Acta Universitatis Agriculturae Sueciae

Doctoral Thesis No. 2021:35
Faculty of Veterinary Medicine and Animal Sciences

# Rangeland and livestock management practices for improved herder livelihoods in miombo woodland

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SLU
SWEDISH UNIVERSITY
OF AGRICULTURAL
SCIENCES

**DOCTORAL THESIS**
Uppsala 2021

Acta Universitatis Agriculturae Sueciae
2021:35

Cover: Cattle resting in miombo grazed land in Kilosa district, eastern Tanzania
(photo: Peter Rogers Ruvuga)

ISSN 1652-6880
ISBN (print version) 978-91-7760-748-9
ISBN (electronic version) 978-91-7760-749-6

Print: SLU Service/Repro, Uppsala 2021

# Rangeland and livestock management practices for improved herder livelihoods in miombo woodland


## Abstract

Rangelands are valuable resources for livestock production and contribute positively to herders livelihoods. The shrinking of open rangelands used for grazing has led to utilization of miombo woodlands as alternative grazing resource. Miombo woodlands are biomes with both understory herbaceous species and relatively dense tree cover. It is therefore important that livestock and grazing management practices maintain both rangeland condition and tree cover in miombo. The current study was conducted to assess herders' management and condition of assigned grazing land in miombo woodlands. Household survey was used to investigate indigenous rangelands and livestock management practices among herders. Seasonal miombo grazing land condition was evaluated in Ihombwe, Kigunga and Ulaya Mbuyuni villages using botanical composition, vegetation structure and forage condition. A feeding trial with goats was used to evaluate potential supplementary diets (Brachiaria brizantha cv Piatã, Cenchrus ciliaris and concentrates) for their intake and growth performance. Herders in studied miombo kept indigenous livestock species and relied on them mostly for food and income. The miombo grazing land had good tree cover (923-1136 trees/ha) and diverse herbaceous plant communities. Increaser 2a grass species were the most prevalent herbaceous plants in the studied Ihombwe village. These grass species indicated good rangeland condition and moderate grazing intensity. Poor grass cover during dry seasons and high prevalence of Increaser 2b and 2c in Ulaya Mbuyuni and Kigunga villages indicated poor condition and early stage of degradation in the two areas. Above ground herbaceous forage biomass varied seasonally and was at the lowest (299 kg DM/ha) during late dry period. Rangeland improvement practices such as use of forage reserves to enable forage availability during dry season were limited among herders in the studied miombo. Unclear land tenure system was mentioned as the major reason for neglecting rangeland improvement in miombo grazing land. Evaluated supplementary feeds to be fed during dry periods had enough nutrients to meet requirements of indigenous livestock species. Goats fed concentrates had lower feed intake and overall live weight change compared to those in C. ciliaris diet while B. brizantha cv Piatã fed goats were intermediate. C. ciliaris and B. brizantha cv Piatã were shown to be better supplementary diet for feeding livestock during late dry period when there is forage shortage. It was concluded that some studied miombo grazed areas were in poor condition and showed early sign of degradation, however, current livestock grazing in miombo supported herders livelihood without causing negative effects on tree cover.

Keywords: Dry woodlands, land use plan, grazing management, botanical composition, vegetation cover, forage condition, supplementary feed

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# Utunzaji wa mifugo na malisho katika misitu ya miombo kwa kipato bora kwa wafugaji wa jadi

## Muhtasari

Nyanda za malisho ni rasilimali muhimu katika kulishia mifugo ambao ni sehemu muhimu ya pato la wafugaji. Katika siku za kalibuni maeneo ya ardhi yanayotumika kuchungia yamekuwa yakipungua kwa sababu mbalimbali hivyo kupelekea wafugaji kutafuta maeneo mbadala ya malisho. Miongoni mwa maeneo hayo ni misitu ya miombo ambayo imetawaliwa na uoto wa miti pamoja na majani. Uwepo wa miti unaongeza umuhimu wa misitu ya miombo sio tu kwa kuchungia bali pia kwa shughuli nyingine za kiikolojia. Utafiti huu ulifanyika ili kufanya tathmini ya shughuli za ufugaji, umuhimu wa mifugo katika pato la kaya na hali ya misitu ya miombo inayotumika kama maeneo ya kuchungia katika wilaya ya Kilosa, Tanzania. Dodoso miongoni mwa kaya za wafugaji lilitumika kukusanya taarifa za mifugo na utunzaji wa malisho katika misitu ya miombo. Pia uoto, muundo wake na hali ya malisho ilitumika kufanya tathmini ya mabadiliko ya kimsimu na hali ya misitu ya miombo. Mbuzi walitumika kupima uhusiano kati ya aina ya chakula kinacholiwa na mifugo, na ukuaji wao ili kutathmini majani mkate, majani uwele na pumba kama vyakula mbadala ambavyo vinaweza kutumika kulisha mifugo kipindi cha kiangazi. Matokeo yalionyesha kuwa wafugaji wengi wa jadi katika misitu ya miombo walikuwa wakifuga mifugo ya kienyeji. Pia waliitegemea mifugo hiyo kama sehemu ya kujipatia kipato na chakula. Hali ya miti (miti 923-1136 kwa hekari) na bioanuwai ya mimea katika misitu ya miombo wilayani Kilosa ilikuwa nzuri. Ingawaje uwepo kwa wingi wa majani yasiyofaa na hali mbaya ya malisho hasa kipindi cha kiangazi uliashiria kuwa malisho yalikuwa katika hatua za awali za uharibifu. Kiasi cha majani yaliyokuwa yakipatikana kwenye maeneo ya malisho yalikuwa yakibadilika kwa msimu na yalikuwa machache zaidi kuelekea mwisho wa msimu wa kiangazi. Wafugaji wachache sana walijishughulisha na kuboresha hali ya malisho katika misitu ya miombo. Kukosekana kwa mfumo thabiti wa hakimiliki ya ardhi kulitajwa kama sababu kubwa ya wafugaji kushindwa kutunza maeneo yao ya malisho.

