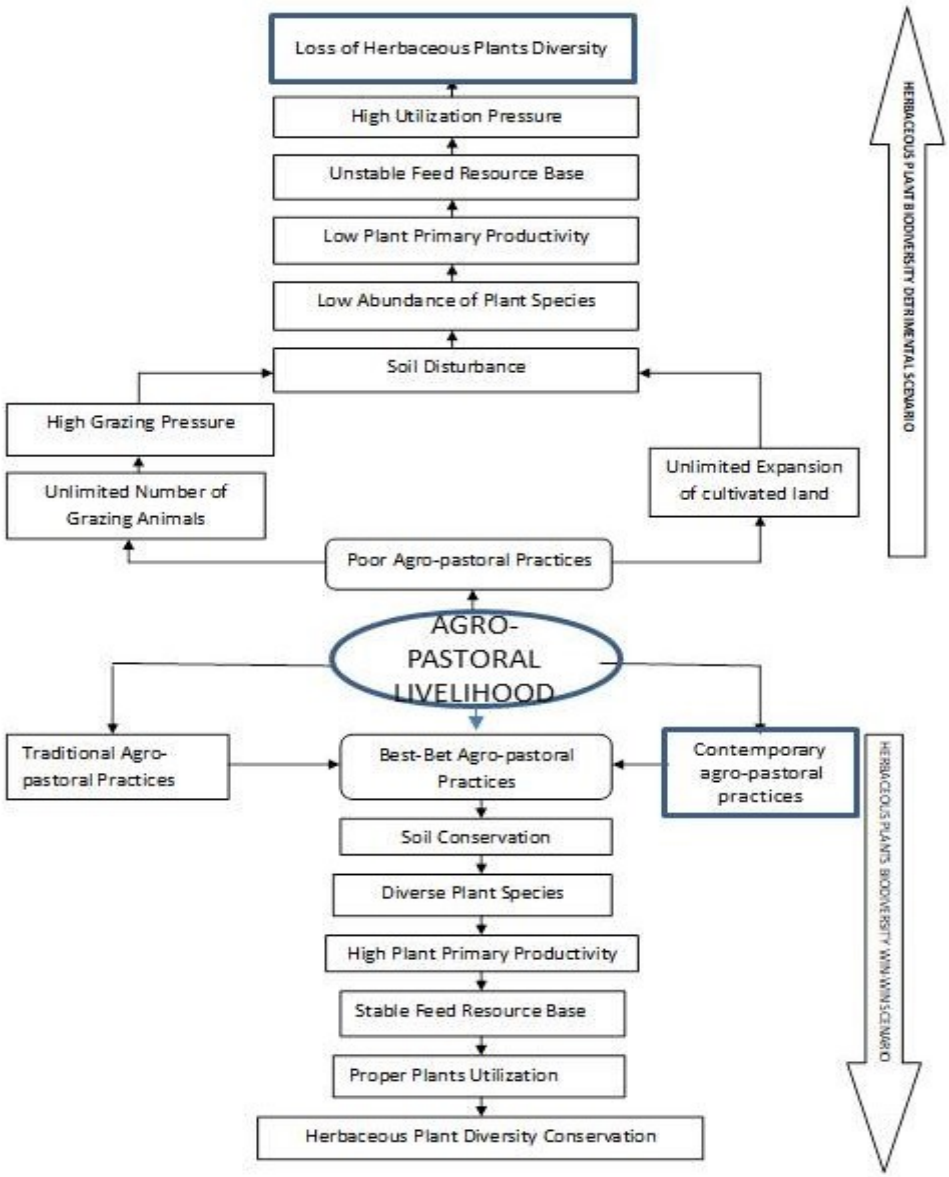

Figure 1.2: Conceptual framework for influence of agro-pastoralism on herbaceous plants diversity and livelihood of communities

Source: Modified from Millennium Ecosystem Assessment (MA, 2003).

1.5 Literature Review

1.5.1 Agro-pastoralism in Tanzania

There are three types of agro-pastoralism practiced in Tanzania based on management of livestock particularly cattle. According to Brandström *et al*. (1979) there is unilocal agro-pastoralism where herd grazes in vicinity of the homesteads and taken back to kraals every night. The second is bilocal agro-pastoralism where herd is grazed near homesteads in one part of the year and then moved far away from homesteads in search of pasture and water in the other part of the year. The third type is multilocal agro-pastoralism where few cattle are kept permanently at the homesteads while major part of the herd is grazed far away from homesteads throughout the year. The highest density of livestock in relation to available land in agro-pastoral areas of Tanzania is found in Southern part of Lake Victoria (Brandström *et al*., 1979). Most of the labour in this agro-pastoral area is invested in cultivation where surplus is directed to livestock production mainly through free grazing crops residues. The same strategy is also practiced in agro-pastoral areas of central Tanzania (Rigby, 1969).

National agriculture census provide agricultural statistics that are required to determine the growth of agro-pastoral sector, measure trend of the contribution of agro-pastoral sector to the livelihood of people and help in stimulation of agro-pastoral based industry investment. Analysis of annual agriculture census data of 2014/15 and 2016/17 (NBS, 2016; NBS, 2018) indicate that agro-pastoralism is practiced in all regions of Tanzania mainland (Figure 1.3).

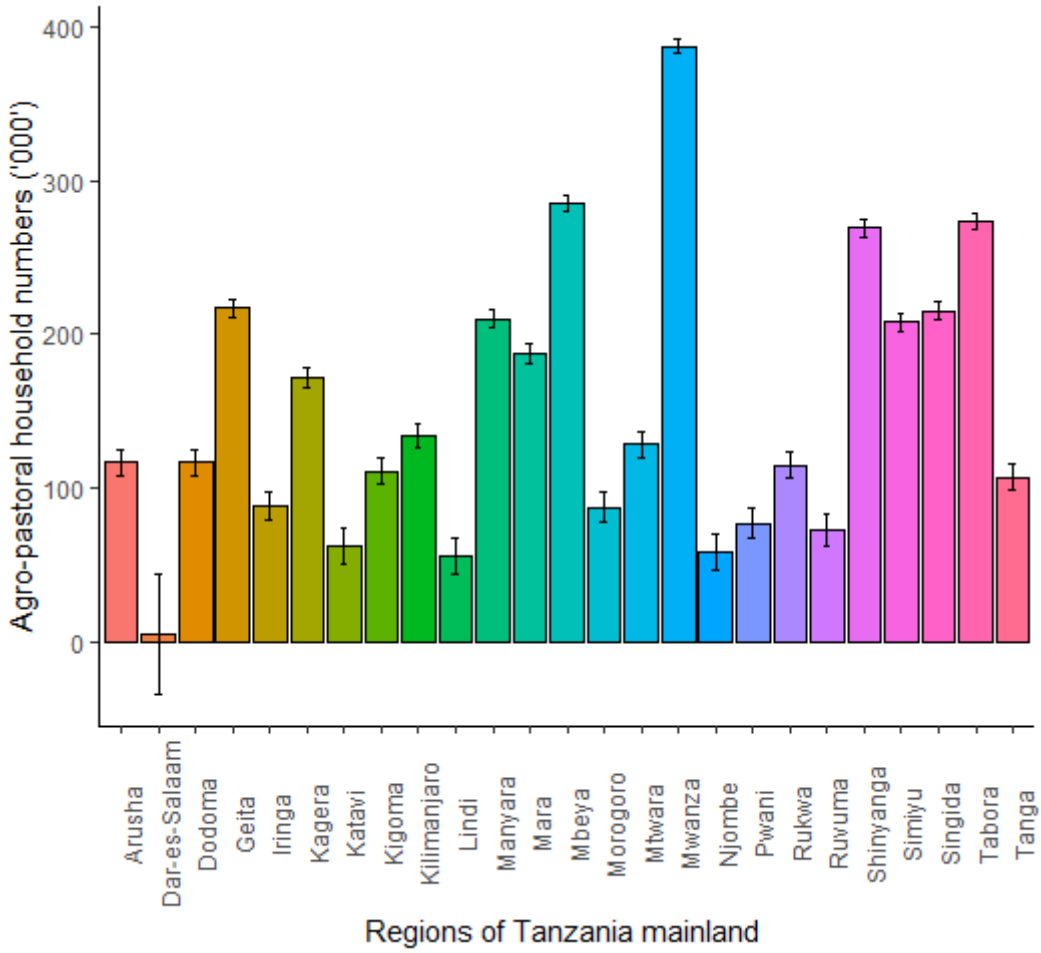

Figure 1.3: **Average number of agro-pastoral operators in different regions of Tanzania mainland**

Source: Author's synthesis from NBS (2016 and 2018) data.

Mwanza region showed the highest number of agro-pastoral operators while Dar-es-Salaam region was the lowest. Cluster analysis of the same data grouped regions into 3 main clusters of agro-pastoralism in Tanzania mainland (Figure 1.4).

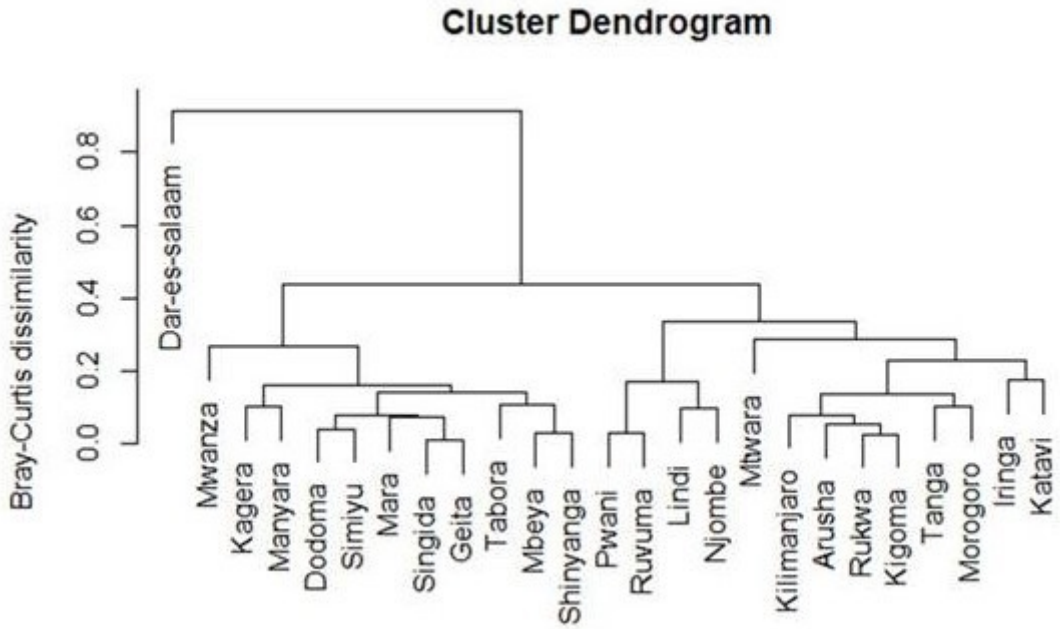

Figure 1.4: **Regional clusters of agro-pastoral operators in Tanzania mainland**

Source: Author's analysis from NBS (2016 and 2018) data.

The first cluster is Dar-es-Salaam region which was a separate from the other two clusters. The second cluster included Mwanza, Kagera, Manyara, Dodoma, Simiyu, Mara, Singida, Geita, Tabora, Mbeya and Shinyanga regions. The third cluster included Pwani, Ruvuma, Lindi, Njombe, Mtwara, Kilimanjaro, Arusha, Rukwa, Kigoma, Tanga, Morogoro, Iringa and Katavi regions. Further analysis of agro-pastoralism, crop farming and pastoralism operators in different clusters showed dominance of crop farming in clusters 1 and 3 (Figure 1.5). However, the number of operators in cluster 1 was very low compared to other clusters. The reason for this could be cluster 1 comprised of a city dwellers who were mainly engaged in salary jobs. Their involvement in crop farming and agro-pastoralism was just for diversification of income sources. Results showed that there is no pastoralism activity in cluster 1 implying no land for roaming animals in the city.

Crop farming per se and agro-pastoralism operators in cluster 2 were almost balanced. Agro-pastoralism in this cluster seemed to become a definite and irreversible choice of social and economic life. This indicates that most likely agro-pastoralists in cluster 2 originated from pastoral community who resorted into farming as a strategy of survival and recuperation from livestock losses through calamities.

Results in cluster 3 showed that crop farming per se was the major economic activity for agrarian communities. This indicates that agro-pastoralists in this cluster were most likely emerged from farming community who decided to engage themselves in the practice of livestock keeping. The reason for engaging in livestock keeping could be due to the climatic variability and the necessity of using livestock to improve crop production to get surplus crops in favourable years.

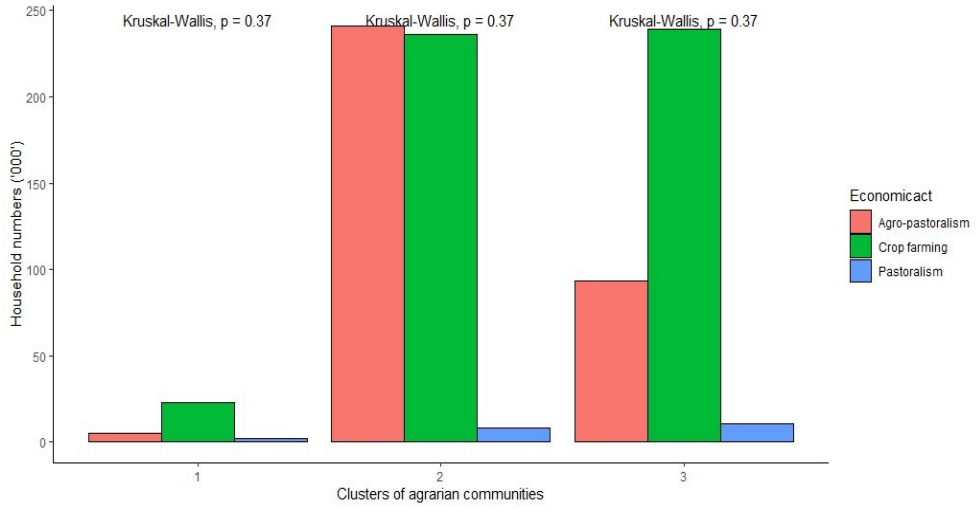

Figure 1.5: **Distribution of households involved in different agricultural activities among clusters in Tanzania mainland**

Source: Author's synthesis from NBS (2016 and 2018) data.

Agrarian households engaged in pastoralism were the lowest in number as compared to those engaged in crop farming and agro-pastoralism in clusters 2 and 3. This indicates difficulties in practicing pastoralism in Tanzania under the influence of human population growth and climate change and variability effects. Climate stress affects amount, patterns and distribution of rainfall, causes longer dry spells and droughts that lead to low livestock production due to decreasing grazing land and water resources (Sangeda *et al*., 2013). Persistence of climate stress in the country might result in shrinkage of households engaged in pastoralism per se in clusters 2 and 3.

Production of crops and livestock were different among the clusters (Figure 1.6). Results indicate that cluster 1 was poorest in crop production (Figures 1.6a and 1.6b) but did better in chicken production (Figure 1.6 c). The reason for cluster 1 to perform well in chicken production could be keeping of chicken within homesteads in confinement while crop production and keeping grazing animals required large area of land. Cluster 2 was relatively better than cluster 3 in cereal crops production (Figure 1.6a) which could be caused by integration of livestock especially cattle in draught power as shown by higher number of cattle in cluster 2 than cluster 3 (Figure 1.6c).

Beans production was the same in cluster 2 and cluster 3 while production of sim sim and green gram was relatively higher in cluster 3. On the other hand cluster 2 was better than cluster 3 in production of chick peas and cow peas. Differences in levels of crops and livestock shown in Figure 1.6 indicate differences in agro-pastoralism practices among clusters. This entails detailed field studies so as to understand current agro-pastoralism practices that prevail in Tanzania mainland. In that manner, current study was developed to understand agro-pastoralism practices in western Serengeti which is in cluster 2.

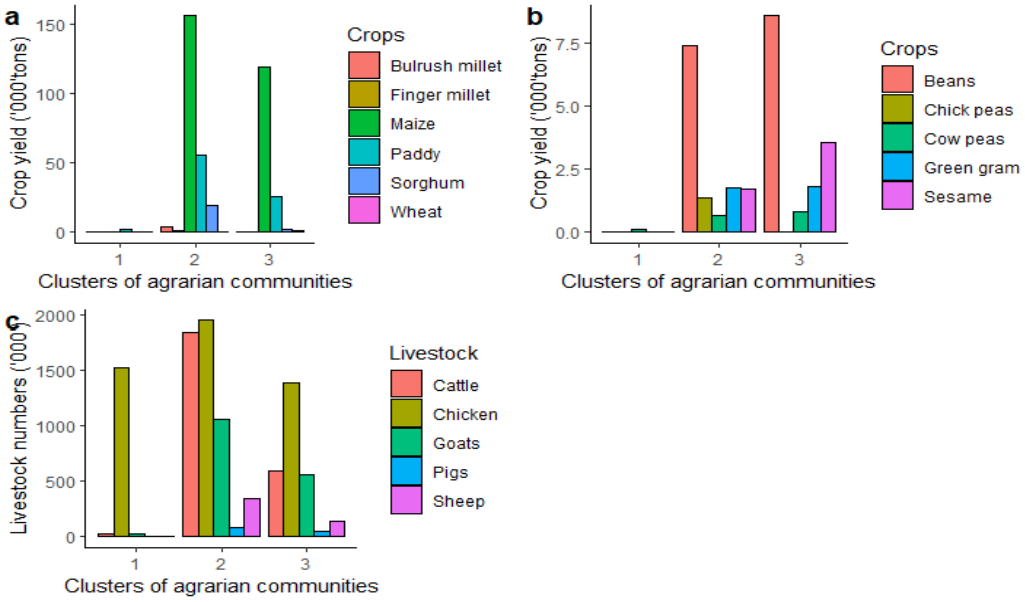

Figure 1.6: **Crops and livestock production in different agrarian clusters in Tanzania mainland**

Source: Author's synthesis from NBS (2016 and 2018) data.

Generally, agro-pastoralism involves implements, techniques and knowledge that are combined to manipulate natural environment in order to produce various commodities. The integration of economic activities that are practiced within agro-pastoral system shape specific agro-pastoral cluster and their differences lead to discrepancies among clusters.

Agro-pastoralism is not unchallengeable and many different variations exist where in some cases emphasizing agriculture to a lesser or greater extent within economic environment of respective community. Neither are agro-pastoralist communities static; there are constant shifts between more herding or more farming through time and these constant variations and shifts are subject to the social, political, ecological and geographical situation in which these communities exist (Lane, 2006).

1.5.2 Agro-pastoral livelihood operation

Understanding of agro-pastoral system requires analysis of the main activities performed by agro-pastoralists. That analysis may enable depiction of the system and cast clues of benefits and limitations that agro-pastoralists encounter when practicing agro-pastoralism.

1.5.2.1 Benefits of agro-pastoral livelihood

The main benefit of agro-pastoralism is insurance of food security where diversification of economic activities reduces the risk of total failure. Choosing to engage in animal husbandry and crop production, the agro-pastoralist is able to minimize the risk of falling below a certain threshold of disaster and thus maximize the probabilities of survival (Upton, 1987).

Integration between crops, pasture and livestock provides economic benefit through the combination of complementary productions (Ryschawy *et al*., 2012). Agro-pastoralism in contrary to pure pastoralism is beneficial because cultivation is considered to be a coping mechanism against drought and, as a source of income that reduces the need for livestock sales for purchasing food and crop residue for livestock feed (Tilahun *et al*., 2017). Agro-pastoralism provides opportunity for employment in agricultural sector.

Agro-pastoralism in Africa was capable of producing half of the world's cereal and a third of beef and milk, making it the livelihood for a billion people (Mukhlis *et al*., 2018). A well composed agro-pastoral system could be source of income, provide food security and conserve environment (Dasgupta *et al*., 2015). Livestock intensification in agro-pastoral systems is normally dormant as compared to food crops, but livestock could contribute positively to improve productivity of agricultural systems (Mukhlis *et al*., 2018). Likewise, the intensification of food crop production could provide dividends for livestock and

improve natural resource management, especially through increased availability of biomass (Duncan *et al*., 2013). In agro-pastoral systems, livestock graze on crop residues and provide manure and draught power which is used for farming operations. Manure provides organic fertilizer which could improve soil structure, conserve soil moisture and prevent crusting of the surface soil (Sariubang, 2010).

1.5.2.2 Limitations of agro-pastoral livelihood

Sustainability of agro-pastoralism in a community requires management skill to understand the interaction between the landscape mosaic and agro-pastoral management practices. Imperfections and limits in detecting variations in the state of the environment under the effects of ecological processes and farming practices lead to deterioration of agricultural land in agro-pastoral systems (Williams, 2011). Economic factors might affect application of some innovations production in agro-pastoral system for example crop farmers' willingness to accept manure depends on the price of synthetic fertilizers.

Farmers are more open to receive manure when the price of mineral fertilizers is high (Schipanski *et al.,* 2014). In addition to that manure application without mechanization is laborious task. The physical costs of transporting plant manure and farmyard manure determine economic acceptance of manure application by farmers (Wilkins, 2008). Mismatch between supply and demand of nutrients (particularly N, P, and K) as related to location-specific characteristics could limit the relevance of complementary effect of crops and livestock (Hendrickson *et al*., 2008). In intensive agro-pastoral system manure moves from livestock farms to crop farms, but nutrients do not necessarily return to livestock farms through feedstuff (Moraine *et al*., 2014; Peyraud *et al*., 2014). In actual fact, the nutrient content of manure is not certainly known which makes rather difficult to account for nutrient input in crop farms. Inadequate accounting of nutrient supply could lead to

source-sink imbalances among crop and livestock farms and result in soil nutrient leaching on crop farms and soil nutrient depletion on livestock farms (Martin *et al*., 2016). Trade-off analysis show that the nature of competition between crop and livestock indicate that under condition of small land holding, optimum crop and cattle combination require a small cattle herd size and allocation of a high proportion of land and labour to crop production (Jabbar *et al*., 1996).

1.5.3 Importance of plants diversity in agro-pastoral system

Species diversity is defined as the number of different species present in an ecosystem and relative abundance of each of those species (Kent and Coker, 1992). There are two constituents of species diversity namely Species richness which is number of different species present in an ecosystem and Species evenness which is a relative abundance of individuals of each of those species (Magurran, 2004). If the number of individuals within a species is fairly constant across communities, it is said to have a high evenness and if the number of individuals varies from species to species, it is said to have low evenness (Hamilton, 2005). High evenness leads to greater specific diversity and diversity is greatest when all the species present are equally abundant in the area (Pyron, 2010).

Plant species diversity has functional consequences because the number and kinds of species present determine the organism traits that influence ecosystem process (Lundholm, 2015). The importance of plant diversity is reflected on higher trophic-level species richness as in many cases it modifies consumer abundances (Schuldt *et al*., 2019). East Africa is considered to be a centre of genetic diversity for grasses (Reid *et al*., 2005). Grasses are the basal diet for grazing animals; their diversity in East Africa enables abundance of different species of grazing ungulates to be found in East Africa. In a healthy ecosystem, diverse and balanced numbers of species exist to maintain the balance of an

ecosystem. More diverse ecosystems tend to be more productive such that ecosystems with a great variety of producer species produce large biomass to support a greater variety of consumer species (Hooper *et al*., 2005; Vogel *et al*., 2012). Greater species richness and productivity makes an ecosystem more sustainable and stable (Tilman, 2001).

The more diverse the ecosystem the greater its ability to withstand environmental stresses and recovery from like invasive species infestations or droughts (Leps *et al*., 1982; Macgillivray *et al*., 1995; Tracy and Sanderson, 2004; van Ruijven and Berendze, 2010). A greater species richness and diversity cause ecosystems to function more efficiently and productively by making more resources available for other species within the ecosystem (Balun, 2021). This implies that in species-rich communities, each species uses a different portion of resources available as per requirement for example plants with smaller roots absorb water and minerals from upper soil layer and plants with deeper roots tap nutrients from deeper soil layer.

Plant diversity is important for livelihood of people for example in agro-pastoral system plant diversity supports productivity of livestock. Plant species diversity in agro-pastoral system tends to be easily manipulated in grazing and cultivated lands. Some plant species could be added or removed in a system through management practices. The plant community is of particular interest because of its central role as primary producer in livestock production within agro-pastoral system. Studies using grazing experiments showed that diversified pasture species plots yielded more herbage than less diversified pasture species plots (Tilman, 1996; Tracy and Sanderson, 2004; Roscher *et al*., 2005; Cardinale *et al*., 2007; Weigelt *et al*., 2009). Various authors reported interaction of soil and plant species in herbage production. They demonstrated that mixtures based on highly productive forage species performed better in terms of higher yield, better persistence on

heavier soils with greater water holding capacity, whereas mixtures with deeper rooting drought-tolerant grasses performed better on droughty sandy soils (Nie *et al*., 2004a, 2004b; Fischer *et al*., 2014).

The productivity benefit of a diversified ecosystem was attributed to either species complementarity where resources are used more efficiently by a greater number of species, or to the promotion of certain species with superior traits due to a selection or sampling effect (Loreau and Hector, 2001). This is attributed to inherent differences in chemical composition and different stages of maturity in the mixed species plant community (Bruinenberg *et al*., 2002; Huyghe *et al*., 2008). It is important to maintain plant species diversity in agro-pastoral system because decline in diversity is associated with decrease in quantity and quality of forage. The consequence of decrease in quantity and quality of forage is poor performance of grazing livestock which is an important component of agro-pastoral system.

1.5.4 Effect of agro-pastoralism on nutritive value of pasture

Nutritive value of pasture plays an important role in nutrition and performance of grazing animals in agro-pastoral system. Agro-pastoral activities that include livestock grazing management and cultivation affect forage quality of pastures. Forage is defined as edible parts of plants, other than separated grain, that can provide feed for grazing animals, or that can be harvested for feeding (FGTC, 1992). Determination of forage quality is important because performance of animals is associated with quality of forage they consume (Lazzarini *et al*., 2009; Woolley *et al*., 2009).

High performance of grazing animals in agro-pastoral system depends on the amount of nutrients in the forage consumed (Schut *et al*., 2010). Total digestible nutrient (TDN), crude protein (CP) and metabolism energy (ME) are considered as indicators of forage quality (Pinkerton, 2005; White and Wight, 1984). On the other hand, France (2000) noted that the nutritive value of forage depends on the amount of proteins and digestible carbohydrates. The author added that ash, lignin, cellulose, crude fibre, phosphorus, carotene and some other plant chemical compounds are also measured as indicators of forage quality. El-Waziry (2007) and, Rhodes and Sharrow (1990) considered the digestible dry matter as the main index for determining forage quality. Furthermore, Van Soest (1991; 1994) showed that the acid detergent fibre (ADF) was a better indicator for determining the nutritional value compared to crude fibre, because ADF contain cellulose and lignin, and the dry matter digestibility decreased with increasing lignin. Belyea *et al.* (1993) investigated quality of five forage species and stated that nitrogen content and ADF as two important factors in determining the metabolizable energy requirements of livestock. Schut *et al.* (2010) stated that several factors affected forage quality, which include vegetative stage of growth, plant species, climate, soil, temperature, and management factors. Based on these findings, it was found that representative traits of forage quality decrease with advanced stages of development therefore it was considered more practical to use a single index to compare forage quality between species (Moore and Undersander, 2002; Muir *et al*., 2007; Undersander, 2003).

Grazing intensity and season of the year are the most critical factors that affect nutritive value of pastures in agro-pastoral system. It has been demonstrated that grazing intensity affects plant species composition and forage quality (Belesky *et al*., 2002; Ren *et al*., 2012). Continuous defoliation of pastures in high grazing intensity caused pasture to remain in vegetative stage that resulted in higher nutritive value of pasture (Nelson, 2012).

High nutritive value in continuously defoliated pasture was attributed to deceleration of the maturation and lignification processes (Milchunas *et al*., 1995). In addition to continuous grazing, studies showed that grazing intensity together with annual precipitation rate affected nutritive value of forages. Miao *et al*. (2015) showed that inter year variation in the nutritive concentrations of the forage corresponded closely with the annual precipitation in agro-pastoral system of Tibet in China. The authors found that nutritive value of forage improved with increasing grazing intensity of livestock where the concentrations of fibre fractions NDF and ADF decreased, while those of N, TDN and ME increased with grazing intensity.

Despite of positive relationship between intensity of grazing and nutritive value, other studies found positive correlation between crude fibre (CF) and nitrogen content in forage (Hockin *et al*., 2012; Miao *et al*., 2015). This implies that availability of nutrients for higher performance of grazing animals depends on forage biomass ingested by the animals. Therefore long term continuous grazing of livestock in grazing land within agro-pastoral system might result in poor performance of livestock due to decline in forage biomass availability (Stromberg and Griffin, 1996; Klein *et al*., 2007). The decline in availability of forage biomass could be attributed to changes in the species composition by a shifting from palatable plant species to unpalatable plant species due to overgrazing. Therefore grazing management strategies, such as rotation grazing and moderate grazing intensity is important in agro-pastoral system because research finding showed that the increase in forage nutritive values due to high grazing intensity could not compensate for the decrease in forage biomass availability.

1.5.5 Effect of agro-pastoralism on soil properties

Soils and ecosystems evolve together through a mutual interdependence on the balance between soil erosion and soil production (Montgomery, 2007). Soil quality deterioration due to erosion is a complex process that depends on soil properties, elevation, vegetation cover, and rainfall amount and intensity (Selby, 1993).

Agro-pastoralism is an economic activity that depends on land to produce various commodities. Quality of land that involves soil quality, therefore, determines the productivity of agro-pastoral system. Agro-pastoral activities conducted on land contribute to either deterioration of soil quality or improvement of soil quality. This is because soil fertility is a function of agricultural methods and site conditions such as soil type, soil nutrient content, and organic matter content (Montgomery, 2007). Deterioration of soil quality is associated with soil erosion and human societies are an integral part of the balance between soil erosion and soil production (Wynants *et al*., 2019).

Vegetation cover is important in agro-pastoral system in reducing deterioration of soil quality because vegetation reduces the rainfall water flow energy through covering of the soil, anchoring of soil particles by roots and generally improving the soil structure (Greenway, 1987; Thornes, 1990). It has been reported that East African climate is characterised by high inter-annual variability, with dry and wet years or periods (Nicholson, 1996). This results in dynamic ecosystems which are in a constant disequilibrium that deny a concept of climax vegetation and carrying capacity to apply (Wynants *et al*., 2019). These disequilibrium ecosystems are naturally much more vulnerable to soil erosion due to the discrepancies between stabilising vegetation and rainfall (Little, 1996; Ngecu and Mathu, 1999; Sullivan and Rohde, 2002; Kiage, 2013). In addition, many soils in semi-arid East Africa are particularly vulnerable to detachment

processes because of a low organic matter content and weak aggregate stability (Wynants *et al*., 2019). In that manner, overgrazing and cultivation in agro-pastoral system in East Africa contributes to soil erosion.

Overgrazing of rangelands, poor cultivation of croplands, deforestation and urbanization are some of the land use practices that result in increased soil erosion (Seitzinger *et al*., 2010). Studies show that in agro-pastoral systems, soil compaction occur due to high stocking rates, soil texture, season of grazing, and water content and organic matter (Orr, 1960; Howard *et al*., 1981; van Haveren, 1983; Naeth *et al*., 1990). Overgrazing of rangeland; over-cultivation of cropland; water logging; deforestation; and pollution are the most frequently recognized land uses that cause land degradation (Stocking *et al*., 2000). This implies that agro-pastoral activities are among the main recognized contributors of soil deterioration in ecosystems.

Continuous cultivation in combination with excessive precipitation, inclined elevation, and application of inorganic fertilizer are known to result in the reduction of soil pH (Ahmed, 2002). Reduction of soil pH due to cultivation is associated with soil cations drain due to leaching and uptake by plants, with subsequent release of H^+ ions, organic matter decomposition into organic acids, increased carbon dioxide levels through root respiration and nitrification (Juo and Manu, 1996). Low soil pH causes decrease in plant diversity especially when the soil pH is less than 4.2 making aluminium potentially toxic (Bobbink *et al*., 1998). Cascade effect of decline of plant diversity due to low soil pH is poor performance of grazing animals caused by low quantity and poor quality of forage. Low soil pH also causes poor root development that limits the plants' ability to reach moisture in the low soil profiles (Wynants *et al*., 2019). In the humid tropics, soil acidity and associated problems often lead to abandonment of agricultural land and the perpetuation of slash-and-burn agriculture (TropSoils, 1991).

Replacement of forestry for agro-pastoral activities is detrimental to soil quality because cultivation of forests diminishes soil carbon within a few years of initial conversion and substantially lowers mineralizable nitrogen (Murty *et al*., 2002). Further studies showed that soils devoted to crop production tend to lose more phosphorus than soils that are covered by relatively undisturbed forest or natural grass land (Brady and Weil, 1996). Various scholars showed that phosphorus is critical to biotic function and essential to the development and maintenance of ecosystems (Richter *et al*., 2006; Turner and Engelbrecht *et al*., 2011).

Phosphorus is an essential nutrient for plant growth hence its' active uptake by plants and subsequent removal through harvest lead to an acidifying effect on the soils (Wynants *et al*., 2019). Other studies showed that the amount of nutrients removed by cropping depends on the type of crop grown, part of the crop harvested, and the stage of growth at harvest (Whibread *et al*., 2003). Research findings delineate that poor agro-pastoral activities result in deterioration of soil properties. Therefore agro-pastoralism requires consideration of soil management strategies that conserve soil in order to sustain productivity of the land. This is of paramount importance because land is a fixed asset in most of the agro-pastoral systems and agro-pastoral land is diminishing due to increase in human population and other land use requirements.

1.6 Scope and Limitations of the Study

The scope of this study was limited to inclusion of 5 villages that are adjacent to protected areas within 4 districts. One village was selected for each district with exception of Bariadi district where 2 villages were involved due its bordering with two different protected areas (Serengeti National Park and Maswa Game Reserve). Single village per district was opted due to logistic and time limitation as the distance travelled to complete one cycle of data collection was not less than 864 km. In addition, this study was limited to conduction of

vegetation and soil sampling during the rainy season when most of vegetation species were at blooming stage of growth. This was done to enable identification of plant species by using inflorescence and easy opening of soil profiles when soil was moist. However, this study outcome provides the hint for the upcoming development and research interventions to alleviate negative influences of agro-pastoralism on herbaceous plants diversity in similar agro-pastoral systems on other part of Tanzania and East Africa at large.

1.7 Materials and Methods

1.7.1 Study area

The study was conducted in western Serengeti, which is part of the Serengeti ecosystem (Figure 1.7). Average annual rainfall ranges between 500 and 1200 mm, declining towards the Serengeti National Park boundary and increasing towards Lake Victoria (Sinclair *et al*., 2000). However, the average annual rainfall during the study period ranged from 400 to 900 mm. This area was chosen as a study area because it is occupied by agro-pastoralists who live adjacent to protected areas that include a national park and game reserves. Western Serengeti is among the most densely settled areas in the Greater Serengeti ecosystem with human population growth rates exceeding those to the north, east and south of the National Park (Kideghesho, 2010). The study was conducted in 4 districts by selecting villages that were adjacent to protected areas as shown in brackets, namely: Serengeti district (Park Nyigoti), Bunda district (Nyamatoke), Meatu district (Makao) and Bariadi district (Mwantimba and Matale). The western Serengeti is considered to have low suitability for arable agriculture and hence its subsistence economy depends mainly on agro-pastoralism (Emerton and Mfunda, 1999), which is constrained by inadequacies of input supplies such as fertilizers and poor delivery of agriculture extension services that lead to people in villages practicing extensive cropping and livestock keeping, which encroaches on protected areas (Mfunda and Røskaft, 2011).

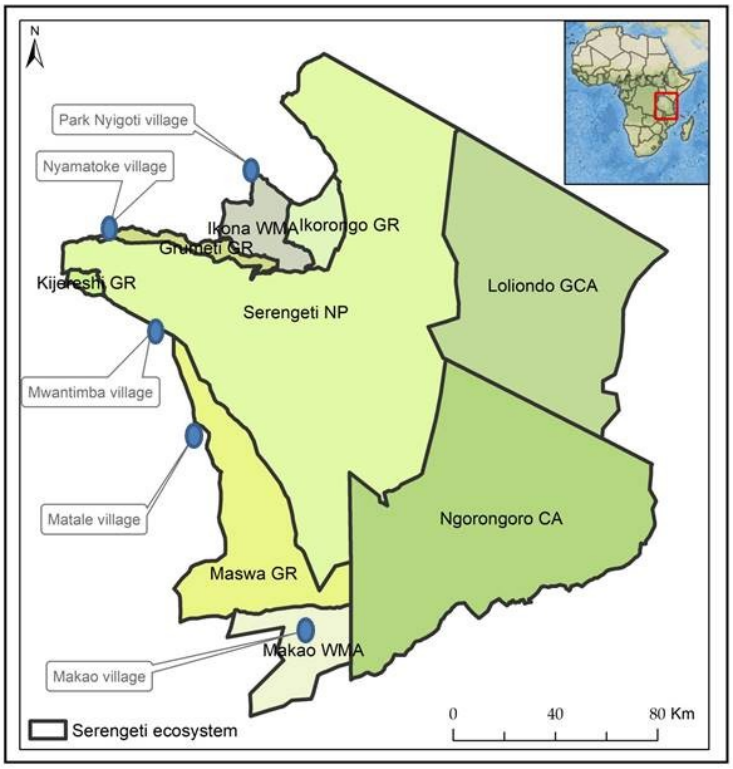

Figure 1.7: **Map of western Serengeti showing villages involved in the study**

Source: **TAWIRI GIS unit**

1.7.2 Study design

A systematic review of the scientific literature on contribution of agro-pastoralism to the livelihood of people in western Serengeti was conducted using guidelines outlined by Pullin and Stewart (2006) and Inskip and Zimmermann (2009). This was done by using various search engines and data sources to establish the body of knowledge concerning the subject. The review involved a pre-defined search protocol using filters for keywords to audit search relevance and applicability according to Pullin and Stewart (2006). Relevant literature was searched with Google Scholar.

Randomized design with 4 factors and 2 replications was used in vegetation studies. The factors included (1) village land that includes communal and private grazing lands that were within villages; (2) protected area that include Serengeti National Park, Game Reserves and Wildlife Management Areas (WMA). Replications were two 4000 m transects extending from village land to protected land. The response variables were considered in each block which included plant species and soil properties.

The study was designed to sample vegetation and assess soil properties 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 dominated land use types. 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 (Figure 1.8).

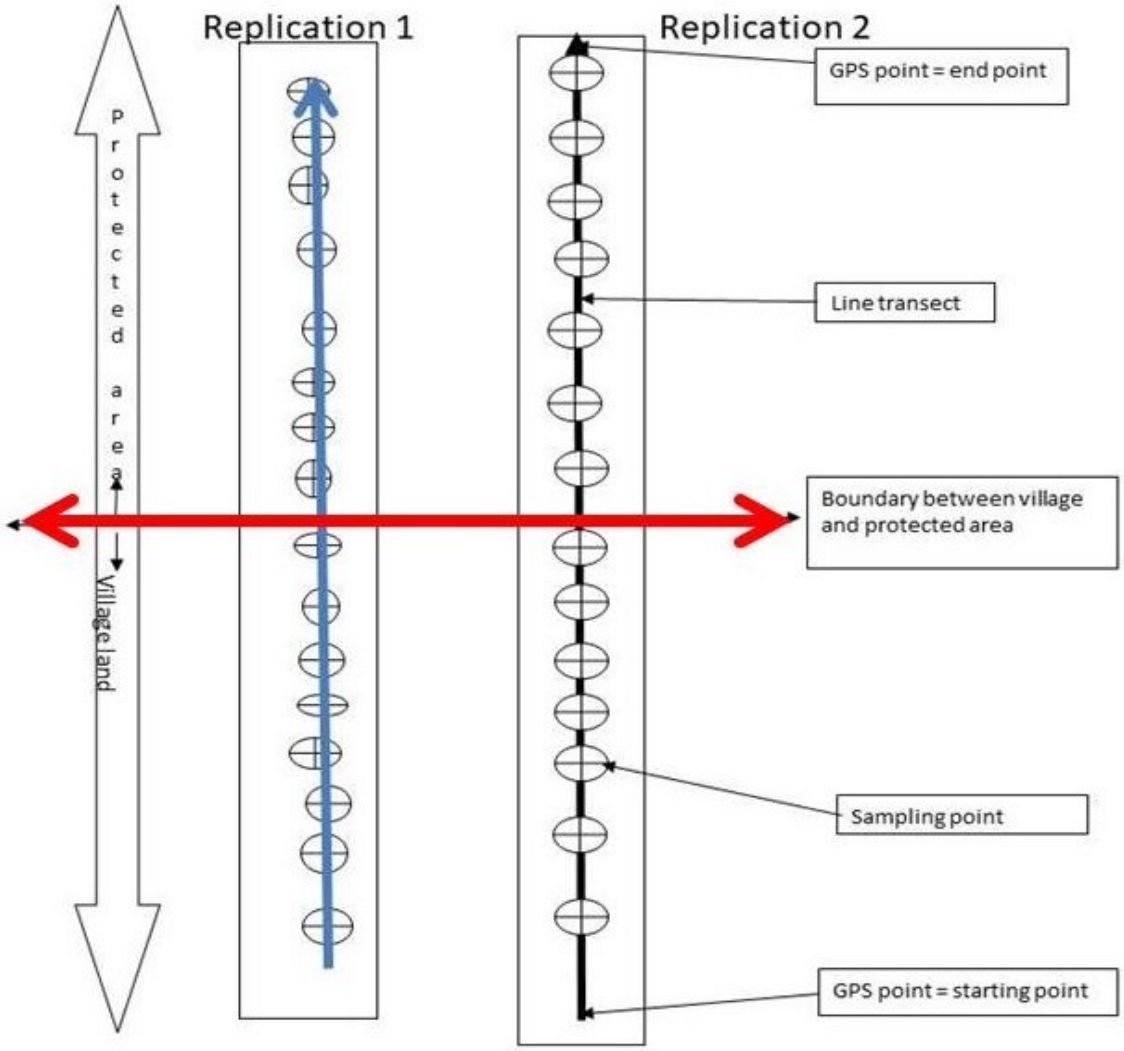

Figure 1.8: **Layout of vegetation and soil sampling in study sites**

Source: Authour 2021

1.7.3 Data collection

1.7.3.1 Documentary survey

Secondary data were used to evaluate contribution of agro-pastoralism on livelihood of people in western Serengeti. Mikkelsen (1995) denoted that “no matter what your research topic is there is almost always a wealth of information hidden in a variety of sources”. In that manner, this study used data from published and unpublished reports on agro-pastoralism, socio-economic, national, regional, districts and area-specific issues to

synthesize information that depicted agro-pastoralism in western Serengeti. The main secondary data were obtained through internet search.

1.7.3.2 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 100 m along each 4000 m 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/function (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.

1.7.3.3 Soil sampling

Soil was sampled at the central point of each 0.25m^2 quadrat. The samples were taken from the depth of 0-30 and 30-50cm at every 300m along transect after clearing of vegetation. Soil depth of 30 – 50 cm was considered for understanding soil properties that accommodate deep rooted plants because the study was conducted in wooded grasslands. Soil samples weighing 500g were taken from each sampling point and kept in labelled polyethylene bag for laboratory preparation process and analysis. Analysis of soil samples was conducted at Soil Laboratory of Sokoine University of Agriculture.

1.7.4 Laboratory Analyses

Laboratory analyses of vegetation and soil samples were conducted at the Department of Animal, Aquaculture and Range Sciences and Department of Soil and Geological Sciences respectively. Nutritional value analysis of herbaceous plant samples was analysed by fibre fractions in detergent system according to Van Soest *et al.* (1991) and invitro digestion according to Tilley and Terry (1963). Soil samples were analyzed for determination of soil texture, pH, soil organic carbon (OC), total nitrogen (TN), available phosphorus (P) and cation exchange capacity (CEC) according to standard procedures (Okalebo *et al*., 2002).

1.7.5 Data Analysis

Data related to agro-pastoral livelihood in western Serengeti were sorted from agriculture census reports and arranged in Microsoft Excel 2003 spread sheet. Then data were statistically analysed by descriptive statistics and cluster analysis using R statistical software version 3.5.0 to depict agro-pastoral production. Explanatory variables included demography, farm size, herd size, yield and market price. All vegetation, nutritive value and soil data were prepared for input by entering into a Microsoft Excel 2003 spread sheet. The compiled spread sheets were saved in .csv format preferred for electronic storage and input into R statistical software version 3.5.0 for further analyses. 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 properties parameters and herbaceous species variables. The r scripts for statistical analyses of different variables are shown in Appendix 1.

The plant species diversity among different land use types was determined by Shannon-Wiener diversity index (Shannon and Wiener, 1948). The herbaceous plant species evenness index (E) was calculated using the formula recommended by Alatalo (1981): Evenness (E) = H/lnS where: H is the Shannon-Wiener index and S is the total number of species from each sampling site.

Models for herbaceous plants ground cover and residue standing biomass were developed by conducting collinearity analysis and construction of Spearman's correlation matrix for each dataset from which input variables for the model were selected according to Zuur *et al*. (2009). Then, a global mixed effects model using lmer package of R statistical software (Kuznetsova *et al*., 2017) was used for selection of the most accurate model.

Effect of land use types on herbaceous plants residue standing biomass, nutritive values and soil properties was analysed by Analysis of Variance (ANOVA) with type III sum of square for unbalanced data.

Herbaceous plants association in the western Serengeti ecosystem was analysed by using probabilistic R package co-occur according to Griffith (2016) while preference of herbaceous plant species to establish in different soil texture classes was analysed by using Venn diagram according to Heberle (2015).

1.8 Organization of the Thesis

This thesis is prepared according to "Publishable manuscript" format of the Sokoine University of Agriculture. It is organized into seven chapters precede by an extended abstract that summarizes the objectives, materials and methods, principal research findings and conclusion of this study. Chapter one consists of the general introduction that covers

agro-pastoralism practiced in different continents, benefits and limitations of agro-pastoralism, importance of plants diversity in agro-pastoral system, effect of agro-pastoralism on nutritive value of pasture, effect of agro-pastoralism on soil properties, problem statement, justification of the study, objectives of the study, research hypothesis, scope and limitations of the study, conceptual framework and organization of the thesis. Chapter two, three, four and five presents the results obtained from each specific objective which are synthesized into either published paper (paper I, paper II and paper III) or prepared manuscript (paper IV) submitted for publication in peer reviewed scientific journal. Chapter six covers general discussion of the results. Chapter seven covers key findings, general conclusions and recommendations. The format and writing style of published papers was according to requirements of respective journals.

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CHAPTER TWO

PAPER ONE

Panorama of agro-pastoralism in western Serengeti: A review and synthesis

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Abstract

Agro-pastoral production system in western Serengeti is subsistence oriented livelihoods directed towards attaining self-sufficiency in food and livestock production and supporting growing human population. Production strategies involves the extensive use of land cultivating for food and cash crops production, and fallowing land. Households form the basic units of production, which utilize land, family labour, livestock keeping and any capital at their disposal to meet their production goals. Livestock, especially cattle have great symbolic value regarded as a bank on hoves, and a basis for various traditional transactions that makes households strive to increase livestock capital. Analysis of crops production and livestock population trends reveal that agro-pastoral system expand due to increase in prices of livestock products. Paucity of land to absorb the growing human and livestock population caused the political and administrative machinery to develop and implement village land use plans to ensure proper land utilization. However, introduction of land use plans alone is not a panacea to land use problems in villages. It was envisaged that land use plan should be accompanied by introduction of sustainable crops and livestock production systems by improving productivity of land in terms of pasture and crops to support the current human and

livestock population in the Western Serengeti. The future direction of agro-pastoralism in Western Serengeti under these circumstances is not well understood. This entails a need for a multidisciplinary study of impact of agro-pastoralism on livelihood of people in Western Serengeti.

Key words: *land use, food security, western Serengeti*

Introduction

Western Serengeti is situated in agro-ecological zones 1/5 and 1/4 (FINNIDA/GRT 1981) and encompasses Serengeti, Bunda, Magu and Bariadi districts. These zones are low potential agricultural areas marginally suitable for arable agriculture. Average annual rainfall ranges between 500-1200 mm, declining towards the Park boundary and increasing towards Lake Victoria (Campbell and Hofer 1995). The area is highly diverse in terms of ethnicity with more than 20 ethnic groups living in the area, the major ethnic groups including Ikoma, Sukuma, Kurya, Ikizu, Natta, Isenye, Zanaki, Zizaki, Ngoreme, Taturu and Jita. The main ethnic groups in Western Serengeti are agro-pastoralists and studies indicate that it is among the most densely populated areas in the Greater Serengeti ecosystem with population growth rates exceeding those to the north, east and south of the National Park (Kideghesho 2010).

Agro-pastoralism relates to a practice of growing crops and keeping livestock as a livelihood strategy (Kerven et al 2011). It is a production system that relies on environmental factors including rainfall and natural resources such as land and natural pastures. Agro-pastoralism emerged as pastoralism systems experienced chronic pressure to alter their land use as a consequence of multiple forces. This include government policy oreiented against the nomadic lifestyle of pastoralism, farming, wildlife conservation; immigration, population growth; encroachment of agriculture; a governmental bias against pastoralists and extreme environmental circumstances, particularly droughts and floods (Olson 2006). The government policies create positive and negative impacts on agro-pastoral production system depending on the interpretation by the state machinery on one hand and agro-pastoralists on the other hand. The general assumption, which normally is adapted by the government technocrats in developing policies, is that the state functions as the motor of development and serves as the central means by which to fulfil social aspirations and bring about positive change in all communities in the country. This perception put emphasis on proper land use plans to accommodate resource needs of different communities. However, agro-pastoralists' perception on resource-use is characterized by diversification strategies to spread risk and flexible mechanisms that allows movement of animals in certain periods. Livestock possession is a central traditional element of agro-pastoral culture. Without livestock, aperson will not have social status, power and cannot support a family. Animals form an integral part of social life, economic and ideological values that guarantee the survival of individuals and the continuity of agro-pastoral system. Livestock is to a large extent seen as a a bank on hooves in many pastoral communities.

Food security

Food is a basic need necessary for supporting the survival of human populations in any society. Human population dynamics in the area determines food demand and security over resources required for food production within ecosystem. Evaluation of population census reports indicates a rapidly growing human population in Western Serengeti from 1960s until the 2010s where the population growth leveled off (Figure 1).

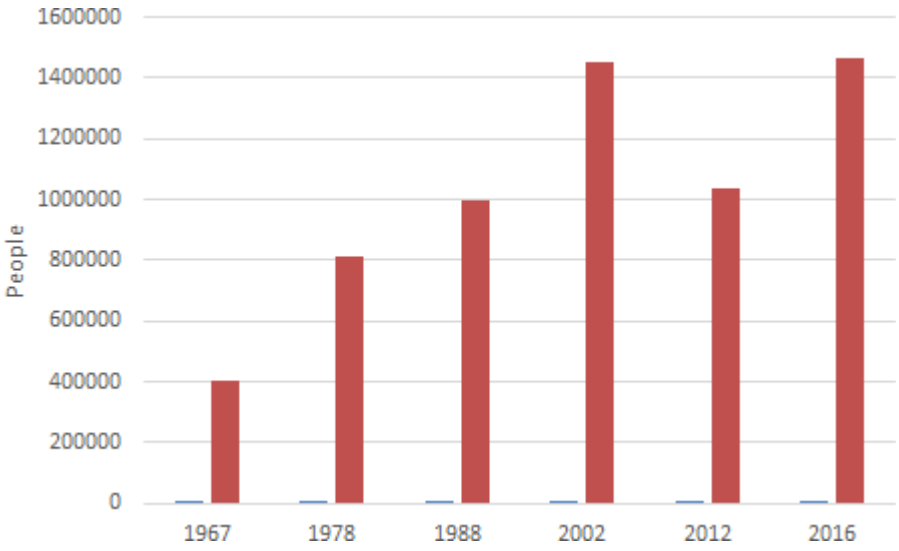

Figure 1. Human population in western Serengeti
Source: *Authors' computation from National Bureau of Statistics reports*

This suggests an increasing demand for food to support this growing population. Increase in population consequently caused an impact on the Serengeti ecosystem due to increased demand of land to grow crops. Several studies have demonstrated the role of human demography in dictating the magnitudes of ecological pressures in the Serengeti ecosystem (Campbell and Hofer 1995; Loibooki et al 2002; Songorwa 2004; Kideghesho et al 2005).

Food crops production in western Serengeti is basically small scale holdings using traditional low efficient methods of the ethnic groups residing in this area. Increase in food production to meet population growth requirement in western Serengeti is mainly based on expansion of cultivated land. This is shown by the similarity of food crops production trend (Figure 2) and the trend of land cultivated for food crops production shown in figure 3.

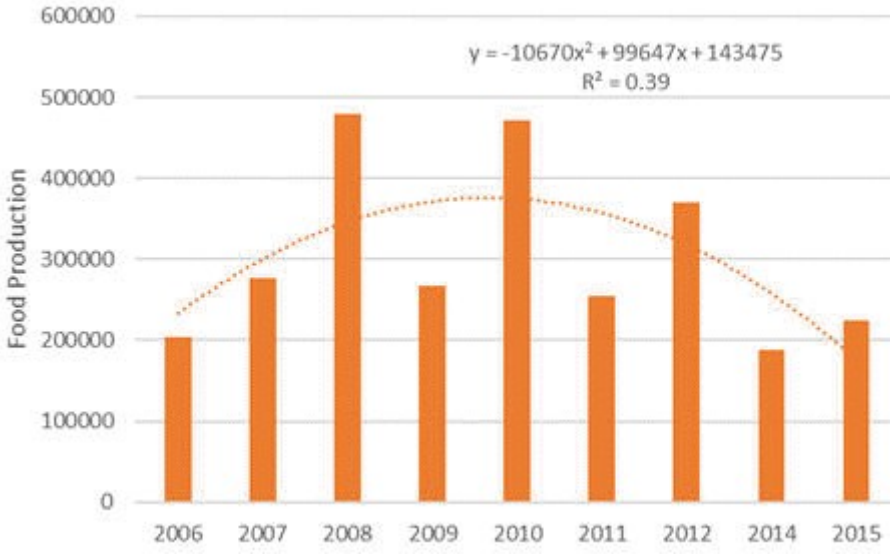

Figure 2. Food crops production in western Serengeti
Source: *Authors' computation from Agriculture census reports and Ministry of Agriculture and Food Security statistics unit*

Expansion of land for food crops production in western Serengeti decreased after 2008 due to increase in human population within limited land and crop raiding caused by wildlife.

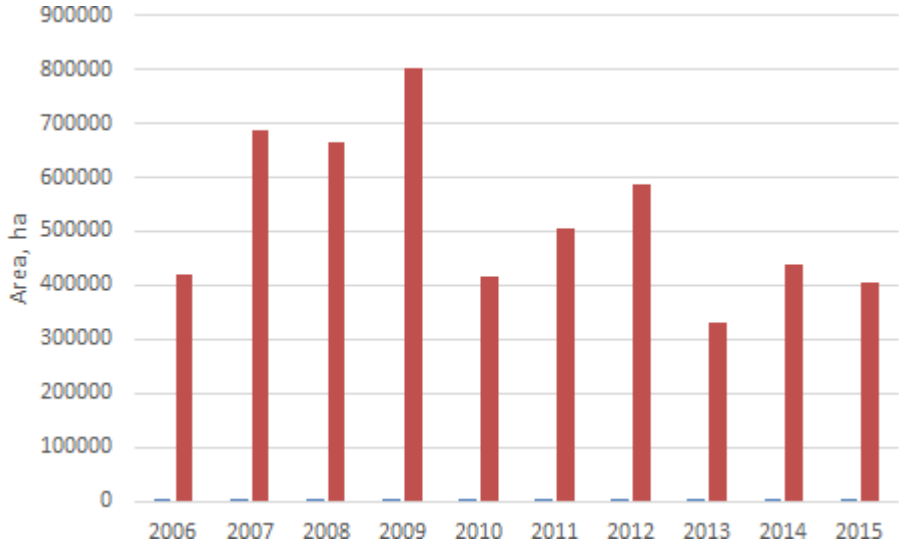

Figure 3. Land cultivated for food crops production in western Serengeti
Source: *Authors' computation from Agriculture census reports and Ministry of Agriculture and Food Security statistics unit*

Field observation and discussion with farmers indicated that high incidences of crop raiding by elephants caused many farmers to abolish cultivation in areas adjacent to protected areas. This situation poses food insecurity threat in western Serengeti. Results shown in figure 4 indicate decrease in food availability per person per year after reaching a peak in 2008.

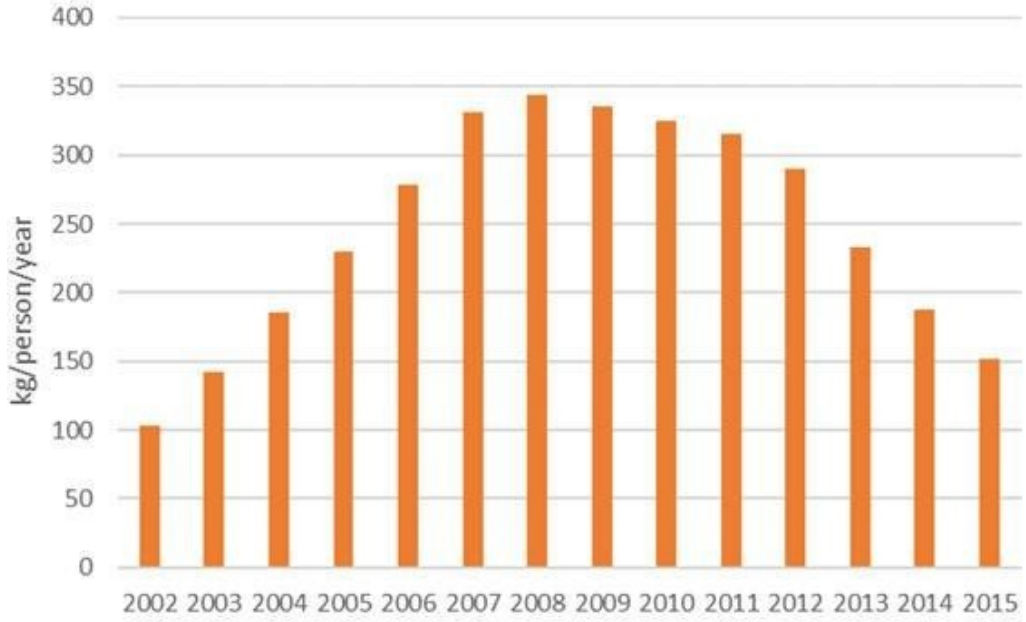

Figure 4. Food availability in western Serengeti

Source: *Authors' computation from National Bureau of Statistics census reports*

According to Frongillo and Nanama (2012), household food insecurity occurs when food is not available, cannot be accessed with certainty in socially acceptable ways, or is not

physiologically utilized completely. Food security in Tanzania is normally measured in terms of amounts of grains harvested, bought, and received freely per capita per year. Generally, households with less than 200 kg per capita per year are considered to be food insecure (Kayunze 2008). This implies that western Serengeti experienced periods of food insecurity between 2002 to 2004 and from 2014 to 2016. Food insecurity is not only expressed in terms of food crops alone as also animal protein is necessary for a normal balanced function of the human body.

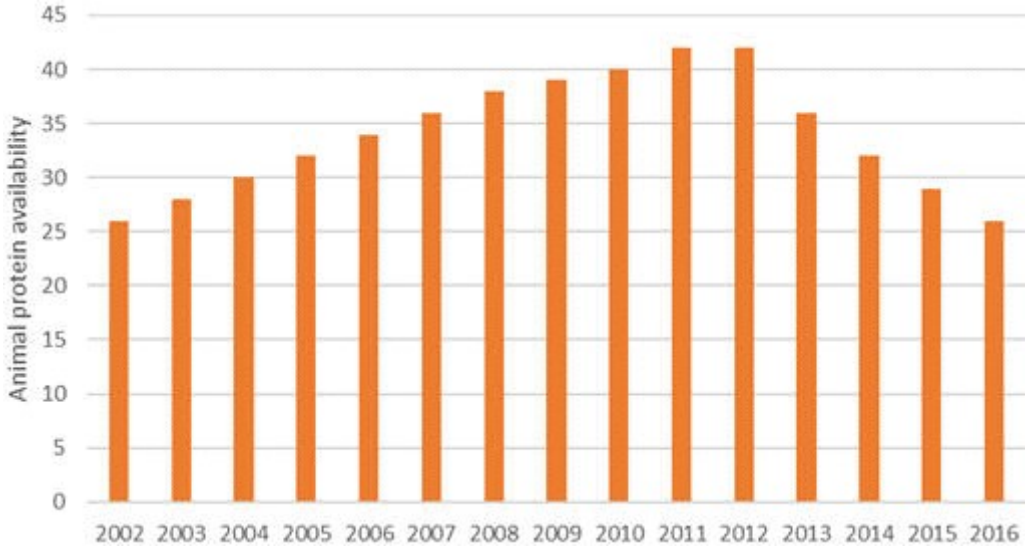

Figure 5. Potential daily supply of animal protein in western Serengeti
Source: *Authors' computation from Human population and livestock census, livestock offtake rate of 10%, dressing percentage of 52% for cattle and 50% for goats and sheep*

Joseph and Ajayi (2002) recommended that a minimum nutrient requirement to be consumed per day per capita for crude protein must at least include 40% (i.e., 26 g) animal protein. Hence, western Serengeti experienced inadequate animal protein production in 2002 and 2016 (Figure 5). The decreasing ruminant livestock population trend shown in figure 6 might exacerbate food insecurity problem in western Serengeti further in the future.

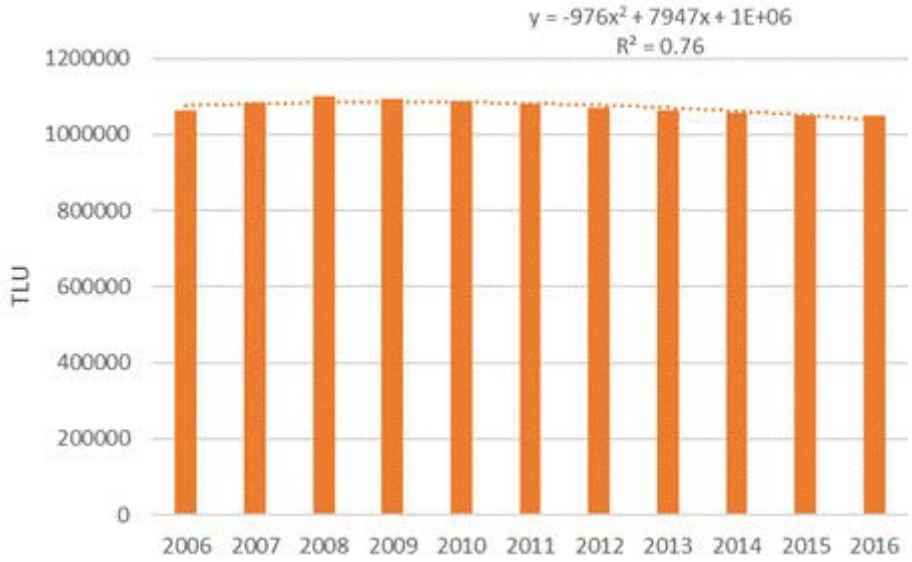

Figure 6. Aggregate ruminant livestock units in western Serengeti
Source: *Authors' computation from Tanzania National Bureau of Statistics census reports, District councils annual reports, Jahnke (1982) and Management of Animal Genetic Resources, Ministry of Agriculture, Livestock and Fisheries of Tanzania*

The decrease in aggregate livestock units observed is attributed to a decline in number of cattle and sheep that are mainly grazers as compared to goats (Figure 7).

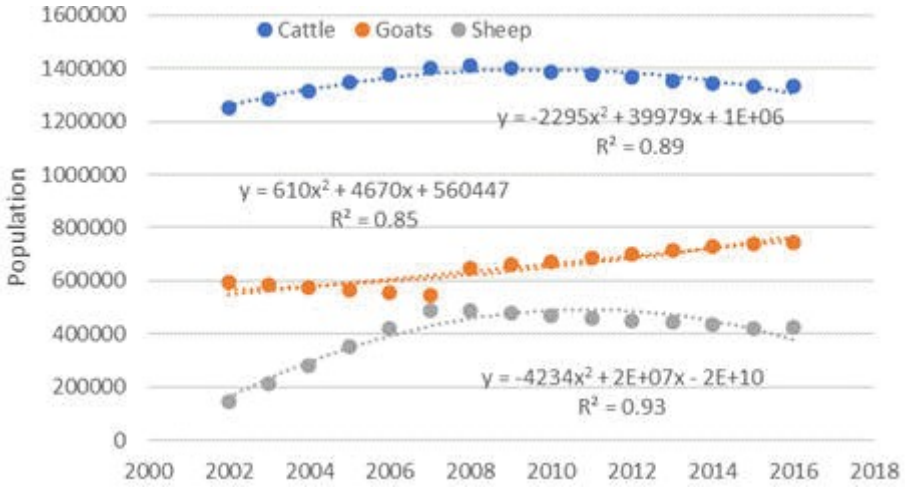

Figure 7. Ruminant livestock population in western Serengeti
Source: *Authors' computation from District Councils Annual Reports and National Bureau of Statistics Agriculture census reports*

The slight decrease in number of cattle and sheep might be caused by unfavourable condition for cattle and sheep (grazers) such as unavailability of pasture to support grazers in village lands. Unfavourable condition on village lands might have compelled livestock keepers to shift cattle and sheep to other grazing areas. However, a detailed study on changes in agro-pastoralism activities in western Serengeti is needed to justify this argument. Detailed study

might establish a base for developing sustainable agro-pastoral production model to ensure food security in western Serengeti for supporting human population.

Economic importance of agro-pastoralism in western Serengeti

The contribution of agro-pastoralism to the economy of people in western Serengeti and the nation is largely invisible.A direct result of the contribution of agro-pastoralism to the people of western Serengeti and national economy is however, the fact that the people do not rely on imported meat and staple food, but rely entirely on local production. Existing trade in agro-pastoral areas in western Serengeti and Tanzania in general is difficult to document. Records are scattered, and it is in general poorly documented because informal trade dominates formal trade in many areas. From the scattered, often anecdotal information that does exist, it is clear that, the value and the potential of agro-pastoralism in the economy of western Serengeti is significant. Figure 8 indicate that returns from meat produced in western Serengeti is increasing thereby generating billions of money to traders.

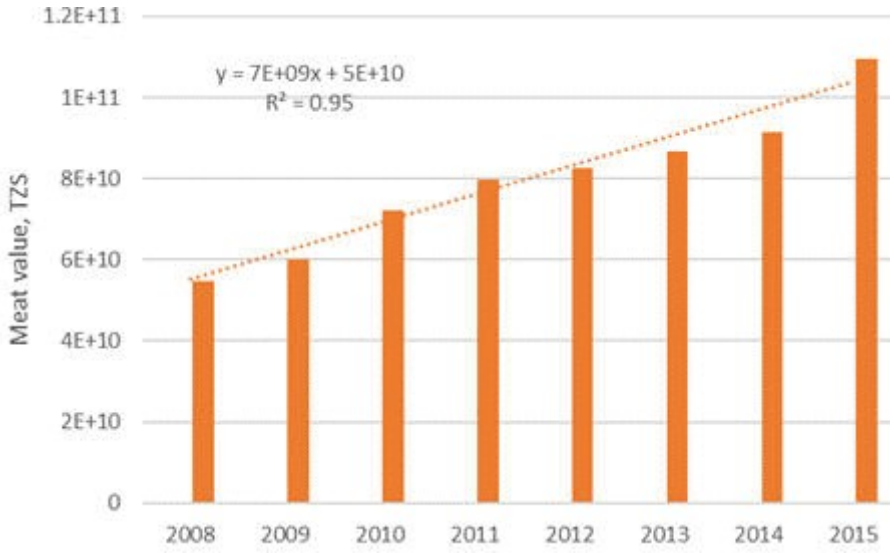

Figure 8. Value of meat produced in western Serengeti
Source: *Authors' computation from Tanzania data abstracts of National Bureau of Statistics, District Councils Annual Reports and East African Community Facts and Figures Report of 2016*

The value of meat produced increased despite of a slight decline in numbers of cattle and sheep as demonstrated in figure 7. This could be attributed to steady yearly increase in price of meat that makes livestock production a lucrative business. This makes people in western Serengeti continue focusing on livestock keeping as one of the sources of income for households but the increase in livestock population is limited by availability of feed resources within village lands. On the other hand, the value generated by maize production in western Serengeti (Figure 9) decreased steadily due to decrease in production while production of maize in other places within the country increased that stabilized maize price.

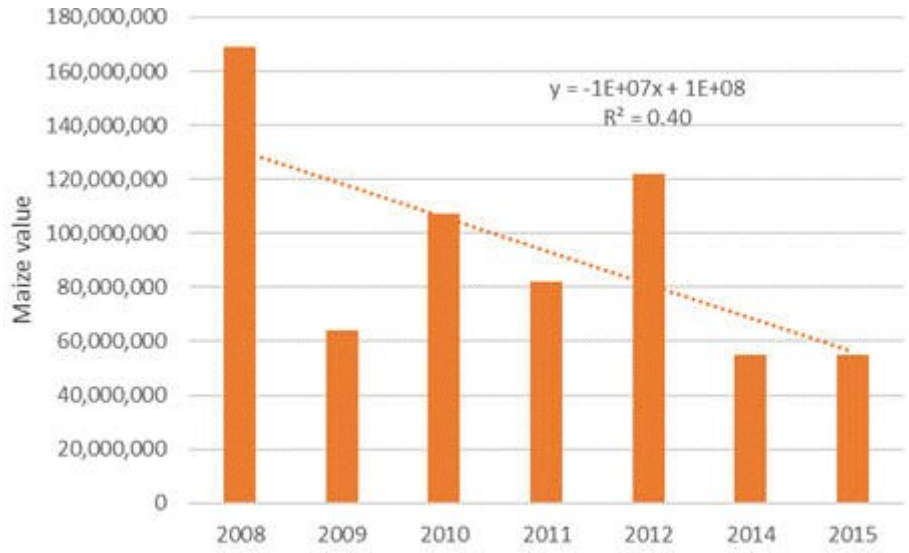

Figure 9. Value of maize (TZS) produced in western Serengeti
Source: *Authors' computation from Tanzania data abstracts of National Bureau of Statistics*

The decline in value of maize production together with crop raiding by wild animals in western Serengeti contributes to abandoning of maize farming as source of cash income and instead shifting the focus to producing mainly for subsistence.

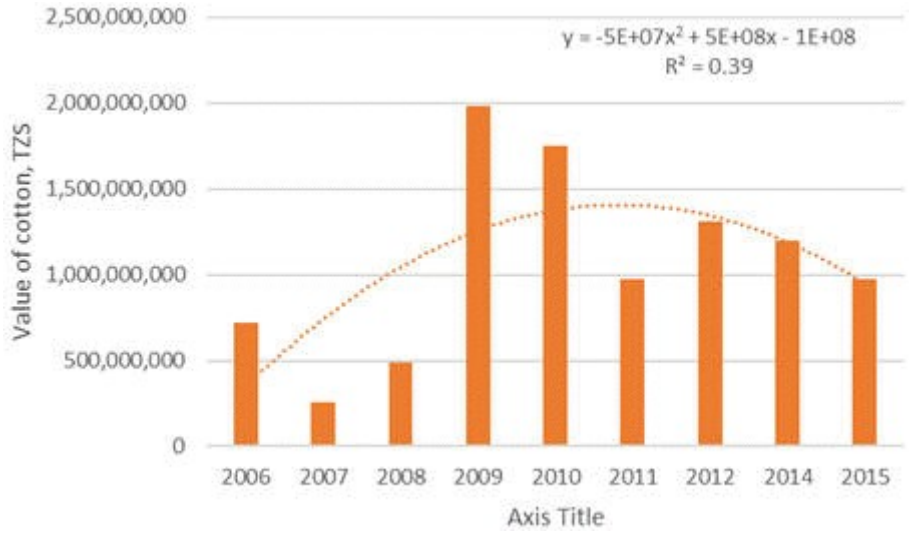

Figure 10. Value (TZS) of cotton produced in western Serengeti
Source: *Authors' computation from Tanzania data abstracts of National Bureau of Statistics*

The value of cotton produced as a cash crop (Figure 10) decreased steadily from 2012 probably due to a decrease in the price of cotton combined with crop raiding problems in western Serengeti. However, the overall value of agro-pastoralism activities that include monetary values of crops and livestock produced in western Serengeti (Figure 11) indicates a steady increase mainly due to the contribution made by income generated from livestock business.

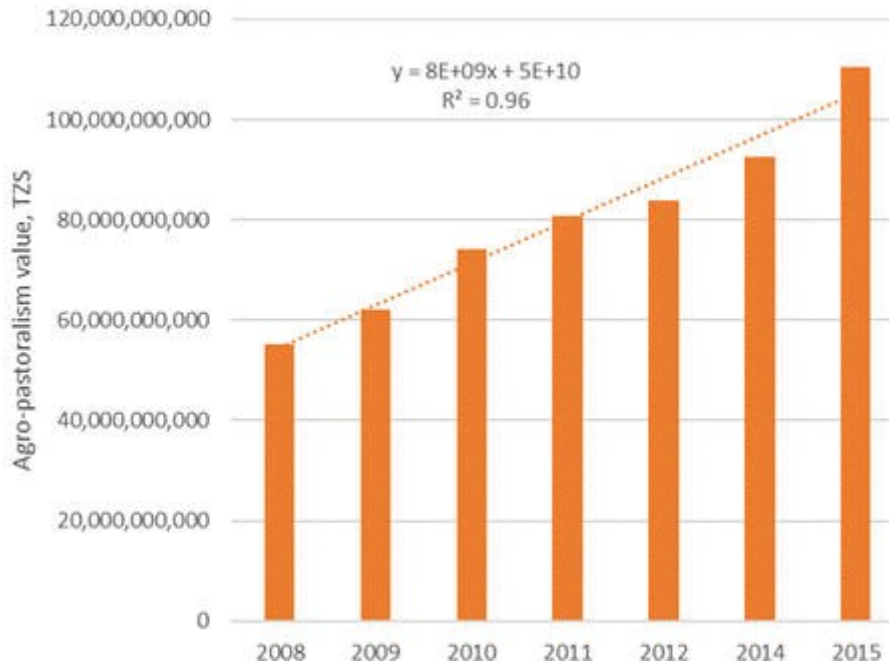

Figure 11. Overall value of agro-pastoralism in western Serengeti
Source: *Authors' computation from Tanzania data abstracts of National Bureau of Statistics, District Councils Annual Reports and East African Community Facts and Figures Report of 2016*

This indicates that livestock keeping is an important economic activitity for agro-pastoral communities in western Serengeti. Sustainable livestock and crops production in western Serengeti is nessessary to prevent agro-pastoral communities in western Serengeti from falling into poverty due to declining trends shown in terms of livestock numbers and crops production.

Land Use

Land available for crops and livestock production in western Serengeti is estimated to 1,203,798 ha. Results in figure 12 indicate decrease in land cultivated for crop production from 2010 to 2016. This situation has increased the area of fallow land that is normally used for livestock grazing.

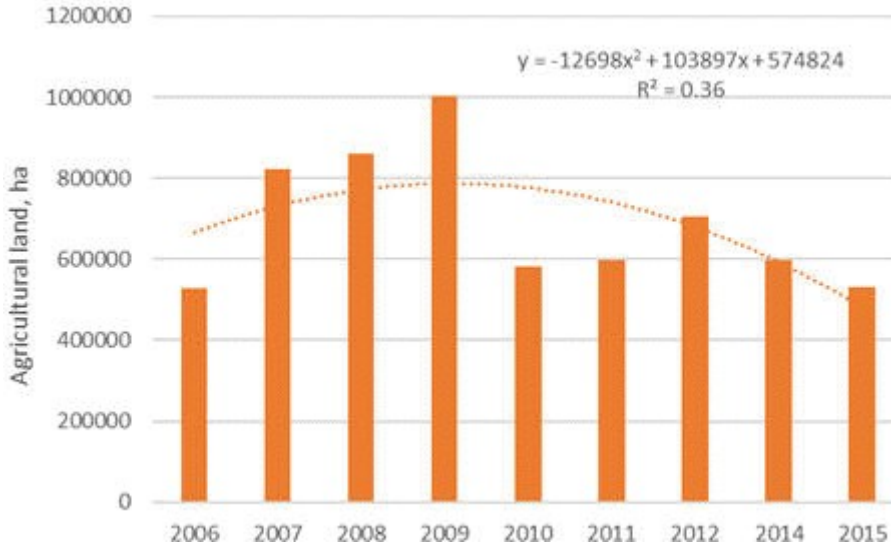

Figure 12. Land cultivated for crop production in western Serengeti
Source: *Authors' computation from Agriculture census reports and Ministry of Agriculture and Food Security statistics unit*

Although decrease in cultivated land provided fallow land reflected in increased grazing land per animal unit as shown in figure 13, the individual pald parcles available are very small (0.40
– 0.62 ha/TLU/year) compared to the national average of 3.4 ha/TLU/year (NBS, 2016).

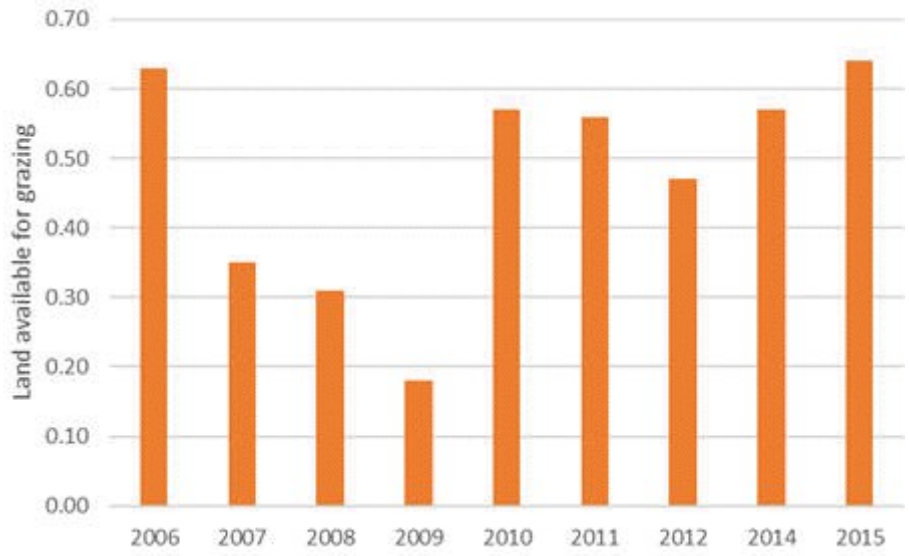

Figure 13. Land availability for livestock grazing in western Serenge
Source: *Authors' computation from Agriculture census reports and Ministry of Agriculture and Food Security statistics unit*

This indicates that grazing land available in western Serengeti may be insufficient to support the current population of livestock without detrimental effects to the land itself. This entails a need for detailed study on effect of livestock grazing on vegetation and soil properties in western Serengeti. In an endeavour to ensure proper land utilization in western Serengeti, the Government introduced land use plans in some villages. However, in practice there is limited implementation of land use plans in villages probably due to poor involvement of stakeholders

and lack of necessary expertise at the planning stage. Result presented in Figure 14 reveal that >50% of village lands were allocated for crop production while <10% of village lands were allocated for grazing livestock.

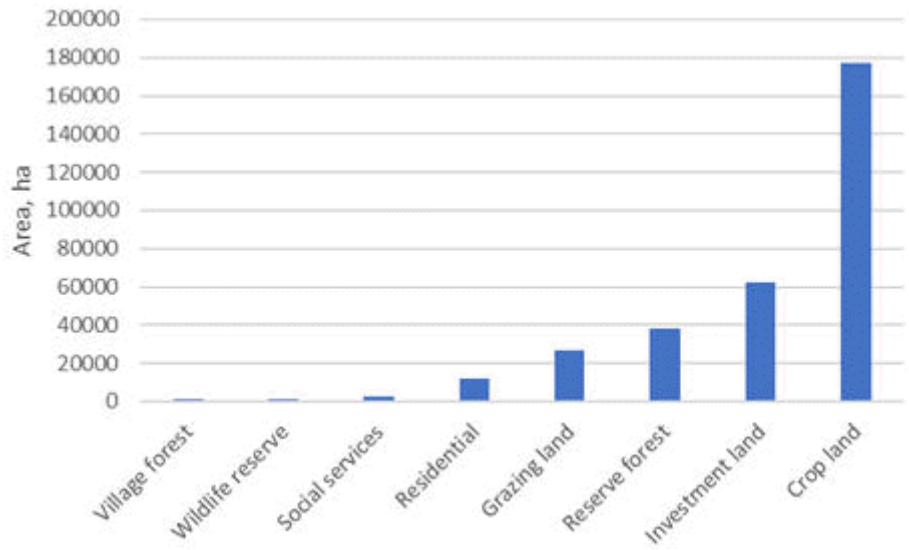

Figure 14. Land allocated for different uses in western Serengeti
Source: *Authors' computation from Tanzania's National Land Use Commission baseline data*

Based on the current livestock population of 1,049,363 TLU and a national average carrying capacity of 3.4 ha/TLU/year, grazing land required for livestock in western Serengeti is 3,567,834 ha (356.8 km^2). This is three times the size of land available (1,203,798 ha) for both crop and livestock production in western Serengeti. Certainly, the implementation of land use plans as currently shown in this study is not a panacea to proper land utilization. Introduction of land use plans in villages should be accompanied with introduction on development of sustainable agro-pastoralismby improving the productivity of land in terms of pasture and crops production to support the human and livestock population currently existing in western Serengeti.

Conclusion

- Human and livestock population in western Serengeti is high relative to land available for food crops and livestock production under prevalent traditional farming techniques.
- The determinants of the direction that agro-pastoralism is developing in western Serengeti is not clearly understood. A combined model including economic, social and ecological components could enable predictions about the future of agro-pastoralism in this area.
- The current development and implementation of land use plans will not be a panacea to solve land use problems in the area unless accompanied by introduction of sustainable crops and livestock farming strategies.

Implication

There is a need to study agro-pastoralism in detail through multidisciplinary approach so as to derive a scenario that depicts the situation existing in western Serengeti. Improvement of pasture productivity for livestock grazing and forage conservation techniques are required for sustainable livestock production in western Serengeti so as to maintain the current livestock population.

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CHAPTER THREE

PAPER TWO

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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 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.

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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).

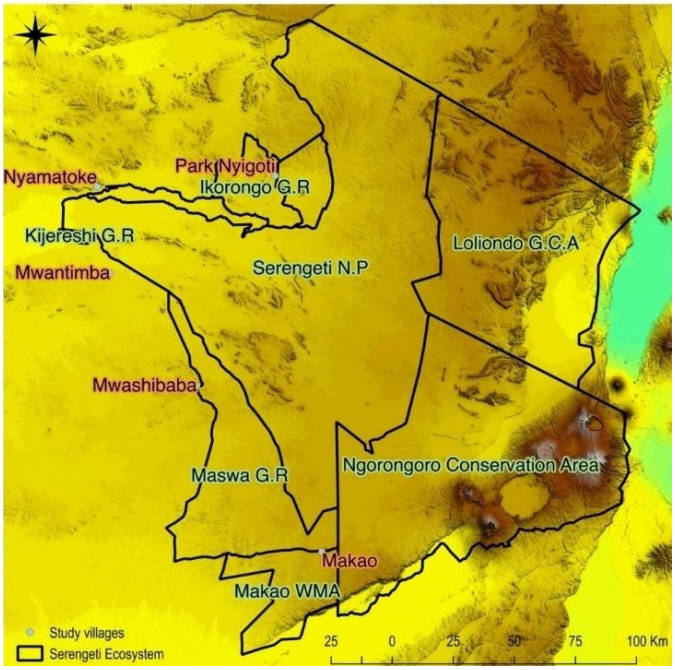

Figure 1. Map of Serengeti ecosystem showing the study sites in western Serengeti.

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:

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 pacage 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.

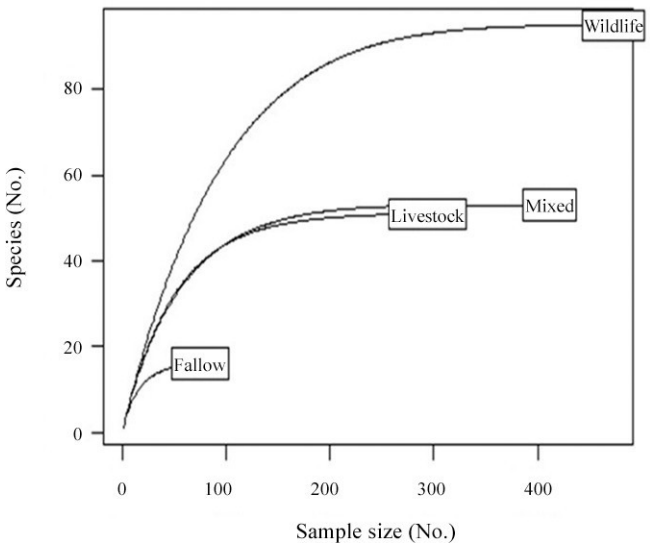

Figure 2. Herbaceous plant species accumulation curves in different land use types in western Serengeti, Tanzania.

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*.

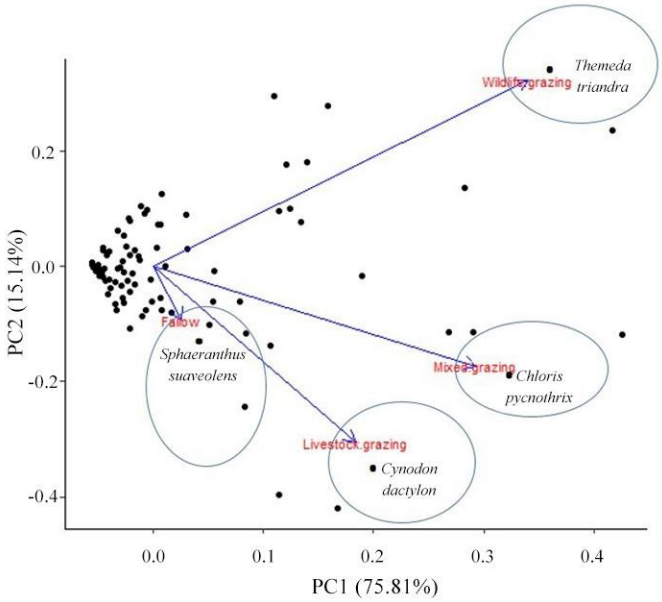

Figure 3. Ordination of plant species composition based on land use type.

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.

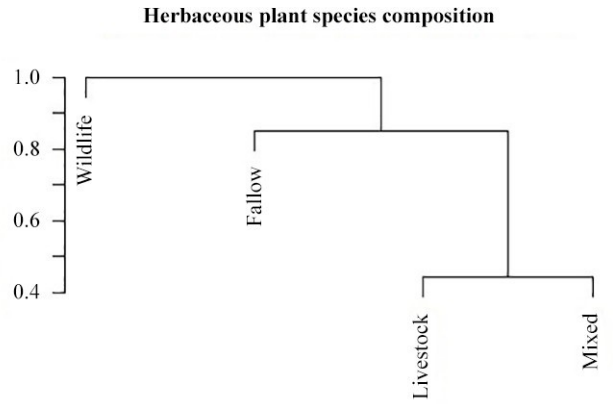

Figure 4. Cluster analysis of herbaceous plant species composition for different land uses.

Herbaceous plant species diversity

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

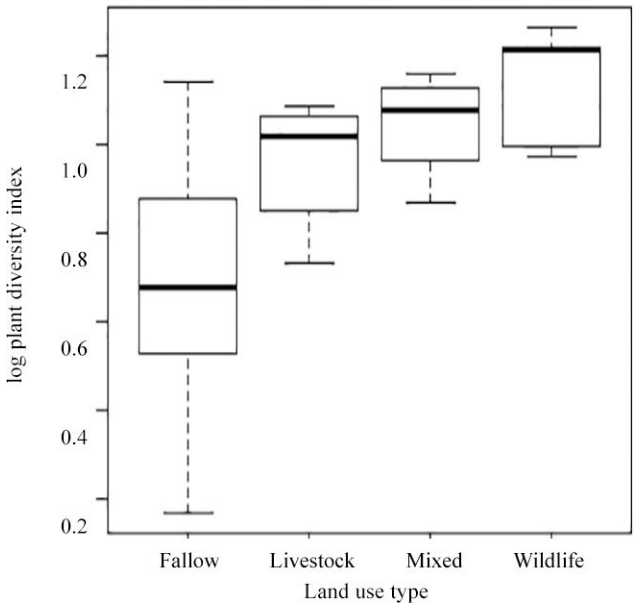

Figure 5. Comparison of herbaceous plant diversity among different land use types.

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).

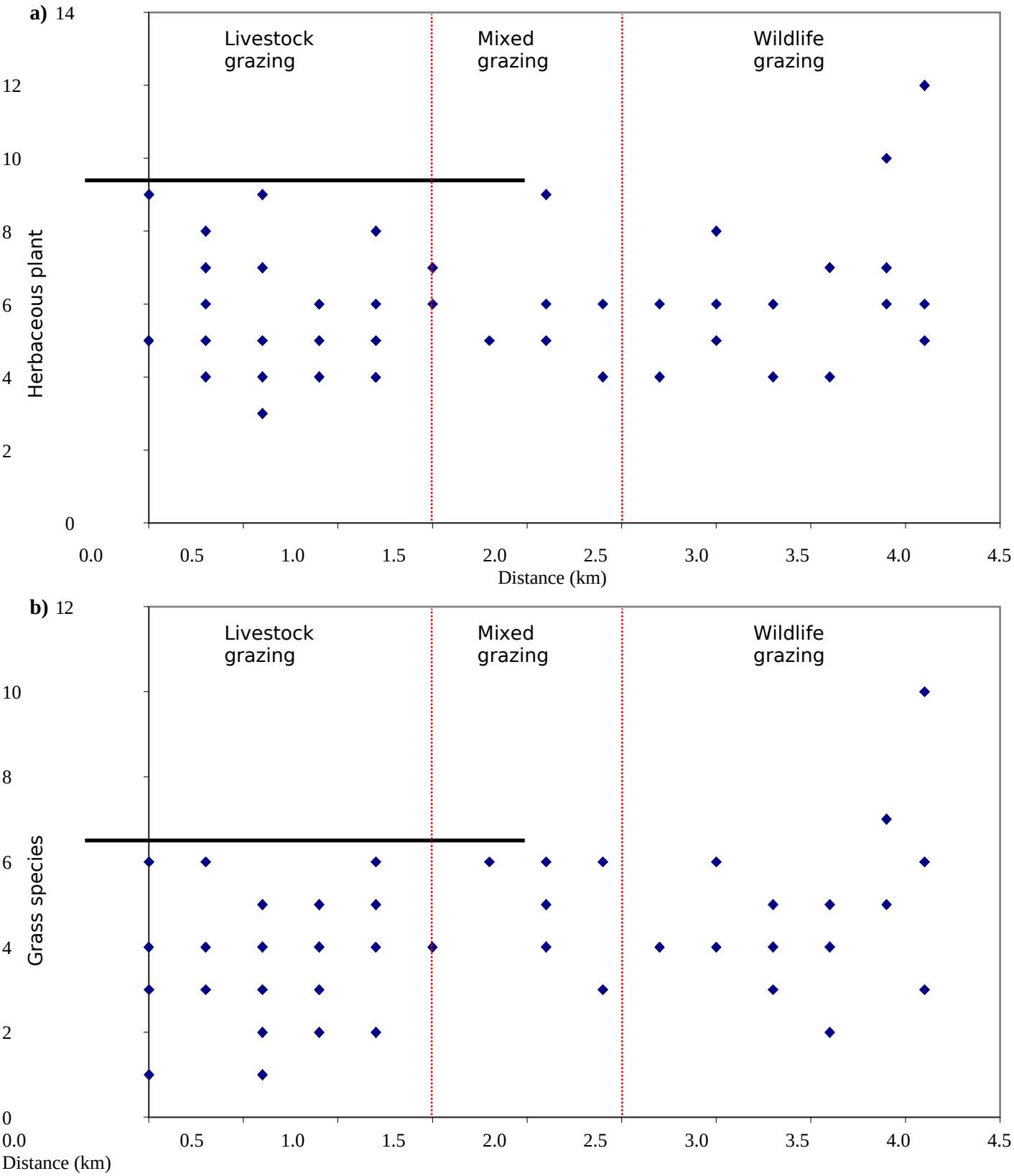

Figure 6. Availability of herbaceous plant species in western Serengeti as a function of location (distance from village to protected areas) and grazing strategy: a) all species; b) grasses only.

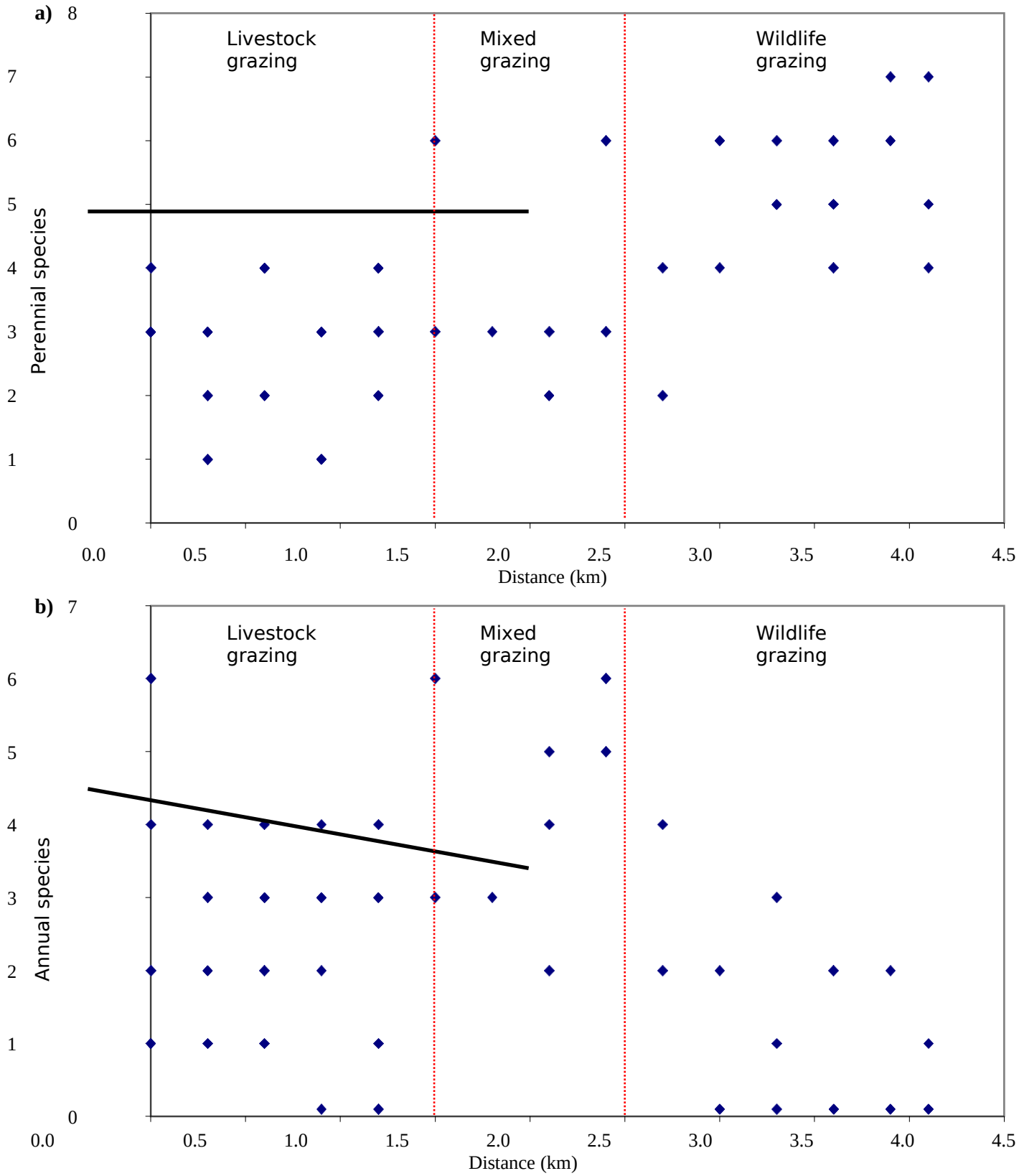

Figure 7. Availability of perennial (a) and annual (b) species as a function of location (distance from village to protected areas) and grazing strategy.

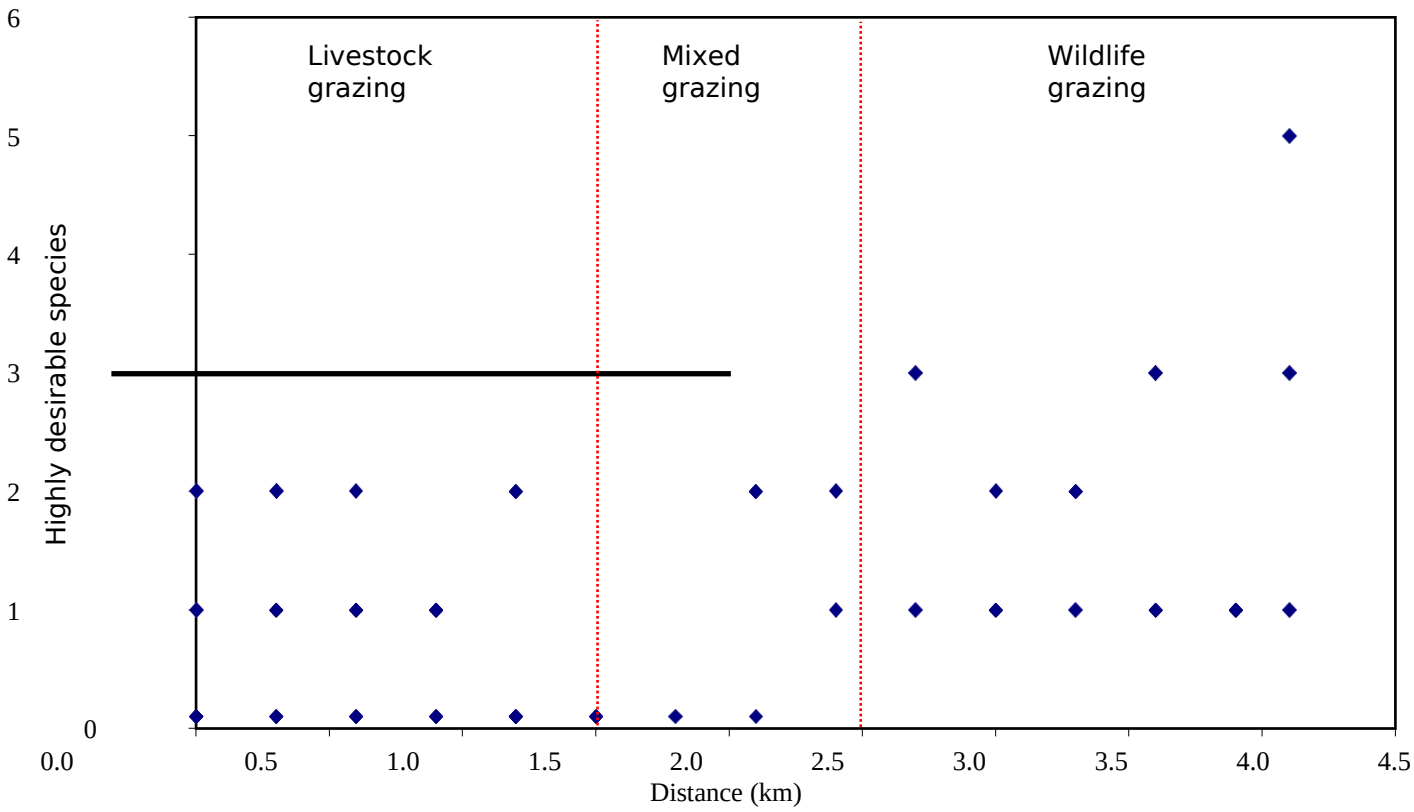

Figure 8. Availability of highly desirable herbaceous plants as a function of location (distance from village to protected areas) and grazing strategy.

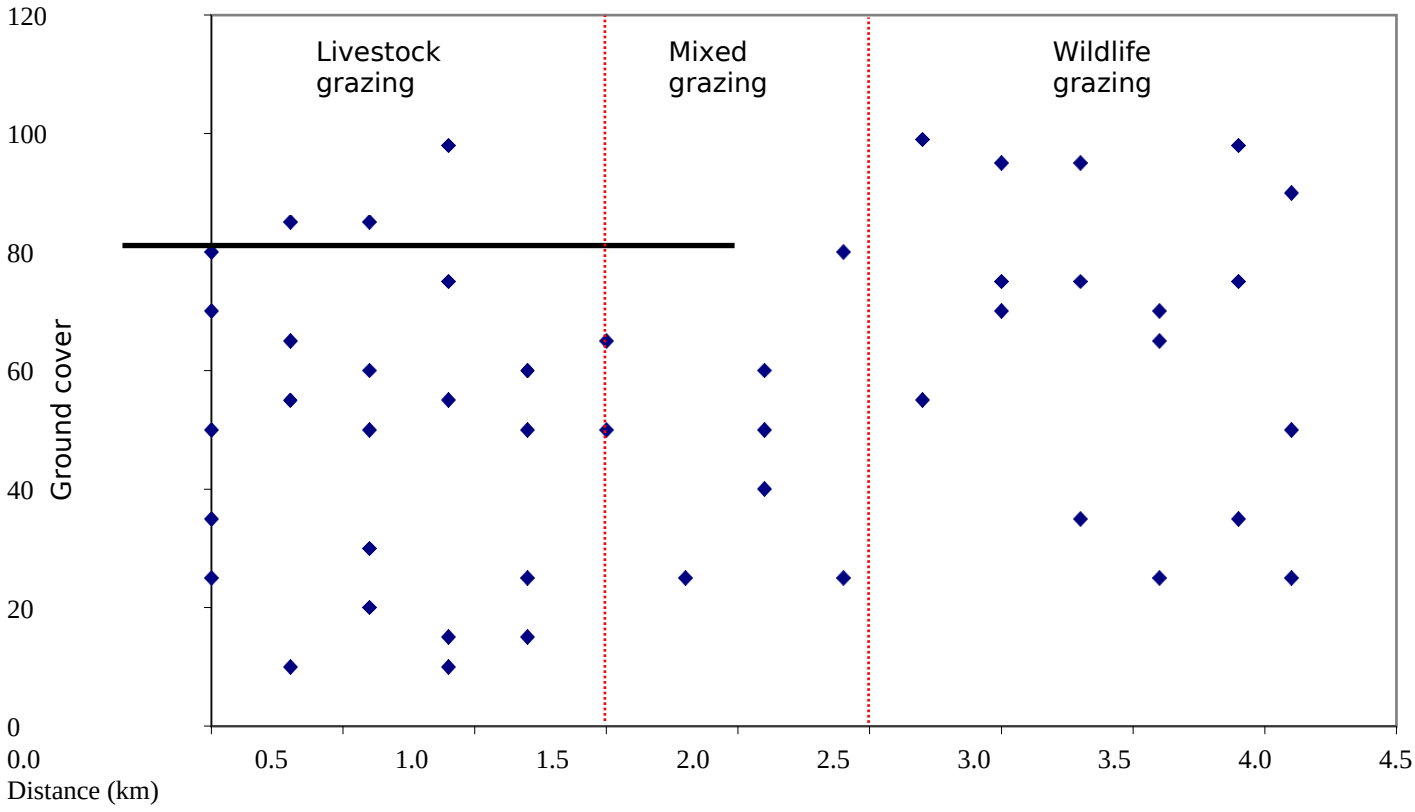

Figure 9. Ground cover of herbaceous plants as a function of location (distance from village to protected areas) and grazing strategy.

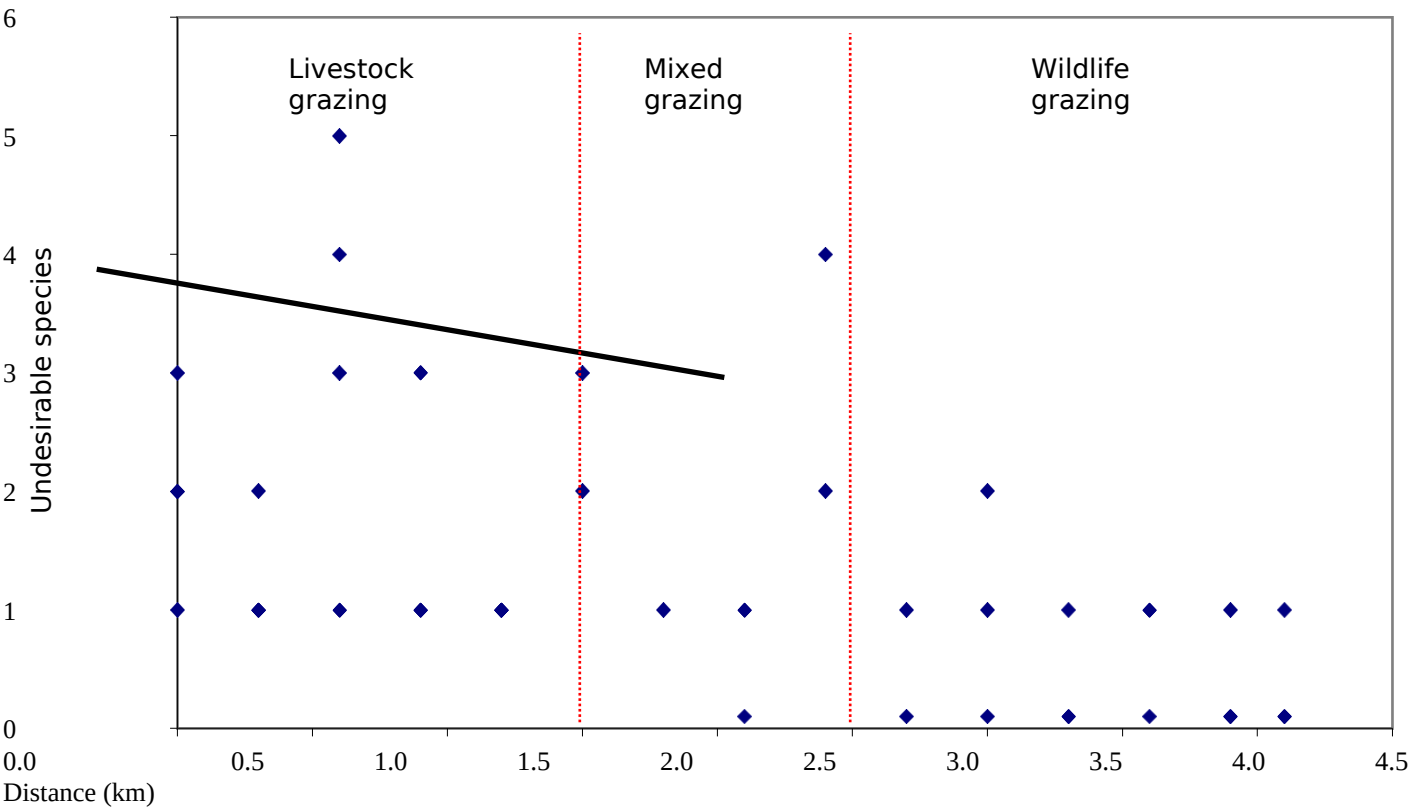

Figure 10. Undesirable herbaceous plants as a function of location (distance from village to protected areas) and grazing strategy.

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%, respec- tively. 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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(Note of the editors: All hyperlinks were verified 18 November 2019.)

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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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CHAPTER FOUR

PAPER THREE

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Research Paper

How does agro-pastoralism affect forage and soil properties in western Serengeti, Tanzania?

¿Cómo afectan actividades agro-pastoriles el forraje y las características del suelo en Serengeti occidental, Tanzania?

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Abstract

The impacts of agro-pastoral activities on soil properties, plus nutritive value and residual standing biomass of herbaceous plants in areas of different land uses in western Serengeti, were evaluated. Vegetation and soil were sampled along 4,000 m transects laid across fallow land, areas grazed only by livestock, mixed grazing (livestock and wildlife) and wildlife grazing only. A total number of 123 plant species were encountered during sampling. Analyses of soil and vegetation samples were conducted at Sokoine University of Agriculture laboratories. The estimated average density of grazing animals encountered was 160 TLU/km^2 on transects within livestock-dominated grazing lands, 129 TLU/km^2 for mixed grazing and 83 TLU/km^2 for wildlife grazing only. Results indicated that ADF, IVDMD, IVOMD, ME and TDN in residual herbaceous forage at flowering were significantly ($P<0.05$) affected by land use type but CP, NDF and ADL were not affected. Soil pH, OC, CEC, C:N ratio and Ca differed significantly ($P<0.05$) between land use types. An overall evaluation indicated that regardless of climatic conditions, residual biomass of herbaceous plants in western Serengeti is determined by intensity of grazing, soil C:N ratio and concentrations of Ca and P in the soil. We conclude that agro-pastoral practices conducted in western Serengeti affected residual standing biomass of herbaceous plants and soil properties. We recommend that grazing pressure in communal grazing lands be reduced by either reducing number of grazing animals or duration of grazing in a particular grazing area, and specific studies be conducted to establish stocking rates appropriate for specific communal grazing lands in villages.

Keywords: Grazing pressure, land use type, nutritive value, residual standing biomass.

Resumen

En el oeste de la región de Serengeti, Tanzania, se evaluaron los impactos de diferentes actividades agropastoriles en las características del suelo, la biomasa residual y el valor nutritivo de las plantas herbáceas. Para el efecto se tomaron muestras de la vegetación y del suelo a lo largo de transectos de 4,000 m en áreas con diferentes sistemas de uso: (1) barbecho; (2) pastoreo con ganado (vacunos,

caprinos y ovinos); (3) pastoreo mixto con ganado y animales silvestres; y solo (4) pastoreo por animales silvestres. En total fueron identificadas 123 especies diferentes de plantas. Los análisis de las muestras de suelo y plantas fueron realizados en los laboratorios de la University of Agriculture de Sokoine. Se encontró que la densidad promedio de animales estimada fue de 160 unidades tropicales de ganado (TLU)/km^2 en áreas de pastoreo por solo ganado, 129 TLU/km^2 en áreas de pastoreo mixto, y 83 TLU/km^2 en áreas de pastoreo solo por animales silvestres. Los resultados mostraron que en la época de floración de la vegetación utilizada para pastoreo, la fibra detergente ácida, la digestibilidad in vitro de la materia seca, la digestibilidad in vitro de la materia orgánica, la energía metabolizable y el total de nutrientes digestibles en la biomasa herbácea residual fueron afectados ($P<0.05$) por el tipo de uso del suelo. Por el contrario, la proteína cruda, la fibra detergente neutra y la lignina detergente ácida no fueron afectados. El pH del suelo, la capacidad de intercambio catiónico, las concentraciones de carbono orgánico y calcio (Ca) y la relación C:N fueron diferentes ($P<0.05$) en los diferentes tipos de uso del suelo. Una evaluación general indicó que, independiente de las condiciones climáticas, la biomasa residual de las plantas herbáceas en el oeste de Serengeti está determinada por la intensidad del pastoreo, la relación C:N del suelo y las concentraciones de Ca y P en el suelo. Los resultados permiten concluir que las prácticas agropastoriles en el oeste de Serengeti afectan la biomasa residual de las plantas herbáceas utilizadas por los animales en pastoreo, y las características del suelo. Los resultados sugieren (1) la necesidad de reducir la intensidad de pastoreo en las tierras comunales de la región, bien disminuyendo el número de animales en pastoreo o la duración del pastoreo en un área en particular, y (2) realizar estudios específicos para determinar ciclos de uso y cargas animal apropiadas en zonas de pastoreo comunal específicas.

Palabras clave: Biomasa residual, presión de pastoreo, uso de la tierra, valor nutritivo.

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Introduction

Agro-pastoralism as a livelihood strategy involves some traditional and contemporary 'best-bet' practices such as deferred grazing, in Tanzania traditionally known as Ngitiri or Alalili, grass band cultivation, zay pit cultivation, traditionally known as Ngoro system, and controlled grazing. The best-bet agro-pastoral practices are considered to contribute to sustainable systems due to reduced disturbance to soil and native plants, resulting in retention of diverse plant species that contribute to high primary production. However, some agro-pastoral practices, such as keeping large herds of livestock within a small grazing area, exert high grazing pressure on plant species and soil (Veblen 2008), affecting species composition and abundance. Other practices, such as unlimited expansion of cultivated land, affect availability of herbaceous species due to land clearing, thereby reducing the feed resource base for grazing animals. Both livestock keeping and cultivation are important for the livelihood of people in western Serengeti, so good land use planning is needed to accommodate both activities.

Both land clearing and cultivation disrupt stable ecosystems (Cassman and Wood 2005) and result in changes in species composition of vegetation that consequently influence the quantity and quality of herbaceous plants available (Butt and Turner 2012). Herbaceous plants are the primary feed resource for grazing animals in western Serengeti, so any significant disturbance to herbaceous vegetation affects performance of grazing animals in the ecosystem. This suggests a need for careful consideration when allocating specific areas for either grazing or cropping as establishing cultivation within grazing lands might reduce availability of natural feed resources but availability of crop residues could offset the reduction.

Both the human population and conversion of pasture lands to cropping are increasing in western Serengeti (Estes et al. 2012). However, little is known (Nortjé 2015; Lankester and Davis 2016) regarding the effects of agro-pastoralism on soil properties, livestock and wildlife performance, forage richness and diversity and biomass production. Increased human and livestock populations around the Serengeti National Park resulted in progressive livestock encroachment in the western part of the Park. Currently, no scientific study has been conducted to evaluate contradicting views between conservationists and agro-pastoralists on the effects of agro-pastoralism on conservation of wildlife in protected areas of the western part of the Serengeti ecosystem.

This work was designed to evaluate the impacts of agro-pastoral activities on soil properties plus standing biomass and quality of the herbaceous plant layer in western Serengeti. It was hypothesized that there are no variations in quantity and quality of residual standing biomass of herbaceous plants and soil properties as a result of agro-pastoral activities in fallow, livestock, mixed and wildlife-dominated land use types.

Materials and Methods

Study area

The study was conducted in western Serengeti, which is part of the Serengeti ecosystem as shown in Figure 1. Average annual rainfall ranges between 500 and 1,200 mm, declining towards the Serengeti National Park boundary and increasing towards Lake Victoria to the west (Sinclair et al. 2000). However, rainfall during the study period ranged from 400 to 900 mm. Western Serengeti is occupied by agro- pastoralists and is one of the most densely settled areas in the

Greater Serengeti ecosystem with human population growth rates exceeding those to the north, east and south of the National Park (Kideghesho 2010). The study was conducted in 4 districts by selecting villages that were adjacent to protected areas as shown in brackets, namely: Serengeti district (Park Nyigoti), Bunda district (Nyamatoke), Meatu district (Makao) and Bariadi district (Mwantimba and Matale). While the western Serengeti is considered to be unsuitable for arable agriculture, the subsistence economy depends mainly on agro-pastoralism (Emerton and Mfunda 1999), which is constrained by inadequate inputs of resources, e.g. fertilizers, and poor delivery of agricultural extension services, and people in villages practice extensive cropping and livestock keeping, which encroaches on protected areas (Mfunda and Røskaft 2011).

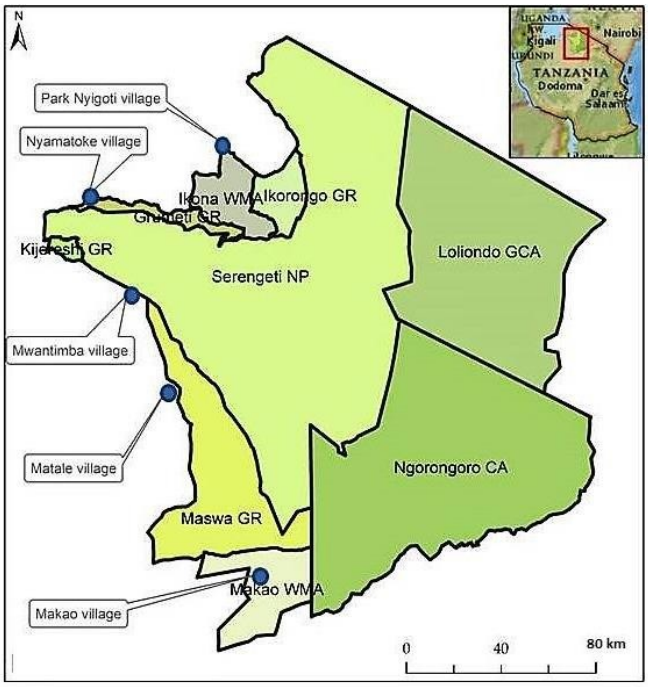

Figure 1. A map of Serengeti ecosystem showing the study sites and protected areas in western Serengeti. CA = Conservation Area; GCA = Game Controlled Area; GR = Game Reserve; NP = National Park; WMA = Wildlife Management Area.

Field data collection

Vegetation was sampled at the peak blooming period of herbaceous plants during April and May 2016 and 2017 to enable field identification by inflorescences. Herbaceous plants were sampled along 4,000 m transects in selected villages that were adjacent to protected areas. Transects were aligned in each village to cross different land use types in such a way that each transect started in village land and progressively traversed 0–1,000 m in lands dominated by cropping, 1,000–2,000 m in lands dominated by livestock grazing, 2,000–3,000 m crossing the boundary between village land and protected areas, where mixed grazing of livestock and wildlife occurred, and the remaining 3,000–4,000 m was in the protected areas dominated by wildlife grazing. A 0.25 m^2 quadrat was used to sample herbaceous plants at 100 m intervals along each transect. The sampling distance was established during a reconnaissance survey as this frequency ensured that 80–100% of the herbaceous plant species in the study areas would be encountered. Before harvesting, overall herbaceous plant ground cover in each quadrat was estimated visually and expressed as percentage cover. All plant species within quadrats were identified, clipped and weighed for determination of standing dry matter available. Species not identified in the field were taken to the National Herbarium in Arusha for identification. Samples were air- dried in the field and then re-dried to a constant weight in a vacuum oven at 50 °C for 48 hours in a laboratory. The dry samples were ground in a Wiley mill to pass through a 1-mm screen for subsequent laboratory analyses. Follow- ing harvesting of forage, soil sampling was conducted at the central point of each quadrat to a depth of 30 cm at every 300 m along each transect.

Densities of both livestock and wildlife in the study areas were estimated based on observations made along transects during sampling periods. Livestock species commonly observed in study sites included cattle, goats and sheep, while wildlife included wildebeest, zebra, topi, impala, Grant's gazelle, reedbuck and Thomson's gazelle; elephant were encountered once on the border between Maswa Game Reserve and Matale village. Throughout the sampling process, all wildlife and domestic grazing animals spotted within 200 m either side of each transect were identified and counted. Animal counts were converted to tropical livestock units (TLU) based on the respective species average weights, where 1 TLU = 250 kg live weight according to LEAD/FAO (1999).

Laboratory analyses of plant samples

Laboratory analyses included neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), crude protein (CP), in vitro dry matter digestibility (IVDMD) and in vitro organic matter digestibility (IVOMD); they were performed in the laboratory at the Sokoine University of Agriculture. Standard laboratory methods were used as described by Van Soest et al. (1991) for NDF, ADF and ADL, and AOAC (1990) for CP. IVDMD was determined by the Tilley and Terry (1963) method. Total digestible nutrients and metabolizable energy were estimated according to Undersander and Moore (2004) and Spörndly (1989), respectively.

Laboratory analysis of soil samples

Soil samples were taken for determination of soil texture, pH, organic carbon (OC), total N, available P, Ca and CEC according to standard procedures (Okalebo et al. 2002).

Data analysis

Variation of residual standing biomass and nutritive value of herbaceous plants plus soil properties among different land use/grazing types were analyzed by using R statistical software version 3.5.3. Assessment of collinearity among explanatory variables was performed using stepwise variance inflation factor (VIF), whereby all predictor variables were initially included in the linear regression equation. Variables with VIF greater than 4 were eliminated from the model progressively, while the predictor variables with VIF less than 4 were retained. The resulting linear regression model was then used to assess variables that were significantly associated with the response variable standing biomass. Herbaceous plant species association was analyzed by using null model according to Griffith et al (2016). Prominence of herbaceous plant species in different land use types was categorized into 4 groups based on the range of occurrence of all species (0–10.7%). The groups were classified as less common (0–2.7%), common (2.8–5.5%), more common (5.6–8.3%) and most common (8.4–11.1%). Analyses were performed using pooled data for respective land use type with type III sum of squares in ANOVA. Distribution of herbaceous plant species on identified soil texture classes was analyzed according to Heberle et al. (2015).

Results

Herbaceous plant community properties

Average density of grazing animals observed on the various land use types was estimated as 160 TLU/km^2 on livestock-dominated grazing lands, 129 TLU/km^2 on transects dominated by mixed grazing and 83 TLU/km^2 on wildlife grazing areas. A total of 123 plant species (Appendix 1) were encountered during sampling; occurrence of common species is shown in Table 1.

Table 1. Occurrence (%) of common herbaceous plant species in different land use types in western Serengeti.

Species[1]	Land use type			
	Fallow	Livestock grazing	Mixed grazing	Wildlife grazing
Aristida kenyensis Henrard (Poaceae)	0.3	2.3	6.3*[2]	0.0
Bidens schimperi Sch.Bip. ex Walp. (Compositae)	0.0	2.0	4.7*	1.0
Blepharis linariifolia Pers. (Acanthaceae)	0.0	0.3	4.7*	0.7
Bothriochloa insculpta (A. Rich.) A. Camus (Poaceae)	1.0	1.7	0.3	3.7*
Brachiaria semiundulata (Hochst.) Stapf (Poaceae)	1.3	6.0**[3]	7.3**	4.3*
Chloris pycnothrix Trin. (Poaceae)	0.7	5.7**	10.7***[4]	6.0**
Chrysochloa orientalis (C.E. Hubb.) Swallen (Poaceae)	0.0	0.7	0.0	0.7
Cynodon dactylon (L.) Pers. (Poaceae)	4.0*	7.0**	2.0	0.7
Dactyloctenium aegyptium (L.) Willd. (Poaceae)	0.7	4.7*	8.0**	0.3
Digitaria macroblephara (Hack.) Paoli (Poaceae)	0.0	0.3	0.0	3.7*
Eragrostis racemosa (Thunb.) Steud. (Poaceae)	0.3	0.3	2.3	1.3
Eragrostis patula (Kunth) Steud. (Poaceae)	1.0	1.0	0.0	0.7
Euphorbia inaequilatera Sond. (Euphorbiaceae)	0.0	0.7	1.3	1.7
Heteropogon contortus (L.) P. Beauv. ex Roem. & Schult. (Poaceae)	0.0	0.0	0.0	4.7*
Hyperthelia dissoluta (Nees ex Steud.) Clayton (Poaceae)	0.0	0.0	0.0	4.3*
Indigofera hochstetteri Baker (Leguminosae)	0.0	1.3	1.3	3.3
Indigofera volkensii Taub. (Leguminosae)	0.0	1.3	0.7	3.3
Microchloa kunthii Desv. (Poaceae)	0.0	1.0	3.7*	3.7*
Panicum coloratum L. (Poaceae)	0.0	1.0	3.7*	3.7*
Portulaca quadrifida L. (Portulacaceae)	0.7	0.7	1.0	0.7
Sporobolus festivus Hochst. ex A. Rich. (Poaceae)	0.0	0.0	3.7*	5.0*
Sporobolus ioclados (Trin.) Nees (Poaceae)	0.0	2.3	1.3	2.0
Sporobolus pyramidalis P. Beauv. (Poaceae)	0.0	2.3	1.0	3.3
Themeda triandra Forssk. (Poaceae)	0.0	0.7	0.3	8.3**
Tragus berteronianus Schult. (Poaceae)	1.0	0.7	2.3	0.3

[1]Taxonomy according to The Plant List (theplantlist.org). [2]* = Common. [3]** = More common. [4]*** = Most common. Values without asterisks indicate less common.

Chloris pycnothrix was the most prominent in mixed grazing land use type and was more apparent in livestock and wildlife-dominated grazing land use types. *Aristida kenyensis*, *Bidens schimperi*, *Blepharis linariifolia*, *Microchloa kunthii*, *Panicum coloratum* and *Sporobolus festivus* were common in mixed grazing land use type, while *Brachiaria semiundulata* was apparent in wildlife-dominated land use type and appeared more commonly in both livestock- and mixed grazing land use types. *Dactyloctenium aegyptium* was noticeable in livestock-dominated grazing land use type and more common in mixed grazing land use type. *Digitaria macroblephara*, *Heteropogon contortus* and *Hyperthelia dissoluta* were prominent in wildlife-dominated grazing land use type. *Themeda triandra* was more common only in wildlife-dominated land use type. *Cynodon dactylon* was apparent in cultivated land use type and appeared more commonly in livestock-dominated grazing land use type. Association of herbaceous plant species was analyzed using 325 species pairs combinations that provided the results presented in Figure 2.

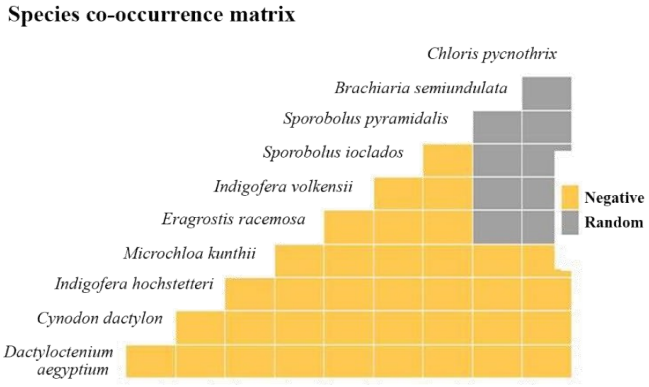

Figure 2. Association of herbaceous plant species in western Serengeti.

Results from Figure 2 show that *Dactyloctenium aegyptium*, *Cynodon dactylon*, *Indigofera hochstetteri* and *Microchloa kunthii* were negatively associated with other herbaceous plant species in the community. The negative association of *Cynodon dactylon* with other herbaceous plant species becomes more prominent under the influence of livestock grazing, while negative association of *Dactyloctenium aegyptium* with other herbaceous plant species became more prominent under the influence of mixed grazing of livestock and wildlife. The negative association of *Microchloa kunthii* with other herbaceous plant species became noticeable under the influence of wildlife grazing. However, the negative association of *Indigofera hochstetteri* with other herbaceous plant species is slightly apparent under the influence of wildlife grazing.

Results shown in Table 2 indicate that standing above-ground biomass of herbaceous plants in grazing lands at flowering was significantly ($P<0.05$) affected by land use type. Wildlife-dominated grazing lands carried 50% more standing above-ground biomass than livestock-dominated land. While ADF, IVDMD, IVOMD, ME and total digestible nutrients were significantly ($P<0.05$) affected by land use type, CP, NDF and ADL were unaffected.

Soil properties

Soil samples collected in different land use types revealed that clay is a major component in all soils of western Serengeti (Figure 3).

Five soil texture classes, namely: clay, sandy clay, sandy clay loam, clay loam and sandy loam, were identified from soil samples collected in this study with the former 3 types being most common (about 95%). Distribution of herbaceous plant species in the different soil texture classes is shown in a Venn diagram (Figure 4).

Table 2. Effects of land use type on residual standing biomass and nutritive value of herbaceous plants at flowering in western Serengeti.

Variable	Land use				P value	Significance
	Fallow	LG	MG	WG		
Biomass (kg DM/ha)	2,320b	2,126b	2,575ab	3,188a	0.02	*
CP (%)	9.2	9.0	8.4	8.4	0.19	NS
NDF (%)	62.9	62.4	60.7	60.0	0.76	NS
ADF (%)	33.4b	33.9ab	35.4ab	36.2a	0.01	**
ADL (%)	3.7	3.7	3.9	3.8	0.96	NS
IVDMD (%)	47.0a	39.5b	39.5b	40.1b	0.00	***
IVOMD (%)	49.0a	44.1ab	42.4b	42.2b	0.00	***
ME (MJ/kg DM)	5.6a	4.4b	4.4b	4.5b	0.00	***
TDN (%)	57.8a	57.6a	55.6ab	54.6b	0.00	***

Values within rows followed by different letters differ significantly ($P<0.05$). LG = Livestock grazing; MG = Mixed grazing; WG = Wildlife grazing.

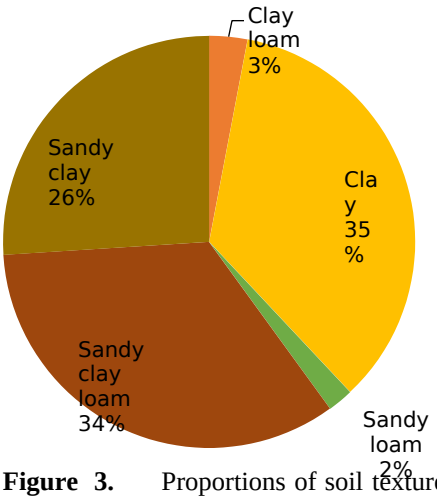

Figure 3. Proportions of soil texture classes in western Serengeti**.**

Figure 4 indicates that 12 herbaceous plant species were most common in clay soil, including: *Eragrostis tenuifolia*, *Achyranthes aspera*, *Brachiaria semiundulata*, *Commelina benghalensis*, *Digitaria milanjiana*, *Ocimum basilicum*, *Justicia exigua*, *Tragus berteronianus*, *Justicia matammensis*, *Cynodon dactylon*, *Chloris gayana* and *Lactuca capensis*. Three herbaceous plant species, i.e. *Oxygonum sinuatum*, *Sporobolus cordofanus* and *Digitaria eriantha*, were most common in sandy clay soil, while *Cycnium tubulosum*, *Setaria sphacelata*, *Heteropogon contortus*, *Indigofera hochstetteri*, *Chrysochloa orientalis*, *Euphorbia inaequilatera* and *Kyllinga nervosa* occurred mainly in sandy clay loam soil. *Corchorus aestuans* grew in sandy loam soil only. The species observed in both clay and clay loam soils was *Panicum coloratum*, while *Portulaca quadrifida* occurred in sandy loam and sandy clay loam soils. *Sporobolus festivus*, *Sporobolus ioclados* and *Dactyloctenium aegyptium* were found in 4 soil texture classes, namely: clay, clay loam, sandy clay loam and sandy loam, while *Bothriochloa insculpta* and *Themeda triandra* occurred in clay, clay loam and sandy clay loam soils. *Aristida kenyensis*, *Bidens schimperi* and *Blepharis linariifolia* were found in clay and sandy clay soils. A universal herbaceous plant species that was growing in all 5 soil texture classes was *Microchloa kunthii*.

Table 3 shows the average values of the measured soil parameters and reveals that soil pH, soil OC, CEC, soil Ca and soil C:N ratio were significantly ($P<0.05$) different among land use types.

Using stepwise variance inflation factor (VIF) of distance from communal grazing land towards protected areas, herbaceous ground cover and soil variables indicated that distance, cover, soil C:N ratio and Ca and P concentrations in the soil had VIF values below the threshold that sufficed development of a linear model (Table 4) for prediction of residual standing biomass (Figure 2) in western Serengeti.

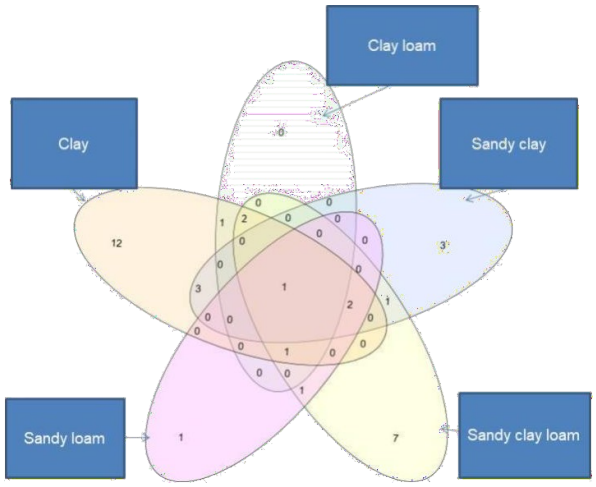

Figure 4. Distribution of herbaceous plant species in different soil texture classes in western Serengeti.

Figure 3 presents examples of the accuracy of this model in predicting residual standing biomass with the following equation:

$y = 1{,}278 + 0.49x$ ($r^2 = 0.46$), where:

y = predicted biomass; and x = actual biomass.

Table 3. Soil properties of different land use types in western Serengeti.

Parameter	Land use				P value	Significance
	Fallow	LG	MG	WG		
pH	7.2b	7.9ab	8.3a	7.4ab	0.0453	*
OC (%)	0.78b	1.64a	1.64a	1.32a	1.46a	**
P (mg/kg)	1.36	1.26	1.76	1.63	0.1620	NS
CEC (cmol/kg)	16.14b	23.94a	22.68a	23.73a	0.0008	**
Ca (cmol/kg)	10.52b	12.63b	18.10a	13.08b	0.0077	**
Total N (%)	0.10	0.13	0.12	0.12	0.5240	NS
C:N ratio	7.74b	14.10a	11.20	12.72a	0.0442	*

Values within rows followed by different letters differ significantly ($P<0.05$). LG = Livestock grazing; MG = Mixed grazing; WG = Wildlife grazing; NS = Not significant.

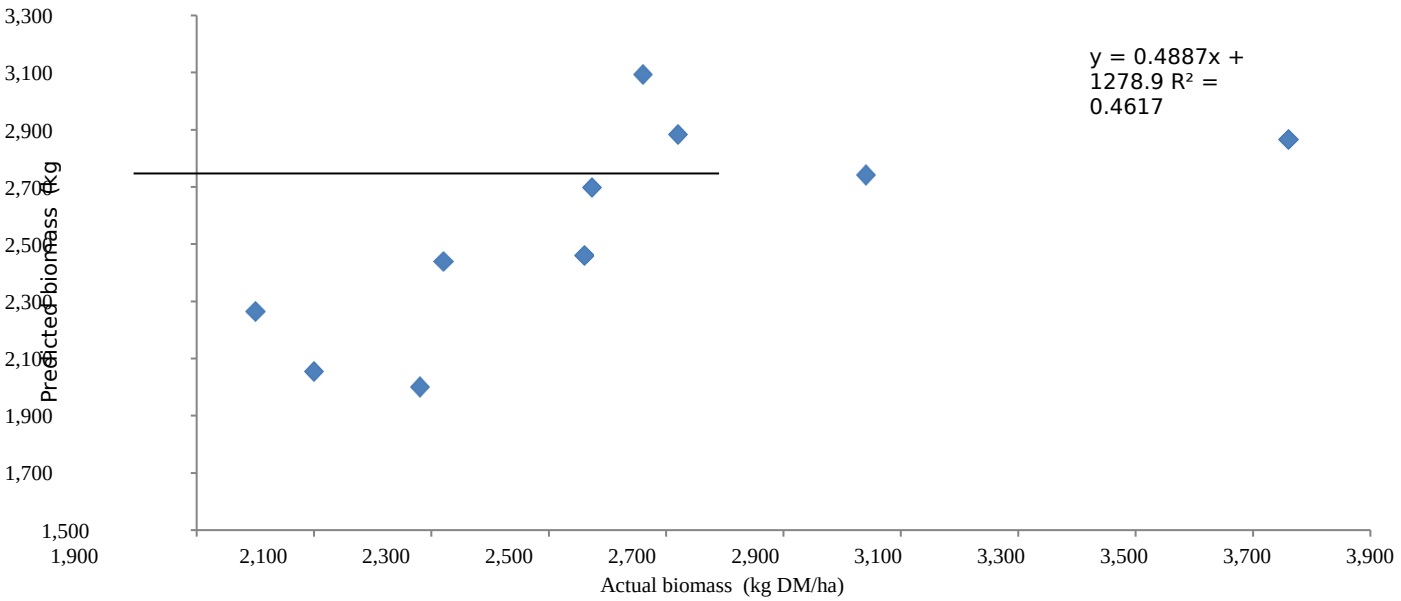

Figure 3. Residual standing biomass prediction model validation output.

Table 4. Variables for herbaceous plant residual standing biomass prediction model.

Variable	Coefficient (estimate)	VIF
Intercept	1,059.5	
Distance (m)	0.45	1.44
Cover (%)	11.67	1.40
Soil C:N ratio	16.70	1.25
Soil Ca (cmol/kg)	1.10	1.08
Soil P (mg/kg)	8.64	1.07

Model: Residual Standing Biomass = 0.45 Distance + 11.67 Cover + 16.70 C:N + 1.10 Ca + 8.64 P + 1059.54.

Discussion

Effects of agro-pastoralism on residual standing biomass

This study showed that grazing areas under high density of animals and continuous livestock grazing had lower residual standing biomass than areas with low animal density and intermittent animal grazing, e.g. in protected areas. This result was not surprising, given the different densities of animals grazing the different areas and hence grazing pressure applied. Low residual standing biomass levels on heavily grazed areas observed in this study are consistent with observations by Ngatia et al. (2015) in Kenya and Mbatha and Ward (2010) in South Africa. However, other studies on effects of grazing on standing biomass showed that the effect is site-specific, influenced by environmental conditions and grazing history (Osem et al. 2002; Jia et al. 2018). Livestock at high density tend to graze herbaceous plants to ground level without strong plant selection (Adler et al. 2001; Hayes and Holl 2003), which reduces the ability of livestock to graze out more desirable species. However, pastures need periodic rest periods to allow species to recover and it is up to herders to control these grazing patterns. In village lands, high density of domestic animals occurs during the rainy season and extends until late dry season, when communal grazing lands become bare. Herders then shift groups of animals to more remote areas in search of pastures, including trespassing in protected areas based on independent decisions of livestock owners. As a result grazing pressure on the village lands is reduced at this time. Wildlife, in contrast, move freely on grazing areas to select nutritious herbaceous plants depending on their mouth width and body weight (Fynn 2012; Bukombe et al. 2017) but at much lower grazing pressures. These differences in grazing pressure and duration of grazing on specific areas for livestock and wildlife obviously contributed to the big differences in residual standing biomass observed between livestock- and wildlife-dominated grazing lands. Cultivation resulted in low standing biomass of herbaceous plants due to removal of herbaceous plants in crop farms as they are viewed as weeds in the crops.

Effects of agro-pastoralism on nutritive value of herbaceous plants

While some significant differences in nutritive parameters for forage from the different land use types were recorded, the magnitude of most differences was scarcely significant from an overall perspective.

IVDMD and IVOMD were highest in herbaceous plants found in cultivated lands as compared with other land use

types, which is possibly a function of release of nutrients

from the soil during plowing/hoeing etc. plus plants not having been grazed and the more digestible components still being present. Energy is an important indicator of the nutritive value of feeds and considerably more nutrient is required to maintain normal energy metabolism than for all other purposes combined (Dietz 1970). The most common nutritional deficiency affecting range animals is lack of available energy in feeds, digestible energy or both (Michalk and Savile 1978; Corbett and Ball 2002). Results from this study showed that herbaceous plants found in cultivated lands and lands grazed by livestock had highest metabolizable energy and total digestible nutrients.

Effects of agro-pastoralism on soil properties

Clay formed the major texture component of soils of the study area in western Serengeti with a range from straight clay to sandy loams. As would be expected, different herbaceous plant species were found on the different soil types, which produced a mosaic pattern of herbaceous plants in the Serengeti ecosystem. The aggregation of herbaceous plants according to soil texture classes supports findings reported by Kavana et al. (2019), which showed soil texture as an important input variable in herbaceous plant ground cover models. *Microchloa kunthii* was the only herbaceous species present in all soil texture classes, highlighting the versatility of this species and its ability to compete with other herbaceous plant species by exhibiting negative association as shown in Figure 2.
While in general wildlife distribute their faeces and urine at random, except for camping areas where there is some accumulation of faeces, livestock deposit much of their faeces in specific areas such as kraals and other resting areas, where they are generally held at night. Returning of this manure to cultivated areas would help counteract the rundown of nutrients on fallow where lowest CEC and equally lowest soil OC, Ca, P, C:N ratio and pH were measured. Juo et al. (1995) in Nigeria and Lian et al. (2013) in China reported a decline in fertility on cultivated areas in the absence of fertilizer inputs.

Broader implications of agro-pastoralism on grazing land systems

In addition to weather conditions, residual standing biomass production in western Serengeti relies on a range of variables that affect the complex soil and plant systems. The finding that distance from the protected areas, ground cover, C:N ratio, soil Ca and P were key factors in determining amount of standing biomass was of interest. Distance from protected areas was possibly merely a reflection of the grazing pressure applied to the relevant areas as was ground cover. The C:N ratio indicates whether or not mineralization of N is taking place in the soil and the amount available to plants and is significantly correlated (Appendix 2) with CEC (r = 0.51), so is important. Soil Ca is important as building blocks for herbaceous plant cells as Ca has a structural role in the cell wall membranes and as a counter cation for inorganic and organic anions in the cell vacuole (Marschner 1995). The importance of P for fundamental processes of photosynthesis, flowering, fruit- ing (including seed production) and maturation of herba- ceous plants is well understood (Weil and Brady 2017).

Conclusion

This study contributes to the understanding of the ecological effects of agro-pastoralism on the herbaceous vegetation and soil properties in Western Serengeti. The results indicate that decrease in residue standing biomass and soil properties as a result of agro-pastoral activities is significant, highlighting the need for sustainable agro-pastoralism. It was shown that persistence and successful production of herbaceous plants in western Serengeti requires consideration of agro-pastoral activities that are not detrimental to adequate C:N ratio, and Ca and P concentrations in soil. Grazing pressure appeared to affect seriously residual standing biomass in communal grazing lands that requires reduction in order to allow recovery of herbaceous plants. Grazing pressure should be reduced by either reducing number of animals or duration of grazing on these lands. Specific studies should be conducted by respective local government authorities to establish appropriate stocking rates and grazing patterns for specific communal grazing lands in villages. Based on the findings, appropriate grazing strategies can be developed. Manure accumulated in kraals should be returned to at least cultivated areas to reduce soil run-down.

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(Note of the editors: All hyperlinks were verified 15 December 2020.)

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Appendix 1. Herbaceous plant species occurrence (%) in different land use types (taxonomy according to The Plant List; theplantlist.org).

No.	Species (Family)	Fallow	Livestock	Mixed	Wildlife	Overall
1.	*Abutilon mauritianum* (Jacq.) Medik. (Malvaceae)	0	0.283	0.243	0	0.189
2.	*Achyranthes aspera* L. (Amaranthaceae)	0	0.283	0.973	0	0.472
3.	*Aeschynomene indica* L. (Leguminosae)	1.136	0	0	0	0
4.	*Albuca kirkii* (Baker) Brenan (Asparagaceae)	0	0	0.243	0	0.094
5.	*Alternanthera pungens* Kunth (Amaranthaceae)	0	0	0	0.678	0.189
6.	*Amaranthus graecizans* L. (Amaranthaceae)	0	0	0.243	0	0.094
7.	*Andropogon greenwayi* Napper (Poaceae)	0	0.85	0.243	0	0.378
8.	*Aristida adoensis* Hochst. ex A. Rich. (Poaceae)	0	0	0.243	0.339	0.189
9.	*Aristida kenyensis* Henrard (Poaceae)	2.273	1.983	4.623	0	2.455
10.	*Asparagus africanus* Lam. (Asparagaceae)	0	0.567	0.487	0.339	0.472
11.	*Aspilia mossambicensis* (Oliv.) Wild (Compositae)	0	0	0	1.356	0.378
12.	*Bidens schimperi* Sch.Bip. ex Walp. (Compositae)	2.273	1.7	3.406	1.017	2.172
13.	*Blepharis linariifolia* Pers. (Acanthaceae)	0	0.283	3.406	0.678	1.605
14.	*Blepharis maderaspatensis* (L.) B. Heyne ex Roth (Acanthaceae)*	0	0	0.486	1.695	1.699
15.	*Bothriochloa insculpta* (A. Rich.) A. Camus (Poaceae)	4.545	3.966	2.676	3.729	3.399
16.	*Brachiaria brizantha* (A .Rich.) Stapf (Poaceae)	0	2.833	1.46	1.017	1.794
17.	*Brachiaria jubata* (Fig. & De Not.) Stapf (Poaceae)	0	0.567	0	0.678	0.378
18.	*Brachiaria semiundulata* (Hochst.) Stapf (Poaceae)	4.545	5.099	5.353	4.407	5.005
19.	*Brachiaria serrata* (Thunb.) Stapf (Poaceae)[1]	0	0.85	0.73	0	0.567
20.	*Cenchrus ciliaris* L. (Poaceae)	0	0.283	0	0.339	0.189
21.	*Centrapalus pauciflorus* (Willd.) H. Rob. (Compositae)	1.136	0	0	0.339	0.094
22.	*Chamaecrista mimosoides* (L.) Greene (Leguminosae)	1.136	0	0	0	0
23.	*Chloris gayana* Kunth (Poaceae)	2.273	0	0.73	1.356	0.661
24.	*Chloris pycnothrix* Thrin. (Poaceae)	4.545	5.949	8.029	6.102	6.799
25.	*Chloris virgata* Sw. (Poaceae)	0	0	0.243	0	0.094
26.	*Chrysochloa orientalis* (C.E. Hubb.) Swallen (Poaceae)	0	1.416	0.487	0.678	0.85
27.	*Cleome monophylla* L. (Cleomaceae)	2.273	0	0	0	0
28.	*Clitoria ternatea* L. (Leguminosae)	0	0.283	0	0	0.094
29.	*Commelina africana* L. (Commelinaceae)	0	0.567	0.243	0.339	0.378
30.	*Commelina aspera* G. Don ex Benth. (Commelinaceae)	0	0	0.243	0	0.094
31.	*Commelina benghalensis* L. (Commelinaceae)	2.273	0.567	0.487	0.678	0.567
32.	*Corchorus aestuans* L. (Malvaceae)	0	0.283	0.243	0	0.189
33.	*Corchorus trilocularis* L. (Malvaceae)	1.136	0	0	0	0
34.	*Craterostigma plantagineum* Hochst. (Linderniaceae)	0	0.85	0.487	0.339	0.567
35.	*Crotalaria spinosa* Benth. (Leguminosae)	0	1.416	0.243	0.339	0.661
36.	*Cycnium tubulosum* (L.f.) Engl. (Orobanchaceae)	0	0	0	1.017	0.283
37.	*Cymbopogon caesius* (Hook. & Arn.) Stapf (Poaceae)	3.409	0	0	0	0
38.	*Cynodon dactylon* (L.) Pers. (Poaceae)	13.636	7.082	1.946	0.678	3.305
39.	*Cynodon plectostachyus* (K. Schum.) Pilg. (Poaceae)	0	0	0	0.339	0.094

Continued

No.	Species (Family)	Fallow	Livestock	Mixed	Wildlife	Overall
40.	*Cyperus pulchellus* R.Br. (Cyperaceae)	1.136	1.216	0.73	1.017	1.138
41.	*Cyphostemma serpens* (Hochst. ex A. Rich.) Desc. (Vitaceae)	0	0	0.243	0	0.094
42.	*Dactyloctenium aegyptium* (L.) Willd. (Poaceae)	5.682	4.816	6.083	0.339	4.06
43.	*Desmodium tortuosum* (Sw.) DC. (Leguminosae)	0	0.283	0	0	0.094
44.	*Digitaria abyssinica* (A.Rich.) Stapf (Poaceae)	0	0	0.243	0	0.094
45.	*Digitaria bicornis* (Lam.) Roem. & Schult. (Poaceae)	0	0	0.243	0	0.094
46.	*Digitaria eriantha* Steud. (Poaceae)	0	0	0.243	0	0.094
47.	*Digitaria longiflora* (Retz.) Pers. (Poaceae)	2.273	0.85	0.73	0	0.567
48.	*Digitaria macroblephara* (Hack.) Paoli (Poaceae)	0	0.283	2.676	3.729	2.172
49.	*Digitaria milanjiana* (Rendle) Stapf (Poaceae)	1.136	0.567	1.703	0	0.85
50.	*Digitaria ternata* (A. Rich.) Stapf (Poaceae)	0	2.266	0.243	0.339	0.944
51.	*Dyschoriste radicans* (Hochst. ex A. Rich.) Nees (Acanthaceae)	0	0.567	0.487	0.678	0.567
52.	*Echinochloa pyramidalis* (Lam.) Hitchc. & Chase (Poaceae)	0	0.283	0	1.356	0.472
53	*Eleusine indica* (L.) Gaertn. (Poaceae)	0	0.283	0.243	0	0.189
54.	*Eragrostis aspera* (Jacq.) Nees (Poaceae)	1.136	0.283	0.243	0	0.189
55.	*Eragrostis cilianensis* (All.) Janch. (Poaceae)	1.136	0	0.243	0	0.094
56.	*Eragrostis patula* (Kunth) Steud. (Poaceae)	3.409	2.266	0	0.678	0.944
57.	*Eragrostis racemosa* (Thunb.) Steud. (Poaceae)	1.136	1.416	2.92	1.356	1.983
58.	*Euphorbia inaequilatera* Sond. (Euphorbiaceae)	0	2.266	0.973	1.695	1.605
59.	*Eustachys paspaloides* (Vahl) Lanza & Mattei (Poaceae)	0	0	0.243	0.339	0.189
60.	*Gomphrena globosa* L. (Amaranthaceae)	3.409	1.133	0.243	0	0.472
61.	*Gutenbergia cordifolia* Benth. ex Oliv. (Compositae)	0	0.283	0.973	0.339	0.567
62.	*Gutenbergia petersii* Steetz (Compositae)	1.136	0	0	1.017	0.283
63.	*Harpachne schimperi* A. Rich. (Poaceae)	0	0.567	0.73	1.017	0.755
64.	*Heliotropium nelsonii* C.H. Wright (Boraginaceae)[1]	0	0.567	0	0	0.189
65.	*Heliotropium steudneri* Vatke (Boraginaceae)	0	0.567	0	0	0.189
66.	*Heteropogon contortus* (L.) P. Beauv. ex Roem. & Schult. (Poaceae)	1.136	0	2.19	4.746	2.172
67.	*Hygrophila auriculata* (Schumach.) Heine (Acanthaceae)	0	0.85	0	0.678	0.472
68.	*Hyparrhenia hirta* (L.) Stapf (Poaceae)	0	0	0	0.678	0.189
69.	*Hyperthelia dissoluta* (Nees ex Steud.) Clayton (Poaceae)	1.136	0	0.73	4.407	1.511
70.	*Hypoxis hirsuta* (L.) Coville (Hypoxidaceae)	0	0	0.243	0	0.094
71.	*Indigofera basiflora* J.B. Gillett (Leguminosae)	2.273	0	0.243	0	0.094
72.	*Indigofera hochstetteri* Baker (Leguminosae)	0	2.55	0.973	3.39	2.172
73.	*Indigofera spicata* Forssk. (Leguminosae)	1.136	1.133	0	0	0.378
74.	*Indigofera volkensii* Taub. (Leguminosae)	0	1.983	1.703	3.39	2.266
75.	*Ipomoea mombassana* Vatke (Convolvulaceae)[2]	0	0	0	0.678	0.189
76.	*Justicia betonica* L. (Acanthaceae)	0	0.85	0.73	0.339	0.661
77.	*Justicia exigua* S. Moore (Acanthaceae)	0	0	0.73	0.339	0.378
78.	*Justicia glabra* K.D. Koenig ex Roxb. (Acanthaceae)	0	0	0.243	0	0.094
79.	*Justicia matammensis* (Schweinf.) Oliv. (Acanthaceae)	0	0.283	0.73	0	0.378
80.	*Kyllinga nervosa* Steud. (Cyperaceae)	1.136	1.983	0.73	0.678	1.133
81.	*Lactuca virosa* Habl. (Compositae)	1.272	0.283	0	0	0.094

Continued

No.	Species (Family)	Fallow	Livestock	Mixed	Wildlife	Overall
82.	*Lepidagathis scabra* C.B. Clarke (Acanthaceae)	0	0.567	0	0	0.189
83.	*Leucas aspera* (Willd.) Link (Lamiaceae)	0	0	0.243	0.678	0.283
84.	*Leucas deflexa* Hook.f. (Lamiaceae)	3.409	0	0.243	0	0.094
85.	*Leucas martinicensis* (Jacq.) R.Br. (Lamiaceae)	1.136	0	0	0	0
86.	*Macroptilium atropurpureum* (DC.) Urb. (Leguminosae)	0	0	0	0.339	0.094
87.	*Melhania ovata* Spreng. (Malvaceae)	1.136	0	0	0	0
88.	*Microchloa kunthii* Desv. (Poaceae)	0	4.249	5.839	3.729	4.721
89.	*Mollugo nudicaulis* Lam. (Molluginaceae)	0	0.283	0	0	0.094
90.	*Ocimum basilicum* L. (Lamiaceae)	1.136	0.283	0.487	0.339	0.378
91.	*Ocimum gratissimum* L. (Lamiaceae)	0	0	0	0.339	0.094
92.	*Ormocarpum kirkii* S. Moore (Leguminosae)	0	0	0.243	0	0.094
93.	*Ormocarpum trichocarpum* (Taub.) Engl. (Leguminosae)	0	0	0	0.339	0.094
94.	*Oxygonum sinuatum* (Hochst. & Steud. ex Meisn.) Dammer (Polygonaceae)	1.136	0.283	0.487	0	0.283
95.	*Panicum coloratum* L. (Poaceae)	0	1.133	1.46	3.729	1.983
96.	*Panicum maximum* Jacq. (Poaceae)	0	0	0.243	1.356	0.472
97.	*Pennisetum mezianum* Leeke (Poaceae)	0	0.283	0.973	1.695	0.944
98.	*Portulaca oleracea* L. (Portulacaceae)	0	0.283	0	0.339	0.189
99.	*Portulaca quadrifida* L. (Portulacaceae)	2.273	2.266	0.73	0.678	1.228
100.	*Rhynchosia minima* (L.) DC. (Leguminosae)	0	0	0.243	0	0.094
101.	*Senna occidentalis* (L.) Link (Leguminosae)	0	0.283	0	0.339	0.189
102.	*Sesbania sesban* (L.) Merr. (Leguminosae)	0	0.567	0	0	0.189
103.	*Setaria pumila* (Poir.) Roem. & Schult. (Poaceae)	1.136	1.7	0	0	0.567
104.	*Setaria sphacelata* (Schumach.) Stapf & C.E. Hubb. ex Moss (Poaceae)	1.136	0.283	0.487	1.356	0.661
105.	*Setaria verticillata* (L.) P. Beauv. (Poaceae)	2.273	0.283	0.243	0	0.189
106.	*Sida acuta* Burm.f. (Malvaceae)	0	0.283	0	0	0.094
107.	*Solanum incanum* L. (Solanaceae)	1.136	0.283	0.487	0.678	0.472
108.	*Sphaeranthus suaveolens* (Forssk.) DC. (Compositae)	0	2.266	0.243	0	0.85
109.	*Sporobolus africanus* (Poir.) Robyns & Tournay (Poaceae)	0	0	0.243	0.678	0.283
110.	*Sporobolus cordofanus* (Hochst. ex Steud.) Hérincq ex Coss. (Poaceae)	0	0.283	0	0.339	0.189
111.	*Sporobolus festivus* Hochst. ex A. Rich. (Poaceae)	0	0.567	6.569	5.085	4.155
112.	*Sporobolus ioclados* (Trin.) Nees (Poaceae)	0	5.382	0.973	2.034	2.738
113.	*Sporobolus kentrophyllus* (K. Schum.) Clayton (Poaceae)[2]	0	0.567	0.73	0	0.472
114.	*Sporobolus pyramidalis* P. Beauv. (Poaceae)	0	2.266	1.946	3.39	2.455
115.	*Tagetes minuta* L. (Compositae)	2.273	0	0	0	0
116.	*Talinum portulacifolium* (Forssk.) Asch. ex Schweinf. (Talinaceae)	0	0	0	0.339	0.094
117.	*Tephrosia pumila* (Lam.) Pers. (Leguminosae)	0	0.567	1.46	1.356	1.133
118.	*Themeda triandra* Forssk. (Poaceae)	1.136	3.966	5.596	8.475	5.855
119.	*Tragus berteronianus* Schult. (Poaceae)	3.409	0.85	1.703	0.339	1.039
120.	*Tribulus terrestris* L. (Zygophyllaceae)	0	0.567	0.243	0	0.283
121.	*Triumfetta rhomboidea* Jacq. (Malvaceae)	0	0	0	0.339	0.094
122.	*Urochloa brachyura* (Hack.) Stapf (Poaceae)	0	0.283	0	0	0.094
123.	*Xanthium strumarium* L. (Compositae)	0	0.283	0	0	0.094

[1]Taxonomy according to Global Plants (JSTOR); plants.jstor.org. [2]Taxonomy according to African Plants data base (ville-ge.ch/musinfo/bd/cjb/africa).

Appendix 2. Correlation analysis for soil and plant properties in western Serengeti.

	Distance	Biomass	Soil pH	Clay	Silt	Sand	Soil N	Soil OC	Soil C:N	Soil P	Soil C:P	Soil N:P	CEC	Soil Ca	Forage CP	NDF	ADF	ADL	IVDMD	IVOMD	TDN	ME
Distance	1.00																					
Biomass	0.68***	1.00																				
Soil pH	0.10	0.06	1.00																			
Clay	0.18	0.03	0.24	1.00																		
Silt	0.06	0.13	-0.59***	-0.06	1.00																	
Sand	-0.18	-0.08	0.03	-0.91***	0.37	1.00																
Soil N	0.20	-0.18	-0.07	0.37	0.05	-0.36	1.00															
Soil OC	0.13	-0.09	0.04	0.59***	0.15	-0.61***	0.58***	1.00														
Soil C:N	-0.04	0.03	0.04	0.38	0.15	-0.42*	-0.10	0.73***	1.00													
Soil P	0.04	-0.05	-0.17	-0.35	0.06	0.31	0.18	-0.23	-0.43	1.00												
Soil C:P	0.19	-0.07	0.01	0.59***	0.13	-0.60***	0.67***	0.97***	0.61***	-0.18	1.00											
Soil N:P	0.07	-0.07	0.14	0.61***	0.01	-0.57***	0.53**	0.61***	0.30	-0.67***	0.63***	1.00										
CEC	0.08	0.01	0.46*	0.90***	-0.18	-0.76***	0.27	0.63***	0.51**	-0.44*	0.59***	0.64***	1.00									
Soil Ca	0.12	0.05	0.73***	0.63***	-0.49**	-0.38	0.24	0.36	0.17	-0.32	0.26	0.49**	0.81***	1.00								
Forage CP	-0.28	-0.12	-0.10	0.05	0.18	-0.13	-0.27	0.20	0.52**	-0.19	-0.02	0.00	0.17	-0.05	1.00							
NDF	-0.15	-0.15	-0.15	0.00	0.12	-0.05	0.30	-0.07	-0.38	0.14	-0.04	0.15	-0.02	0.08	-0.11	1.00						
ADF	0.27	0.20	0.02	-0.11	0.01	0.11	0.02	-0.22	-0.33	0.05	-0.10	-0.09	-0.20	0.03	-0.51	0.20	1.00					
ADL	0.07	0.18	0.19	0.32	0.20	-0.38	0.13	0.05	-0.10	-0.03	0.11	0.18	0.24	0.15	-0.24	0.06	0.18	1.00				
IVDMD	0.03	-0.02	0.05	0.06	0.27	-0.17	0.23	0.32	0.20	0.21	0.25	0.10	0.12	0.01	0.34	0.08	-0.66***	0.11	1.00			
IVOMD	0.17	0.12	-0.07	0.28	0.12	-0.31	0.16	0.13	0.00	0.01	0.15	0.18	0.18	0.09	0.05	0.19	-0.40	0.09	0.60***	1.00		
TDN	-0.27	-0.20	-0.02	0.11	-0.01	-0.11	-0.02	0.22	0.33	-0.05	0.10	0.09	0.20	-0.03	0.51**	-0.20	-1.00***	-0.18	0.66***	0.40*	1.00	
ME	0.17	0.12	-0.07	0.28	0.12	-0.31	0.16	0.13	-0.01	0.01	0.15	0.18	0.18	0.08	0.05	0.19	-0.40	0.09	0.60***	1.00***	0.40*	1.00

Values with asterisks indicate significant correlation (* = P<0.05; ** = P<0.01; *** = P<0.001).

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CHAPTER FIVE

MANUSCRIPT ONE

Repercussions of agro-pastoralism on soil condition in western Serengeti, Tanzania

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Running title: Agro-pastoral effects in soils of western Serengeti

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2.1 Abstract

Overgrazing of rangeland and continuous cultivation of cropland are among human activities contributing to the deterioration of soil properties. To elucidate the effect of agro-pastoral activities on soil properties in western Serengeti, we examined soil properties in four land use types, namely fallow land, communal grazing land, mixed grazing land and wildlife dominated grazing land. The soil sampling sites were along the landscape from village lands towards protected areas while crossing all four land use types. Soil pH was not significantly different ($p \geq 0.05$) although it was relatively low in fallow and communal grazing lands. Clay content in soils was not affected by land use types whereas sand and silt contents were significantly different ($p \leq 0.05$) among land use types. In terms of soil nutrients, OC, CEC and soil P showed a significant difference ($p \leq 0.05$) among land use types but land use did not affect TN and Ca^{2+}. Bare land within quadrats was highest in communal grazing lands (1233 cm^2/quadrat) and lowest in wildlife dominated grazing lands (906 cm^2/quadrat). Protected areas represented by wildlife grazing sites had the highest soil stability expressed in terms of soil structure stability index. Soil quality declined with increase in bare land. Further, high density of grazing animals caused a decline in soil properties. The study demonstrated that the four land use types had negative influence on soil properties. It was further noted that the current practices of livestock grazing and cultivation had higher negative effects on soil properties than the other land use types. Long term monitoring study on impacts of agro-pastoralism in western Serengeti is needed so as to establish proper stocking rates to avoid reaching an irreversible soil properties deterioration situation.

Key words: Animal density, degradation, grazing animals, land use type, soil properties, quadrat.

2.2 Introduction

Agro-pastoralism is the integration of crop production and livestock production as a livelihood strategy where crop production constitutes the basis of household economy [1, 2, 3]. The agro-pastoral activities involve land clearing that consequently causes land cover changes. Land cover changes associated with human activities and natural factors compromise many ecosystem attributes including soil and site stability, hydrologic function and biotic integrity [4] and hence reduction of important ecosystem services such as crop and livestock production. Agro-pastoral activities that involve overgrazing of rangeland and continuous cultivation of cropland are among human activities that contribute to land degradation [5]. Continuous grazing of large herds on the same area cause land degradation due to high grazing pressure on plant species and soil disturbance caused by trampling. Extensive cultivation involves land clearing and pulverization of soil that subjects the land to soil erosion due to wind and rainfall runoff. Trampling by animals causes compaction of soil that leads to increased surface water runoff. Removal of plants due to large number of grazing animals causes bare land that in combination with poor water infiltration causes surface water runoff and accelerated soil erosion during the rainy season. Different land uses types influence land degradation differently; cultivation and human settlements considered to cause higher land degradation than grazing [6]. Conversion of vegetated land to bare land through cultivation results in soil nutrient loss due to disruption of soil surface and mineral horizons as well as organic matter supply cut off [7]. Continuous cultivation without appropriate management practices results in low soil fertility due to overutilization of soil nutrients by crops [8, 9]. Different grazing managements tend to affect soil properties differently [10]. Normally, livestock grazing is managed by herders but wildlife graze freely in rangelands [11, 12]. In that manner, livestock and wildlife may affect soil properties differently in grazing lands. This study

therefore was designed to evaluate the impacts of agro-pastoral activities on soil properties in different land use types of western Serengeti. It was hypothesized that there are no variations in soil properties as a result of agro-pastoral activities in fallow, livestock, mixed and wildlife-dominated land use types.

2.3 Materials and methods

2.3.1 Site description

The study was conducted in western Serengeti within five villages that are adjacent to protected areas as shown in Figure 2.1. The western Serengeti lies in agro-ecological zones 1/5 and 1/4 characterized as low potential areas less suitable for arable agriculture [13]. Average annual rainfall ranges between 500-1200 mm, declining eastwards towards the Park boundary and increasing westwards towards Lake Victoria [14]. It is the most densely populated area in Serengeti ecosystem surpassing the north-east and south of the Serengeti National Park [14, 15, 16]. While the western Serengeti is considered to be unsuitable for arable agriculture, the subsistence economy depends mainly on agro-pastoralism [17]. Agro-pastoralism in this area is practiced by extensive cropping and livestock keeping which normally lead to encroachment of protected areas [18]. Common grazing livestock kept in western Serengeti include cattle, goats and sheep while crops cultivated include maize, sorghum, paddy, cassava, sesame and cotton. The study area is diverse in terms of ethnic groups as it is composed of over 25 tribes which are dominated by the Ikoma, Ikizu, Kurya, Natta and Sukuma [19].

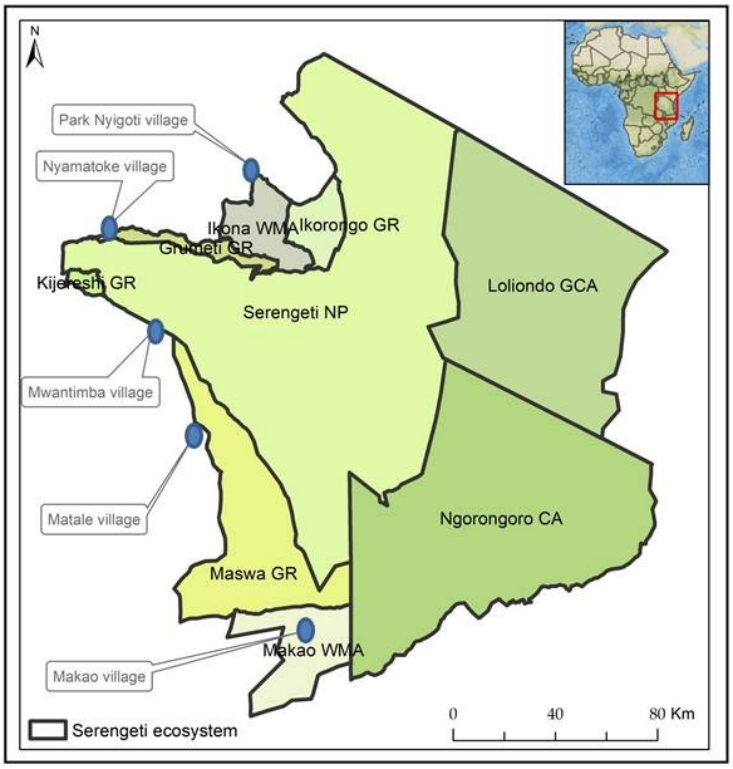

Figure 2.1: Map of Serengeti ecosystem showing study villages in western Serengeti

2.3.2 Data collection

Transects were aligned in each village to cross different land-use types where each transect started in the village land. Transects traversed 0–1 000m in lands dominated by cropping, 1 000–2 000m in lands dominated by livestock grazing, 2 000–3 000m crossing the boundary between village land and protected areas, where mixed grazing of livestock and wildlife occurred, and the remaining 3 000–4 000m was in the protected land dominated by wildlife grazing.

The properties of a particular soil are the result of soil-forming processes acting through time and under the influence of parent material, climate, topography, and biota. There are four general soil-forming processes: 1) transformations, which are the modification, loss,

or creation of soil materials such as the breakdown of organic matter or the formation of secondary clays and carbonates; 2) translocations of soil material up or down the profile, mostly by water but also by soil organisms; 3) additions of new material to the soil, such as dust, organic matter, and soluble salts; and 4) losses from the soil profile due to such processes as leaching and erosion [20]. The relative dominance of these four processes creates differences in soil properties at different depths. Soil was sampled at the central point of each 0.25m^2 quadrat. The samples were taken from the depth of 0-30 and 30-50cm at every 300m along transect. Soil depth of 30 – 50 cm was considered for understanding soil properties that accommodate deep rooted plants because the study was conducted in wooded grasslands. Bare land within quadrat was estimated according to [21] by taking the difference between 100% and the top cover corresponds to the proportion of vegetation coverage. Densities of both livestock and wildlife for determination of grazing pressure in the study areas were estimated based on observations made along transects in accordance to [22]. Animal counts were converted to tropical livestock units (TLU) based on their species average weight where tropical livestock units was considered as 1 TLU = 250 kg live weight according to [23].

2.3.3 Laboratory analysis

A total of 150 soil samples were collected where 35 samples were collected from each land use type namely livestock grazing, mixed grazing and wildlife grazing while 45 soil samples were collected from fallow land. All 150 soil samples collected were taken to the laboratory at Sokoine University of Agriculture for determination of soil texture, bulk density, pH, organic carbon (OC), total N, available P, Ca^{2+} and CEC according to standard procedures [24].

2.4 Data analysis

All statistical analyses were performed with R software (Rx64 3.5.0). Analyses were performed using pooled data for respective land use type with type III sum of squares in ANOVA. The relationship among bare land area, animal density and soil properties was evaluated by using global mixed effects model using lmer package of R statistical software [25]. Bare land area was considered as an output variable while the input variables included animal density, soil texture components (clay, silt and sand), soil pH, total nitrogen content, organic carbon, extractable phosphorus, available calcium and CEC. Land use type (fallow, livestock, mixed and wildlife) was defined as a random effect. The input variables were standardized using Gelman's approach [26] and the dredge function in package MuMIn [27] 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) [28] to obtain the top model based on variables with highest relative importance. Assessment of collinearity among explanatory variables was performed using step-wise variance inflation factors (VIF) with all predictor variables initially included in the linear regression equation. Variables with VIF greater than 4 were eliminated from the model progressively, while the predictor variables with VIF less than 4 were retained. The resulting linear regression model was then used to assess variables that were significantly associated with the response variable bare land area. Spatial heterogeneity of soil properties in the study area was assessed based on coefficient of variation (CV) according to [29] where parameters CV > 35% considered as most heterogeneous, CV 15 -35% was moderately heterogeneous

and CV < 15% considered as the least heterogeneous. Soil structural stability index (SSSI) of different land use types was estimated according to [30]. Soil structural stability index expresses the risk for soil structural degradation associated with soil OC depletion. It is expressed as follows:

SSSI = [(1.72 x SOC)/(Clay + Silt)] x 100

Where; SOC is the soil organic carbon content (%) and clay + silt constitute the combined clay and silt content of the soil (%).

2.5 Results

2.5.1 Effect of land use type on soil quality

Results from this study showed that soil pH was not statistically different ($p \geq 0.39$) among different land use types though pH was relatively lower in fallow and livestock grazing than in mixed and wildlife dominated grazing lands (Figure 2.2a). The slight low pH in agro-pastoral dominated land use types (fallow and livestock) indicates progress in lowering of pH due to agro-pastoral activities. The soil pH and clay were not affected by land use types (Figures 2.2a and 2.2b) but silt and sand contents showed significant difference ($p \leq 0.02$, 6.9×10^{-11}) as shown in Figures 2.2c and 2.2d respectively.

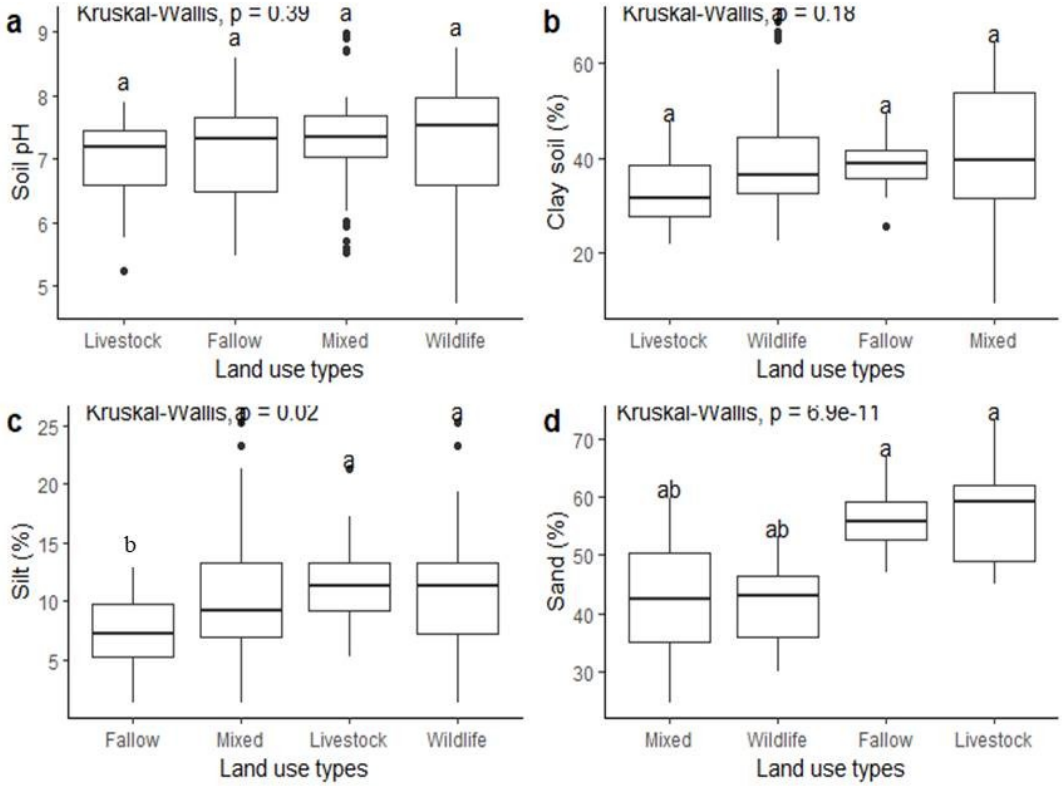

Figure 2.2: Effect of land use types on soil pH and texture components in western Serengeti

Land use types showed significant difference ($p \leq 0.05$) in terms of OC and soil P (Figures 2.3b and 2.3c). Soil total nitrogen did not show significant difference among land use types and the total nitrogen content in the soil ranged between 0.1 to 0.2% (Figure 2.3a).

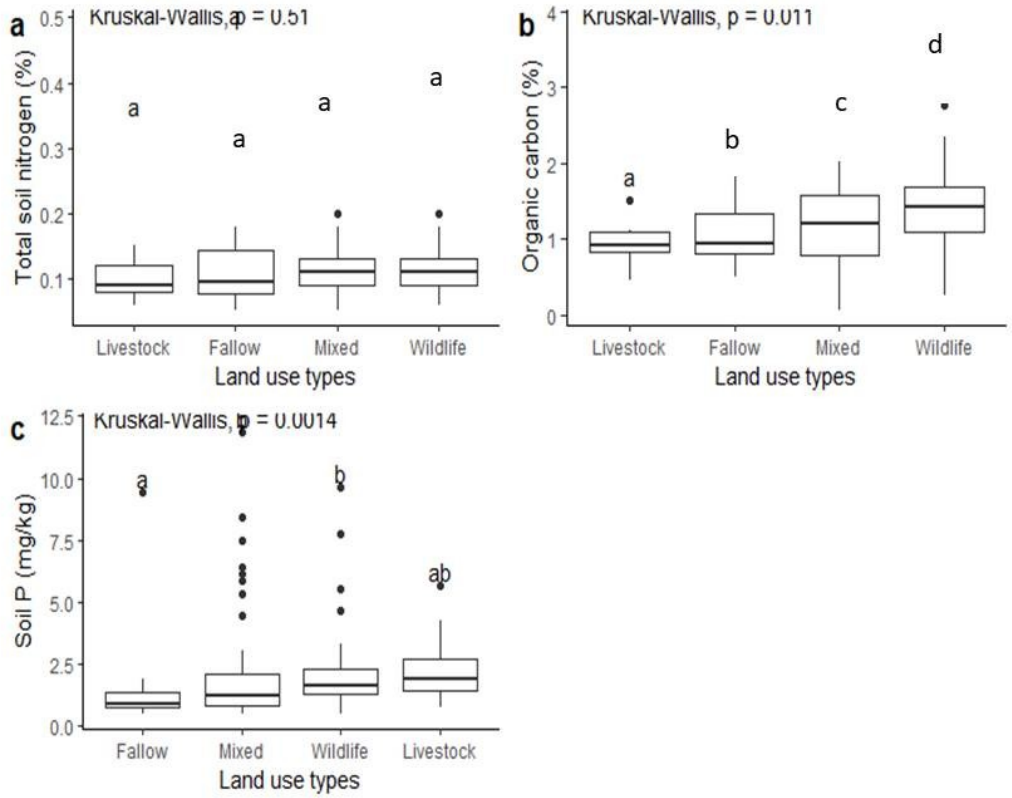

Figure 2.3: Effect of land use type on soil TN, OC and P in western Serengeti

Furthermore, results from this study showed that land use types had highly significant effect on CEC as well as in Ca^{2+} (Figure 2.4).

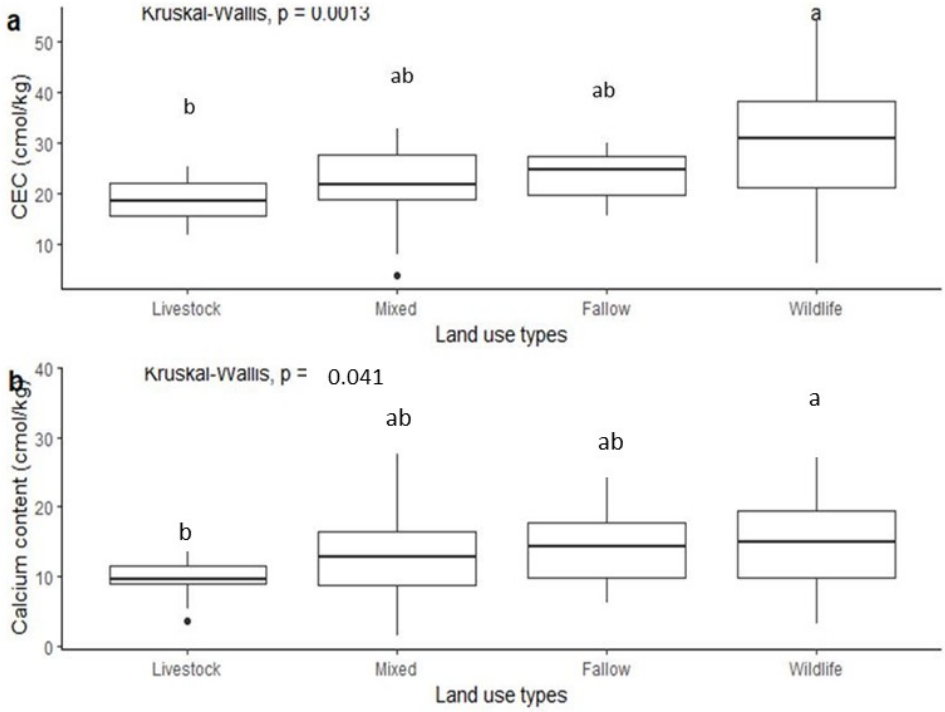

Figure 2.4: Effect of land use types on CEC and available calcium in the soil of western Serengeti

2.5.2 Influence of land use type on bare land and soil stability

In our study, results showed significant difference ($p \leq 0.019$) in terms of bare land area among different land use types. Fallow and livestock grazing land use types had higher bare land within quadrats than in mixed and wildlife dominated land use types (Figure 2.5a).

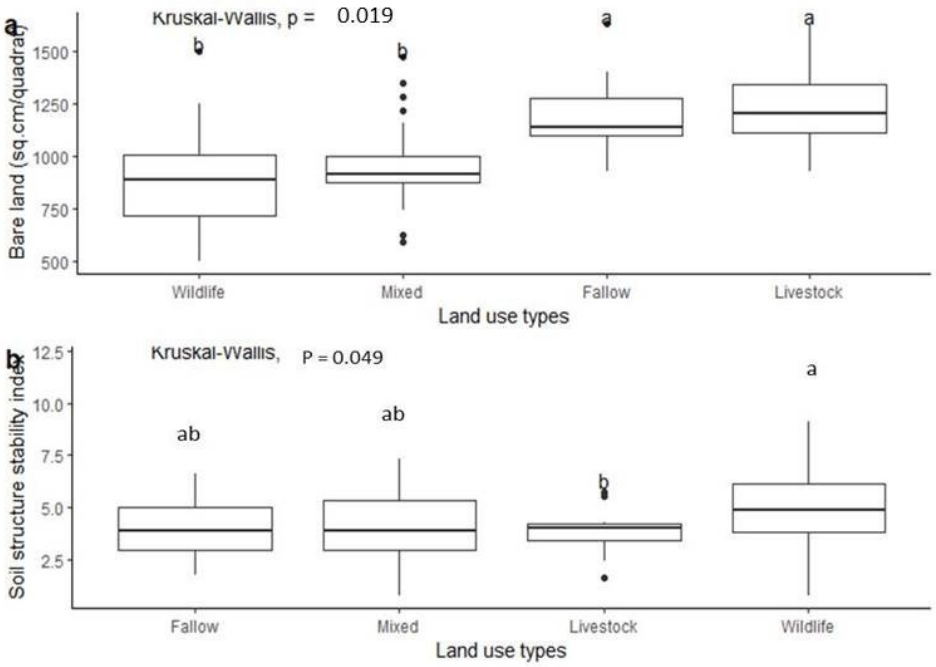

Figure 2.5: Effect of land use type on presence of bare land and soil structure stability in western Serengeti

Soil structure is an important property that mediates many biological and physical processes in the soil. Differences in soil structure stability obtained in this study are shown in Figure (2.5b). The highest soil structure stability index (SSSI) was found in soils within protected areas.

2.5.3 Effect of bare land on soil properties

Bare land affects soil properties due to the removal of top soil that contains soil nutrients by erosion. The observed effects of bare land on soil properties are presented in Figure 2.6. Results show that an increase in bare land area caused a decline in soil pH, CEC and nutrients contents.

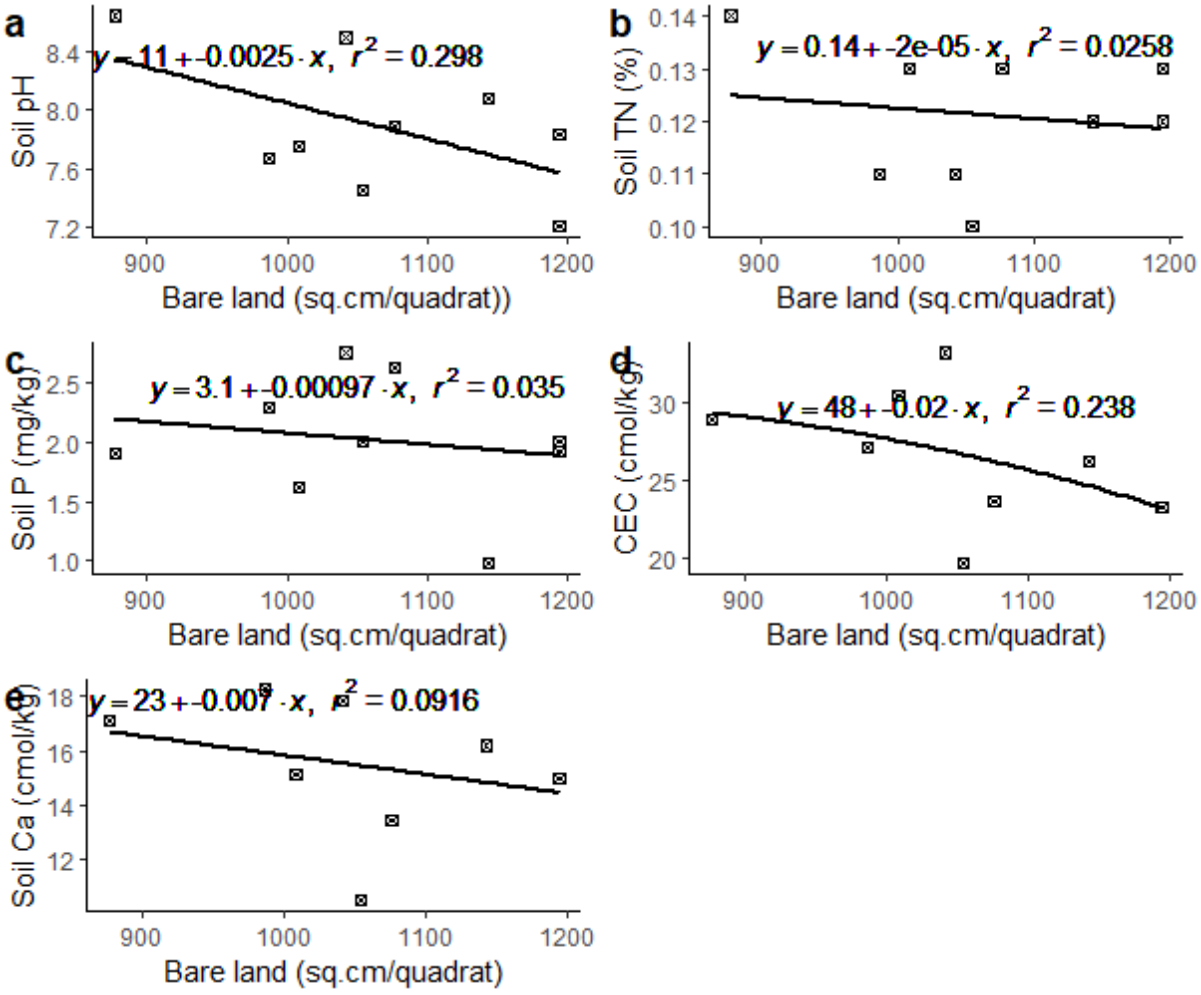

Figure 2.6: Effect of bare land size on soil properties in western Serengeti, Tanzania

2.5.5 Effect of grazing animals' stocking rate on soil properties

Our study showed that increase in animal density expressed as stocking rate caused decrease in soil pH, OC, CEC and nutrient elements as shown in Figure 2.7.

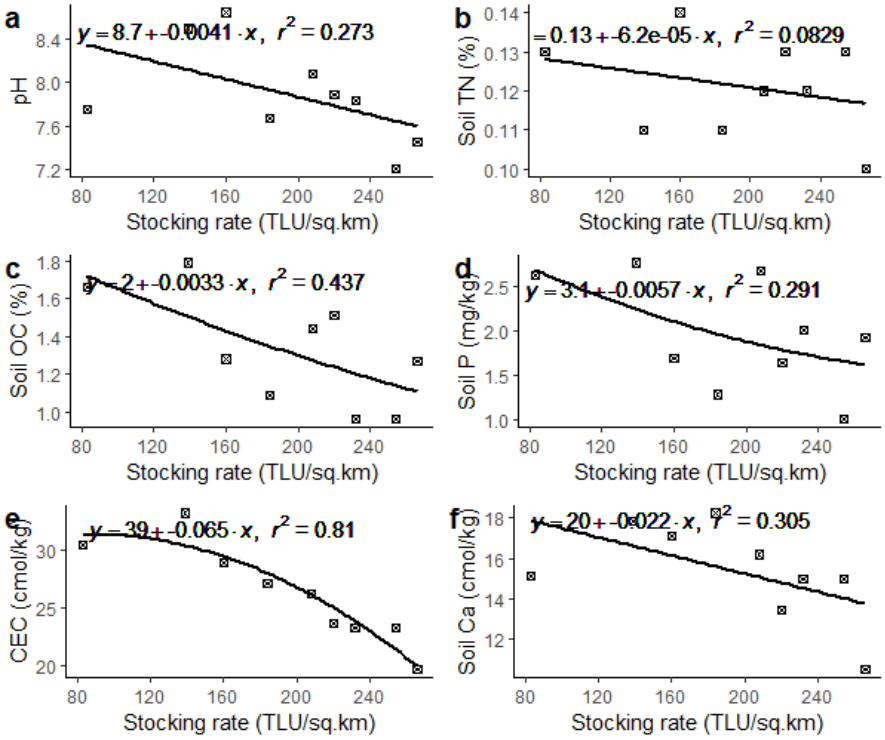

Figure 2.7: Effect of grazing animals' density on soil properties in western Serengeti, Tanzania

Correlation analysis results (Table 2.1) indicated that animal density was positively correlated to clay soil, sandy clay soil, sandy loam soil and bare land area which implied that the effect of high animal density manifested well in these soil properties. On the other hand, animal density was negatively correlated to clay loam soil, pH, total nitrogen content, organic carbon, extractable soil phosphorus, cation exchange capacity and available calcium in the soil implying decrease in these parameters due to high animal density.

Table 2.1: Correlation coefficients of the relationship between soil properties and stocking rates in western Serengeti

	Clay soil	Clay loam soil	Sandy clay soil	Sandy clay loam soil	Sandy loam soil	Bare land area	pH	TN	OC	P	CEC	Ca^{2+}	Animal density
Clay soil	1.00												
Clay Loam soil	-0.50	1.00											
Sandy clay soil	-0.65	0.00	1.00										
Sandy clay loam soil	0.32	-0.42	-0.69	1.00									
Sandy loam soil	-0.30	-0.51	0.11	0.64	1.00								
Bare land area	-0.27	-0.69	0.64	0.06	0.72	1.00							
pH	0.61	0.35	-0.84	0.19	-0.62	-0.92	1.00						
TN	-0.50	1.00	0.00	-0.42	-0.51	-0.69	0.35	1.00					
OC	-0.20	0.93	-0.37	-0.15	-0.54	-0.89	0.65	0.93	1.00				
P	0.08	0.76	-0.16	-0.59	-0.94	-0.84	0.66	0.76	0.78	1.00			
CEC	-0.50	0.99	-0.08	-0.30	-0.42	-0.70	0.38	0.99	0.95	0.70	1.00		
Ca^{2+}	-0.20	0.94	-0.35	-0.20	-0.58	-0.89	0.65	0.94	1.00	0.81	0.95	1.00	
Animal density	0.18	-0.93	0.37	0.18	0.58	0.90	-0.67	-0.93	-1.00	-0.81	-0.94	-1.00	1.00

2.5.6 Heterogeneity of soil properties in western Serengeti

Results showing coefficient of variation in Table 2.2 indicate that only soil pH was least heterogeneous (CV ≤ 15%). Clay and silt contents in soil texture classes as well as OC and total N were moderate heterogeneous (15 – 35% CV). The most heterogeneous soil parameters were sand content in soil textural classes, soil extractable P, exchangeable calcium and CEC.

Table 2.2: Variation of soil properties in western Serengeti

Parameter	Mean	SD	Minimum	Maximum	F-value	CV	P-value
Soil pH	7.14	0.81	4.70	8.98	0.676	0.11	0.568
Clay (%)	40.04	11.52	8.88	68.88	0.469	0.30	0.704
Silt (%)	10.22	4.74	1.28	25.28	3.503	0.30	0.017
Sand (%)	49.74	12.59	24.40	87.84	0.807	0.52	0.492
Total N (%)	0.11	0.04	0.05	0.20	0.587	0.28	0.625
OC (%)	1.19	0.47	0.05	3.63	4.159	0.35	0.007
Soil P (mg/kg)	2.00	1.82	0.47	11.82	0.797	0.45	0.498
Exchangeable Ca (cmol/kg)	13.38	6.14	1.33	38.03	2.490	0.52	0.063
CEC (cmol/kg)	24.60	8.27	3.60	54.00	9.244	0.40	≤0.001

2.5.7 Differences in soil properties between depths

Top soil had significantly higher pH, Clay, Sand, total N and OC than sub soil (Table 2.3). Top soil, however did not differ significantly with sub soil in terms of silt content, extractable P, Ca and CEC.

Table 2.3: Difference in soil properties between soil depths regardless of land use types

Parameter	Soil depths		F-value	P-value	Level of significance
	0 – 30 cm	30 – 50 cm			
pH	7.33[a]	7.04[b]	4.240	0.0413	*
Clay (%)	40.23[b]	43.03[a]	4.628	0.0332	*
Silt (%)	10.14[a]	10.70[a]	6.075	0.0749	NS
Sand (%)	50.06[a]	46.30[b]	8.872	0.003	**
Total N (%)	0.12[a]	0.10[b]	4.204	0.042	*
OC (%)	1.36[a]	1.11[b]	6.926	0.009	**
Soil P (mg/kg)	2.20	1.73	2.012	0.158	NS
Available Ca (cmol/kg)	14.63	13.35	1.024	0.313	NS
CEC (cmol/kg)	26.45	23.63	2.836	0.943	NS

[a,b]Values with different superscripts within a row differ significantly ($p \leq 0.05$), *= level of significance at $p \leq 0.05$, **= level of significance at $p \leq 0.01$, NS= not significant.

2.5.8 Effect of animal density and soil properties on bare land

Using stepwise variance inflation factor (VIF) of Log (bare land area), pH, Clay, Silt, Sand, Total Nitrogen, Organic carbon, Soil P, CEC, Ca and Animal Density (AD) indicated that log (Bare land area), animal density, Soil pH, OC and Soil P had VIF values below the threshold that sufficed development of a linear model (Table 2.4) for prediction of bare land area based on animal density and soil properties. The model developed for relationship of bare land area with stocking rate and soil properties is expressed as follows:

$$Log(Bare) = 0.001AD + 0.072OC – 0.012P + 0.001pH + 2.762.$$

Table 2.4: Variables for bare land prediction model

Variable	Coefficient (estimate)	VIF
Intercept	2.762	
Animal density	0.001	3.804
OC (cmol/kg)	0.072	2.018
Soil P (mg/kg)	-0.012	1.041
Soil pH	0.001	0.002

2.6 Discussion

2.6.1 Effect of land use on soil properties

This study demonstrated high sand contents in areas dominated with agro-pastoral activities (fallow and livestock grazing). This is most likely resulting from the preferential removal of clay and silt after disturbance caused by tillage and trampling by livestock. Surface runoff due to rainfall tends to remove light soil particles that include clay and silt in disturbed soil, leaving denser particles such as sand. This result is in agreement with [31] who reported high sand content in soils subjected to cultivation and livestock grazing in Ethiopia. Soil texture is an inherently stable soil property but it is subject to changes due to long term disturbance such as continuous cultivation and overgrazing [32]. Overall results in this study indicate that clay was higher in subsurface soils (30-50 cm) than upper surface soils (0 – 30 cm). The overall increase in clay contents with soil depth may be due to translocation of clay from surface to subsurface layers, which ultimately increased the proportion of sand in the surface soil layers. This suggests that the upper soil surfaces in western Serengeti are subjected to disturbances even in protected areas. Soils in protected areas could be subjected to trampling by wild animals especially large herds of wildebeest during migration periods.

Soil pH is one of the major factors affecting soil processes and properties, including chemical, physical and biological processes and properties [33]. Our study showed that soil pH in western Serengeti was similar among different land use types. However, variation in soil pH occurred across soil depth with low soil pH occurring in subsurface soils. This indicates that spatial distribution of shallow rooted plants like herbaceous plants in western

Serengeti is determined by other factors such as soil texture [34]. Likewise, soil pH was spatially moderately heterogeneous implying that variation of soil pH in the study area was influenced by soil structure and random factors [35].

Soil organic carbon content varied among the land use types and was highest in protected areas. Disturbance in protected area was relatively low as shown by low bare land area. This allowed accumulation of organic material in protected area that decomposed and contributed to the accumulation of soil organic matter. The results were in agreement with [36] who found higher soil organic carbon content in protected area than farmlands of Thailand. Low organic carbon content in agro-pastoral areas could be associated with removal of organic matter due to livestock grazing and use of fire in land preparation before cultivation. The amount and distribution of Soil Organic Carbon (SOC) affects and is affected by plant biomass [37]. This is because carbon storage in soils is a dynamic balance between detrital inputs (primarily litter and dead roots) and organic matter outputs in the form of CO_2 efflux from the soil [38]. This study showed that three land use types expressed in terms of fallow, continuous livestock grazing and mixed grazing of livestock and wildlife resulted in soil organic carbon contents that were below optimum level. The organic carbon between 3 and 5% is considered as optimum with low risk of structural degradation [39]. Soil structural stability index (SSSI) suggested by [40] show that SSSI ≤ 5% indicates a structurally degraded soil; 5 % ≤ SSSI ≥ 7 % indicates a high risk of soil structural degradation; 7 % ≤ SSSI ≥ 9 % indicates a low risk of soil structural degradation; and SSSI ≥ 9 % indicates sufficient SOC to maintain the structural stability. Results from our study demonstrate that agro-pastoral activities expressed in terms of fallow and continuous livestock grazing, and mixed grazing of livestock and wildlife lead to structurally degraded soil. This implies that soils under these land use types were undergoing soil structure disintegration that subjected the land to soil erosion. On the other

hand, soil in protected area had soil structural stability index between 5.0 and 7.5. This implies that soils in protected areas of western Serengeti were at high risk of soil structure degradation. This provides an alarm to management authorities that poor management of rangeland in protected areas could cause land degradation in future.

Soil P and exchangeable calcium were positively correlated (r = 0.81). This indicates that most of the soil phosphorus in western Serengeti occur in form of P-Ca bond i.e., calcium phosphate which is sparingly soluble in water depending on soil pH. This relationship is depicted on similar trends of soil P and exchangeable Ca in different land use types. This form of calcium and phosphorus bonding in the soil limits phosphorus availability to plants [41]. Lowest soil phosphorus and exchangeable calcium in livestock dominated grazing land demonstrated in this study could be attributed to overgrazing. High livestock grazing pressure limited accumulation of organic matter in the soil for recycling of phosphorus and soil trampling that caused phosphorus and calcium loss due to erosion. Findings of the current study are in agreement with [42, 43] who described that decrease in calcium and phosphorus in grazing lands could be attributed to mineral export by grazing animals. An explanation of this is that grazing animals consume plants that extract minerals from the soil which are deposited elsewhere as manure. On the other hand, reduction of exchangeable bases in the soil caused the reduction in pH which led to lowered pH with consequent effect onto increased exchangeable aluminium and decreased availability of phosphorus [44].

2.6.2 Effect of land use on bare land and soil properties

Bare land is devoid of vegetation and exposes the surface soil to agents of soil erosion such as wind and water runoff [45]. The semi-arid areas of Africa particularly Sub-Saharan Africa have fragile soils and get low input from agriculture, as a result they are vulnerable

to degradation [46, 47]. The East Africa rangelands' soils are inherently low in fertility [48] which implies that exposing land surface to soil erosion aggravates the problem of low soil fertility in rangelands. The current study showed that agro-pastoral activities (fallow and continuous livestock grazing) caused higher bare land areas within quadrats as compared to mixed and wildlife grazing. This was attributed to weeding in crop farms and overgrazing in communal grazing lands within villages. Decrease in soil properties with increase in bare land area is consistent with previous findings that bare lands contain low OM, TN, pH, CEC, Exchangeable Ca and soil organic carbon [49, 50]. The low soil nutrients in bare lands result from nutrient losses due to a combination of soil erosion, surface runoff [51]. Paradoxically, [52] found that TN, SOC and TP of bare land significantly decreased but available nutrient concentrations NO^{3-}-N, NH^{4+}-N and available phosphorus (AP) of bare land significantly increased in Qinghai-Tibetan Plateau of China. The possible explanation for low nutrient in bare land is lack of vegetation that cuts off nutrient recycling from organic matter whereas the remaining nutrients on surface soil are taken away by wind and water runoff. Increase in NO^{3-}-N, NH^{4+}-N and AP in bare land is associated with burrowing small mammals where burrows increases soil moisture and oxygenation of bare land [53] due to breakdown of soil aggregates of soil particles [54]. Consequently, it increases the nitrogen mineralization of un-degraded organic matter that increases concentration of available nutrients in bare land soils.

2.6.3 Spatial heterogeneity of soil properties

Spatial heterogeneity refers to the lack of homogeneity and the complexity in the distribution in space of the properties of a system [55]. Understanding the spatial heterogeneity of soil parameters such as pH, organic carbon, nitrogen, phosphorus and potassium, is important due to their influence on the distribution and spatial pattern of

plants in the ecosystem [56]. Our study considered spatial heterogeneity of soil pH because it reflects physical and chemical properties that determine soil quality [55] and has a profound impact on various soil properties [57]. Results based on CV indicated that soil pH was least heterogeneous and low positively correlation with TN and CEC but high positive correlation with OC, P and Ca^{2+}. This implies that variations observed in soil parameters contents in various soils of western Serengeti were caused by factors other than soil pH. Many studies have shown that the spatial variability of soil pH is related to many factors such as soil parent rock material, topography, climate, soil biology, human activities, sampling design and personal error [58, 59, 60]. Our study demonstrated that current agro-pastoral activities expressed in terms of fallow and livestock keeping are the main human activities that affect soil properties negatively in western Serengeti.

2.6.4 Effect of grazing animal density on soil properties

Soil properties contribute to numerous ecosystem services within agro-pastoral system such as water supply through filtration and retention of rain water, climate regulation, and biodiversity conservation and production of both plants and animals. The importance of soil entails the need for assessment of its quality to understand the impact of a particular land use. Livestock keeping particularly grazing animals affects soil properties differently depending on pressure exerted by different number of animals, hence the need for assessment. Results obtained from this study indicated that increase in number of grazing animals within a unit of land caused decline of soil properties such as pH, TN, OC, P, CEC and Ca. Our results conform to findings of a global meta-analysis of livestock grazing impacts on soil properties reported by [61] except for soil pH. Contrary to the increase in soil pH due to high grazing density, our study showed that increase in grazing density caused a decrease in soil pH which agrees with few studies reported by [62, 63, 64] who

conducted studies in sandy soils in semi-arid lands. The reason for this phenomenon could be our study was conducted in area dominated with sandy clay soils [65]. Furthermore, high grazing animals' density subjected sandy soil to erosion and removal of exchangeable bases by water runoff leaving high concentration of hydrogen ions that increased soil acidity.

2.6.5 Implication of agro-pastoralism on grazing land

Agro-pastoralism impacts negatively on grazing land when large herd of grazing animals exert high grazing pressure on vegetation for a long period. This situation affects soil properties in a long run though soil properties can change slowly particularly in semiarid regions where soil responses to management practices occur slowly [66]. Results obtained in this study demonstrated that agro-pastoral activities practiced in western Serengeti triggers decline in soil pH due to high animal density, decrease in soil OC and plant nutrient elements due to cultivation and removal of standing biomass by grazing animals. In addition animal trampling exposes top soil to agents of soil erosion that consequently reduce plant cover leading to expansion of bare land. The model developed in this study pin point animal density as the main agro-pastoral input variable that contribute in prediction of bare land area occurrence. This is because traditionally livestock graze in communal grazing lands and cultivated areas after crop harvest. Therefore grazing animals cause impacts on both communal grazing and cultivated lands. Other input variables include organic carbon which determines texture and holding capacity of nutrients and moisture in the soil for establishment of plants, soil P as an important nutrient for plant roots establishment in the soil and soil pH that determine nutrients availability to plants. The strength or weaknesses of these input variables determine existence of bare land in western Serengeti regardless of climatic condition.

2.7 Conclusion

Continuous grazing in communal grazing lands and fallows affected soil properties due to high animal density. Trampling loosened soil particles that were easily eroded by wind and rainfall. Removal of soil particles led to existence of bare land with consequence lowering of soil pH, OC, P Ca^{2+} and CEC in communal grazing lands and fallows.

Removal of soil nutrients in upper layer of soil caused overall decline in soil nutrients because the underneath layer of soil showed relative low soil nutrient contents. The magnitude of soil properties deterioration varied with increase in grazing animals' density and it was manifested in all land use types examined.

This study therefore demonstrated that the four land use types namely fallow, livestock grazing, mixed grazing and wildlife grazing negatively affected soil properties. However, agro-pastoralism represented by the magnitude of the current practices of livestock grazing and fallows produce more negative effects than the other two land use types on soil properties.

2.8 Recommendation

Grazing animals' density in communal grazing lands and fallows should be monitored and their effects on soil properties be alleviated by either reducing their number or duration of grazing.

The current fallowing system practiced in western Serengeti need to be reviewed in order to assist improvement of soil properties in fallows.

Long term monitoring study on impacts of agro-pastoralism in western Serengeti is needed so as to establish proper stocking rates to avoid reaching an irreversible soil properties deterioration situation.

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2.10 Data Availability

Data used to support the findings of this study are available from the corresponding author upon request.

2.11 Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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CHAPTER SIX

6.0 GENERAL DISCUSSION

Agro-pastoralism varies across continents and agro-ecological zones. The literature dealing with agro-pastoral systems is scarce due to the lack of directed research and development efforts (BOSTID, 1993). Much of agro-pastoralism information was contributed by farming systems research (Harwood, 1979; McDowell and Hildebrand, 1980; Shaner *et al.*, 1982). The variety of agro-pastoral systems and the complexity of mixtures and interactions between crops and livestock discouraged systematic research and development (BOSTID, 1993). However, the impact of climate change on crops and livestock production entails a need for farm diversification, soil conservation, pasture and crop nutrient management that consequently attract research attention on impacts of agro-pastoralism. The work described in this thesis contributes to our understanding of how agro-pastoral activities influence the livelihood of people, diversity of herbaceous plants, nutritive value of livestock feed resource and soil properties.

The general discussion will focus on four objectives of the study as these are the pillars for sustainability of agro-pastoral practices in areas that are adjacent to protected areas.

6.1 Contribution of agro-pastoralism to livelihood of agro-pastoral households in Western Serengeti

The present study shows that agro-pastoralism is a predominant livelihood in western Serengeti where land and natural pasture are primary resources. Livestock moves in the vicinity of the villages and grazes on communal grazing lands, fallow lands, and crop fields after harvest. Increase in human population triggered need for food sufficiency that stimulated cultivation of land and livestock keeping which is based on availability of land. The results from this study showed that there was increase in cultivated land**.** The increase in cultivated land increased food production that followed the same trend as food security trend. This signifies the importance of agriculture for livelihood of people in western Serengeti. Increased cultivation in response to population growth has also been demonstrated in other studies, such as in Ningal *et al.* (2008) for Papua New Guinea, in Turner *et al.* (2011) for Niger, Burgoyne *et al.* (2015) for the Mkuze Game Reserve in South Africa and in Hartter *et al.* (2016) for Uganda.

This shows that in many cases increase in human population in rural areas result in expansion of cultivated land to cater for food demand. However this scenario occurs when land is available for expansion of crop farms. In contrast to this, Reid et al. (2000) in Ethiopia and Giannecchini *et al.* (2007) South Africa respectively showed that increase in population did not result in expansion of crop farms due to scarcity of land and strict land tenure system. Therefore, results showed in this study indicate that land was apparently still available for expansion of crop farms in western Serengeti under the present land tenure system.

Increase in livestock population and cultivated land resulted in decreased availability of grazing land. This situation compelled livestock keepers to trespass their animals in protected areas with consequent conflict between livestock keepers and protected areas' rangers. The conflict is magnified as agro-pastoral communities in Serengeti ecosystem perceived that cropland and livestock keeping provide immediate benefits than conservation of natural resources biodiversity (Mligo, 2015). The argument given by agro-pastoralists is hinged on monetary value accrued from agro-pastoral activities. The current study showed that overall monetary value of agro-pastoralism in western Serengeti increased steadily year after year. This indicates that agro-pastoralism is a lucrative economic activity in western Serengeti that supports livelihood of people. The close interaction between crops and livestock is the most striking feature of agro-pastoralism. The structure of agro-pastoral farming systems is defined by the combination of crop and animal components. The extent of each component, use of on-farm resources, interactions among the components, flows of energy and nutrients, and the individual contribution of each component to agro-pastoral productivity in western Serengeti still needs further research.

6.2 Effect of Agro-Pastoralism Practices on Herbaceous Plants Diversity in Village Lands and Protected Areas of Western Serengeti

Considering diversity of herbaceous plants, the present study shows low herbaceous plants species diversity in communal grazing and fallow lands which was attributed to high livestock density and cultivation respectively. Grazing animals tend to select desirable herbaceous plant species in communal grazing land that led to establishment of few tolerant species to grazing and to physical damage with consequent less species diversity (Olff and Ritchie, 1998).

Protected areas showed high diversity of herbaceous plant species because of low grazing pressure caused by low animal density. Grasses provide feed resource base for grazing animals and.in addition, grasses provide important services and roles including as water catchments, biodiversity reserves, for cultural and recreational needs, and potentially a carbon sink to alleviate greenhouse gas emissions (Boval and Dixon, 2012). Result from the present study indicates that number of grass species increased along a transect from communal grazing lands to protected areas. This shows that grasses experienced high grazing pressure from livestock in communal grazing land.

Grasses are important as they contain linoleic acid and over half of the total fatty acids consist of linoleic acid of which conjugated linoleic acid (CLA) is a potent anticarcinogen. (Carlier *et al.,* 2009). Studies conducted by Dewhurst and King (1998) showed substantial differences in contents of linoleic acids between grass species and cultivars. The CLA is associated with remarkable fat and protein metabolism of the body which is regulated by an increased muscle formation and a decreased fat content (Carlier *et al.,* 2009). Therefore milk and meat that contain CLA have in this respect a much higher nutritive value for human and hence the importance of conserving diversity of grass species in communal grazing lands.

Although this study highlighted the effect of agro-pastoralists activities on herbaceous plants diversity. Yet, our scientific understanding of the dynamic responses of herbaceous plant diversity to other drivers of change and the ecosystem services they provide in western Serengeti remains limited. The abundance patterns of certain herbaceous plant species can be used as an indicator of land degradation, but the decision whether this state

appears permanent largely depends on the species composition and condition of local seed bank in the soil.

Having more and better information at hand regarding the various contributions of herbaceous plant species composition, abundance, and diversity to ecosystem services, functions and resilience would definitely support decision making in both communal grazing lands and protected areas. It is hoped that the gaps highlighted in this section will become a useful motivation to put herbaceous plants diversity onto the agenda of rangeland management research in the country. A way to address some of the gaps would be to specifically conduct long-term monitoring of communal grazing lands in the country capturing spatiotemporal patterns in herbaceous plants association, abundance, diversity, and phenology. Experimental approaches could serve disentangling the separate and combined effects of primary and secondary drivers of herbaceous plants diversity dynamics country-wise. Herbaceous plant species traits considered in this thesis could be used to analyse trait–environment, trait–disturbance, or trait–ecosystem function relationships for country-wise studies. The national research institute such as TALIRI could establish a rangeland monitoring unit for managing open access data base to cater for long term monitoring of communal grazing lands.

6.3 Effect of Agro-Pastoralism Practices on Quantity and Quality of Feed Resource Base in Village Lands and Protected Areas

Herbaceous plants standing biomass is required to support performance of both livestock and wildlife herbivores. This study showed that agro-pastoral activities reduced standing biomass availability in communal grazing and cultivated lands. The reason for this was heavy grazing due to high stocking rate that removed apical meristems of herbaceous

plants which limited growth of plants (Lyons and Hanselka, 2003). Reduction in growth potential of herbaceous plants caused a decline in herbaceous plants' standing biomass.

Findings of this study show that agro-pastoral activities influenced the high quality of herbaceous plants described by relative high TDN, ME, CP, lower contents of ADL and C:N ratio in communal grazing land. Agro-pastoral activities caused high nutritive value of herbaceous plants in communal grazing lands but the performance of livestock was limited by low availability of standing biomass. This study has shown the impact of agro-pastoralism on herbaceous plants quantity and quality under continuous grazing. The appropriate grazing management should enable year round availability of high quantity and quality feed resources.

6.4 Effect of Agro-Pastoralism on Soil Properties that Influence Growth and Development Herbaceous Plant Species

The soil is the critical media of life support systems because it delivers several ecosystem goods and services such as carbon storage, water regulation, soil fertility, and food production, which have effects on human well-being (FAO, 2015). In the ecosystem, the pH of the soil has an enormous influence on soil biogeochemical processes (Neina, 2019). Soil pH is, therefore, described as the "master soil variable" that influences myriads of soil biological, chemical and physical properties and processes that affect plant growth and biomass yield (Minasny, 2016). The findings of this study show that the current practice of keeping large number of livestock in communal grazing land resulted in relatively lower soil pH. It is known that Ca levels in the soil mainly contribute to the pH. Lowest Ca content in the soil observed in communal grazing lands contributed to the presence of relative low pH. The pH decreases as calcium decreased due to natural erosion and agricultural activities (de la PaixMupenzi et al., 2011). Livestock trampling lead to

compact soil which reduce water infiltration culminating into accelerated erosion with calcium loss in the top soil. Once Ca^{++} is removed from the soil its pH reduces. It is widely documented that livestock destroy the top soil aggregate (Bari,1993; Zhou et al., 2010 and Kotzé et al., 2013) leading to reduced water infiltration accelerated soil erosion with calcium loss which eventually led to increase in the hydrogen ions as they replace calcium lost through rain water runoff. The consequence of decrease in soil pH is the decrease in soil microbial activities of decomposing organic matter due to increase in C:N ratio in the soil (Bai *et al.*, 2013). Lowest soil P observed in fallow is a result of soil P drain by crops and grazing of crop residues by livestock. Soil P in crop residues is deposited somewhere else by livestock especially in kraals. The significantly lower P levels in fallow could be an indicator of effect of cultivation on soil P. As P is declining with cultivation also pH is reducing, perhaps this implied initial stages of soil quality decline in the fallow (Okalebo et al., 2002). Lowest organic carbon in communal grazing lands was attributed to continuous grazing that caused depletion of plant cover and litter input (Moussa et al. 2007). This study showed the effect of agro-pastoralism on soil properties under continuous grazing and cultivation. In practice, impact of agro-pastoralism varies with the level of integration of livestock and crops. In some cases the level of integration may contribute positively to one criterion while adversely affecting another.

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CHAPTER SEVEN

7.0 KEY CONTRIBUTIONS, CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter highlights the key contributions the present study has made to the body of existing knowledge. The chapter further presents the conclusions drawn from this study and highlights a number of recommendations.

7.2 Key contributions of the Study

The contribution of the study in knowledge generation depended on the use of theories and models. Therefore, the current study employed ecological theory and sustainable livelihood framework to show how herbaceous plants diversity is influenced by agro-pastoral activities. The study provided a great deal of more understanding how, why and where agro-pastoral activities affect diversity of herbaceous plants where answers to these questions are shown in papers II, I and III respectively.

Most theories and models were designed from metropolitan countries and used in their context. However, this study has extended the horizon of application of models by using global mixed effect model designed for ecological data to be applied in predicting ground cover of herbaceous plants in relationship to functional attributes of plant species, feeding merit of plant species, soil texture and land use type as a random effect. Furthermore, this study extended application of null model which was designed for ecological data to be applied in assessing the influence of agro-pastoral activities in association of herbaceous plant species. Also, methodologically, the study has combined social and approaches to analyse herbaceous vegetation establishment mosaic, which has generated knowledge on

the association between the pattern of herbaceous plant species establishment and soil textural classes that appears in western Serengeti.

The findings of this study uncover a number of issues that are important for the general knowledge among researchers and professionals as well as policy makers that include:

i. Agro-pastoralism is still an important economic activity for livelihood of people because it has been demonstrated that human population in western Serengeti rely on local food crops supply and livestock provide animal products and main income for households.

ii. Human and livestock population in western Serengeti is high relative to land available for food crops and livestock production under prevalent traditional farming techniques.

iii. Current agro-pastoral activities carried out in western Serengeti affected availability of feed resources in communal grazing and fallow lands by reducing the productivity and proliferation of undesirable herbaceous plant species.

iv. Diversity of herbaceous plant species in western Serengeti is negatively affected by continuous livestock grazing and cultivation.

v. The array of pasture species still present in communal grazing areas suggests that rejuvenation of these areas could still be possible if different management strategies were adopted.

vi. Agro-pastoral practices conducted in western Serengeti are detrimental to standing biomass of herbaceous plants at a given point in time

vii. Low soil pH resulting from agro-pastoral activities affects negatively standing biomass and species richness of herbaceous plants.

7.3 General Conclusions

The focus of this research was to determine the influence of agro-pastoral activities on diversity of herbaceous plant species, nutritive values, soil properties and their contribution to the livelihood of people. The study demonstrated that current agro-pastoralism practices in western Serengeti affects negatively diversity of herbaceous plant species diversity as a result of 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 plant species, especially highly palatable ones, limiting recovery of grazed plants. Furthermore, unlimited expansion of cultivated land involving land clearing and weeding affects negatively herbaceous plant species diversity due to reduction of herbaceous species arrays on cropped areas and fallow lands.

Agro-pastoralism practices affects positively nutritive values of herbaceous plant species because of continuous defoliation of plants and weeding keep herbaceous plants in vegetative state. Immature herbaceous plant species tend to have high crude protein, total digestible nutrients and metabolozable energy which are indicators of nutritive value of plants.

Current agro-pastoral practices in western Serengeti affects negatively soil nutrients contents. Trampling by grazing animals and cultivation pulverises soil that subjects light soil particles such as clay and silt to be eroded by wind and water run-off. This causes bare land with poor establishment of herbaceous plants that limits nutrient recycling from plants to the soil.

This study showed that agro-pastoralism contributes to the livelihood of people in western Serengeti and in the country at large from the fact that people do not rely on imported meat and staple food. Also steady increase in total value of commodities produced in agro-pastoral system implies that agro-pastoralism is a good source of income for households.

The strong negative linear and curvilinear relationship that was noted between soil nutrients and increased stocking rates indicated that overstocking is suicide to agro-pastoral system sustainability. The decline in soil nutrients due to high stocking rate would limit pasture and crop production which agro-pastoralists depend entirely for the livelihood. Resource overutilization through overstocking and overgrazing generally leads to soil nutrients losses, soil degradation and vegetation changes, and ultimately impedes crop and animal productivity, and need to be taken into consideration in agro-pastoral systems in the country.

Findings from this study showed that wildlife grazing in protected areas promoted high herbaceous plants diversity. This occurred because wildlife in protected areas practices seasonal grazing in particular areas that allow plants to regrow during resting period. Applying similar practice in village lands would improve diversity of herbaceous plants in communal grazing lands.

Most grazing lands in villages have been degraded because of poor grazing management, overstocking, overgrazing and soil fragility. Rehabilitation of such lands could be achieved through utilization of herbaceous plant species at full growth stages, which are resilient to grazing pressure and short-term strategic exclusion of livestock in order to improve C and N storage while maintaining natural resources and providing ecosystem services and functions.

7.4 Recommendations

i. A combined model including economic, social, ecological components and wildlife conservation is needed to enable predictions about the future of agro-pastoralism in this area.

ii. Rehabilitation of denuded lands in village areas is imperative if the current trend of proliferation of undesirable herbaceous plant species is to be reversed to ensure future availability of feed resources for grazing animals in village lands.

iii. 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.

iv. It is recommended that grazing pressure in communal grazing lands should be reduced by either reducing number of grazing animals or duration of grazing in a particular grazing area. Specific studies should be conducted by respective local government authorities to establish appropriate stocking rates and grazing pattern of specific communal grazing lands in villages.

7.5 Further Studies

i. Long term research is needed to disentangle the effect of changes in rainfall pattern and impacts of climate change on diversity of herbaceous plant species in the study area. This has direct implications for the establishment of priorities

especially in restoration of degraded grazing lands in villages and protected areas.

ii. More research is required to understand the potential for perpetuation of edible herbaceous plant species in western Serengeti. Further, it is crucial to differentiate between natural variability in the herbaceous plant diversity as driven by agro-pastoral practices, spatiotemporal rainfall patterns and long-term ecological changes.

iii. More research studies are needed to evaluate long term effects of other grazing management strategies on soil properties and herbaceous plant species diversity.

iv. Research is required on the magnitude of impacts and the resulting trade-offs due to levels of integration between livestock and crops in different parts of the country.

v. Further research is needed to develop an appropriate restoration strategies of edible herbaceous plant species in overgrazed land. In addition forage conservation technologies of edible herbaceous plants could be investigated on their success in carrying forward excess forage production in some good years to meet the feed scarcity in extended dry seasons.

vi. More research studies are needed to establish appropriate grazing management in communal grazing lands.

APPENDICES

Appendix 1: R scripts used in analyses of data

i. Analysis of variance

```
ws<-read.csv("E:/WSNV.csv", sep=",",header=TRUE)
ws
str(ws)
library(agricolae)
library(coin)
library(multcomp)
library(colorspace)
library(car)
model<-aov(Biomass~LANDTYP,data=ws)
summary(model)
duncan.test(model,"LANDTYP",group = T, console = T)
model1<-aov(NDF~LANDTYP,data=ws)
summary(model1)
duncan.test(model1,"LANDTYP",group = T, console = T)
model2<-aov(ADF~LANDTYP,data=ws)
summary(model2)
duncan.test(model2,"LANDTYP",group = T, console = T)
model3<-aov(ADL~LANDTYP,data=ws)
summary(model3)
duncan.test(model3,"LANDTYP",group = T, console = T)
model4<-aov(CP~LANDTYP,data=ws)
summary(model4)
duncan.test(model4,"LANDTYP",group = T, console = T)
model5<-aov(DDM~LANDTYP,data=ws)
summary(model5)
duncan.test(model5,"LANDTYP",group = T, console = T)
model6<-aov(DMI~LANDTYP,data=ws)
summary(model6)
duncan.test(model6,"LANDTYP",group = T, console = T)
```

```
model7<-aov(RFV~LANDTYP,data=ws)
summary(model7)
duncan.test(model7,"LANDTYP",group = T, console = T)
model8<-aov(INVDMD~LANDTYP,data=ws)
summary(model8)
duncan.test(model8,"LANDTYP",group = T, console = T)
model9<-aov(INVOMD~LANDTYP,data=ws)
summary(model9)
duncan.test(model9,"LANDTYP",group = T, console = T)
model10<-aov(TDN~LANDTYP,data=ws)
summary(model10)
duncan.test(model10,"LANDTYP",group = T, console = T)
model11<-aov(ME~LANDTYP,data=ws)
summary(model11)
duncan.test(model11,"LANDTYP",group = T, console = T)
model12<-aov(pH~LANDTYP,data=ws)
summary(model12)
duncan.test(model12,"LANDTYP",group = T, console = T)
model13<-aov(N~LANDTYP,data=ws)
summary(model13)
duncan.test(model13,"LANDTYP",group = T, console = T)
model14<-aov(OC~LANDTYP,data=ws)
summary(model14)
duncan.test(model14,"LANDTYP",group = T, console = T)
model15<-aov(P~LANDTYP,data=ws)
summary(model15)
duncan.test(model15,"LANDTYP",group = T, console = T)
model16<-aov(CEC~LANDTYP,data=ws)
summary(model16)
duncan.test(model16,"LANDTYP",group = T, console = T)
model17<-aov(Ca2.~LANDTYP,data=ws)
summary(model17)
duncan.test(model17,"LANDTYP",group = T, console = T)
```

```
model18<-aov(C.N~LANDTYP,data=ws)
summary(model18)
duncan.test(model18,"LANDTYP",group = T, console = T)
```

ii. Herbaceous plant species association

```
wsc<-read.csv("E:/wsplntoccur.csv", sep=",",header=TRUE)
wsc
str(wsc)
row.names(wsc) <- wsc$Species
wsc <- wsc[,2:4]
wsc_matrix <- data.matrix(wsc)
library(EcoSimR)
library(cooccur)
library("ggplot2")
library(MASS)
head(wsc_matrix)
test <- cooc_null_model(wsc_matrix, algo="sim9",nReps=10000,burn_in = 500)
summary(test)
plot(test,type="burn_in")
plot(test,type="hist")
plot(test,type="cooc")
cooccur.ws <-
cooccur(mat=wsc_matrix,type="spp_site",thresh=TRUE,spp_names=TRUE)
summary(cooccur.ws)
class(cooccur.ws)
prob.table(cooccur.ws)
plot(cooccur.ws)
pair.profile(cooccur.ws)
cooccur.ws1 <- cooccur(wsc_matrix, type = "spp_site", thresh = TRUE, spp_names =
FALSE,
      true_rand_classifier = 0.01, prob = "hyper",
      site_mask = NULL, only_effects = FALSE,
      eff_standard = TRUE, eff_matrix = FALSE)
```

```
class(cooccur.ws1)
summary(cooccur.ws1)
prob.table(cooccur.ws1)
plot(cooccur.ws1)
```

iii. Biomodel development

```
wn<-read.csv("E:/wsmod.csv", sep=",",header=TRUE)
wn
str(wn)
dim(wn)
Mydata <- wn[,2:15]
Mydata
names(Mydata)
cor(Mydata)
round(cor(Mydata),2)
library(glm2)
library(stringr)
library(glm2)
library(lme4)
library(Matrix)
library(standardize)
library(lazyeval)
library(nlme)
library(arm)
library(MuMIn)
library(stats)
library(AICcmodavg)
library(car)
library(MASS)
library(caret)
library(Hmisc)
library(lattice)
```

```
biomod1<-lmer(Biomass~Distance +Cover+pH+Clay+Silt +Sand +OC+CN +P+ C.P+NP+CEC+Ca+ (1|Grazing.type),data=wn,REML = FALSE, na.action = "na.fail")
stdz_biomod1 <- standardize(biomod1,standardize.y = FALSE, data=wn)
summary(biomod1)
dred_stdz_biomod1 <- dredge(biomod1, trace = TRUE, rank = "AICc", REML = FALSE)
top.mody<-summary(model.avg(get.models(dred_stdz_biomod1, subset=delta<2)))
summary(top.mody)
model2 <- lm(Biomass~Distance +Cover+pH+Clay+Silt +Sand +OC+CN +P+ C.P+NP+CEC+Ca, data =wn)
predictions <- model2 %>% predict(wn)
RMSE = RMSE(predictions, wn$Biomass)
R2 = R2(predictions, wn$Biomass)
vif(model2)
model3 <- lm(Biomass ~ Distance+Cover+Ca+P+CN, data =wn)
predictions3 <- model3 %>% predict(wn)
RMSE = RMSE(predictions3, wn$Biomass)
R2 = R2(predictions3, wn$Biomass)
vif(model3)
print(model3)
predictions
library(survival)
library(rms)
fit<-lm(Biomass ~ Distance+Cover+Ca+P+CN, data =wn)
library(ggplot2)
set.seed(1)
n = dim(wn)[1]
p = 0.667
sam = sample(1:n,floor(p*n),replace=F)
Training<-wn[sam,]
Testing<-wn[-sam,]
fit1<-lm(Biomass ~ Distance+Cover+Ca+P+CN, data =Training)
fit2<-lm(Biomass ~ Distance+Cover+Ca+P+CN, data =Testing)
```

```
summary(fit2)
Ypred<- predict(fit1, newdata=Testing)
y<-wn[-sam,]$Biomass
RMSE<-sqrt(mean((y- Ypred)^2))
print(RMSE)
print(y)
print(Ypred)
summary(fit1)
plot(y~Ypred,wn)
```

iv. Correlations

```
wnr<-read.csv("E:/wspoplivcor.csv", sep=",",header=TRUE)
wnr
str(wnr)
mydata<-wnr[2:5]
cor(mydata)
round(cor(mydata),2)
```

v. Cluster analysis

```
wd1<-read.csv("E:/ws.csv", sep=",",header=TRUE)
wd1
str(wd1)
Mydata1 <- wd1[,-1]
library(ggplot2)
library(ggdendro)
library(DESeq2)
library(reshape)
library(vegan)
library(plyr)
library(scales)
library(grid)
library(picante)
library(ape)
```

```
library(permute)
library(lattice)
library(nlme)
class(wd)
dim(wd)
rownames(wd1)
head(colnames(wd))
dd5=dd[1:4, 1:4]
wdd1=read.csv("E:/ws.csv",header = T,sep=",",row.names = 1)
comm.bc.dist <- vegdist(wdd1, method = "bray")
comm.bc.clust <- hclust(comm.bc.dist, method = "average")
plot(comm.bc.clust, ylab = "Bray-Curtis dissimilarity")
```

vi. Herbaceous plants association

```
wc<-read.csv("E:/Commplnts.csv", sep=",",header=TRUE)
wc
str(wc)
row.names(wc) <- wc$Species
dim(wc)
wc <- wc[,2:4]
wc_matrix <- data.matrix(wc)
library(EcoSimR)
library(cooccur)
library("ggplot2")
library(MASS)
head(wc_matrix)
test <- cooc_null_model(wc_matrix, algo="sim9",nReps=10000,burn_in = 500)
summary(test)
plot(test,type="burn_in")
plot(test,type="hist")
plot(test,type="cooc")
cooccur.wc <- cooccur(mat=wc,type="spp_site",thresh=TRUE,spp_names=TRUE)
summary(cooccur.wc)
class(cooccur.wc)
```

```
prob.table(cooccur.wc)
plot(cooccur.wc)
pair.profile(cooccur.wc)
```

vii. Venn diagram

```
bog<-read.csv("E:/textvege.csv", sep=",",header=TRUE)
str(bog)
names(bog)
library(devtools)
library(VennDiagram)
library(ggplot2)
library(admisc)
library(venn)
library(ggpolypath)
x <- bog[,2:6]
venn.plot <- draw.quintuple.venn(bog, area1 = 301, area2 = 321, area3 = 311, area4 = 321, area5 = 301, n12 = 188, n13 = 191, n14 = 184, n15 = 177, n23 = 194,n24 = 197, n25 = 190, n34 = 190, n35 = 173, n45 = 186, n123 = 112, n124 = 108, n125 = 108, n134 = 111, n135 = 104, n145 = 104, n234 = 111, n235 = 107, n245 = 110, n345 = 100, n1234 = 61, n1235 = 60, n1245 = 59, n1345 = 58, n2345 = 57, n12345 = 31, category = c("A", "B", "C", "D", "E"), fill = c("dodgerblue", "goldenrod1", "darkorange1", "seagreen3", "orchid3"), cat.col = c("dodgerblue", "goldenrod1", "darkorange1", "seagreen3", "orchid3"), cat.cex = 2, margin = 0.05, cex = c(1.5, 1.5, 1.5, 1.5, 1.5, 1, 0.8, 1, 0.8, 1, 0.8, 1, 0.8, 1, 0.8, 1, 0.55, 1, 0.55, 1, 0.55, 1, 0.55, 1, 0.55, 1, 1, 1, 1, 1, 1.5), ind = TRUE )
venn(5, ellipse = TRUE)
venn(5, ilabels = TRUE)
venn(5, ilabels = TRUE, zcolor = "style")
venn("1---- + ----1")
venn("Clay + Sandy.loam", snames = "Clay,Clay.loam, Sandy.clay, Sandy.clay.loam, Sandy.loam")
venn("1---- , ----1", zcolor = "red, blue")
```

```
venn("A, E", snames = "Clay,Clay.loam, Silt.clay, Silt.clay.loam, Silt.loam", zcolor = "red, blue")
venn("1---- , ----1", zcolor = "red, blue", col = "red, blue")
venn(x)
venn(x, ggplot = TRUE)
library(QCA)
venn(x, snames = "", counts, ilabels = FALSE, ellipse = FALSE, zcolor = "bw", opacity = 0.3, plotsize = 15, ilcs = 0.6, sncs = 0.85, borders = TRUE, box = TRUE, par = TRUE, ggplot = FALSE, ...)
set.seed(12345)
b <- as.data.frame(bog[,2:6], replace = TRUE, ncol = 5)
venn(b)
venn(b, ggplot = TRUE)
```

viii. Herbaceous plant species diversity

```
bd<-read.csv("E:/ws.csv", sep=",",header=TRUE)
bd
str(bd)
library(vegan)
dim(bd)
bd$LNDTYP=as.factor(bd$LNDTYP)
bd$Species =as.factor(bd$Species )
str(bd)
mydata<-bd[,-5]
diversity(bd$Abundance)
```