Tathmini ya vyakula mbadala vya mifugo vinavyoweza kutumika kipindi cha kiangazi ilionyesha kuwa vilikuwa vinavirutubisho vya kutosha kuweza kukidhi mahitaji ya mifugo. Hata hivyo mbuzi waliopewa pumba walikula kiasi kidogo na kukua polepole sana ukilinganisha na wale waliopewa majani uwele au majani mkate. Hivyo basi ilionekana kuwa majani uwele au mkate yanafaa zaidi kulisha mifugo kipindi cha uhaba wa malisho kuliko pumba. Ilihitimishwa kuwa hali ya malisho katika misitu ya miombo wilayani Kilosa si ya kuridhisha, hata hivyo uwepo wa mifugo haukuathiri miti na ulichangia kuboresha hali ya wafugaji.

Keywords: Maneno muhimu: Misitu kame, mpango wa matumizi bora ya ardhi, utaratibu wa kuchunga, muundo wa mimea, uoto, hali ya malisho, chakula mbadala cha mifugo.

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# Preface

The future is the very scary and uncertain place to be because most of our natural resources will be depleted by then due to climate change and human population explosion. Human need to adapt quickly and use available resources sustainably to meet our current and future basic needs to guarantee our survivor as the species. Perhaps to some livestock keepers in Africa the future is here, and the transition has already begun for them. Since, they are affected by high population pressure and climate change through the loss or degradation of their traditional grazing lands. Also, livestock keepers have to cope with further changes in land policies and land use which force them to use alternative grazing resources such as miombo woodlands.

Miombo woodlands have unique ecosystem due to presence of tree cover and have been used as the nature reserves in most part of Africa with livestock grazing limited to open rangelands. However, livestock grazing in these woodlands could serve ecological purposes while ensuring animal-source food production. It is important to use these woodlands sustainably so that they can meet our current and future demands for food and other ecological services. The motivation behind this thesis was to investigate management of formally grazed miombo woodlands in eastern Tanzania.

In the thesis, different animal and plant based parameters were evaluated to understand the importance of livestock grazing in miombo and their contribution to livestock keepers livelihood. Livestock keepers had differing opinions regarding different aspects of miombo grazing land management, however, something they had in common was that it was crucial for their livelihood. Some measures were identified in the thesis to ensure that miombo grazing land condition is maintained, and livestock production is improved. Perhaps it is about time now livestock production is intensified in miombo and use the woodlands for what it is “forested-grazing resource”.

# Dedication

To my lovely daughter Charity Ruvuga, for reminding me of life outside miombo.

*Land is precious, nothing comes out of nowhere*
Swahili proverb

# Contents

# List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. Ruvuga, P.R.*, Wredle, E., Mwakaje, A., Selemani, I.S., Sangeda, A.Z., Nyberg, G., Kronqvist, C. (2020). Indigenous rangeland and livestock management among pastoralists and agro-pastoralists in miombo woodlands, eastern Tanzania. Rangeland Ecology and Management, vol 73 (2), pp. 313-320. DOI: 10.1016/j.rama.2019.11.005

II. Ruvuga, P.R.*, Wredle, E., Nyberg, G., Hussein, R.A., Masao, C.A., Selemani, I.S., Sangeda, A.Z., Kronqvist, C. (2021). Evaluation of rangeland condition in miombo woodlands in eastern Tanzania in relation to season and distance from settlements. Journal of Environmental Management, vol 290, 112635. DOI: 10.1016/j.jenvman.2021.112635 (in press)

III. Ruvuga, P.R.*, Wredle, E., Fupi, G.F., Mtwange, C.A., Kasiba, B.R., Selemani, I.S., Kronqvist, C. Feed intake, dry matter digestibility and growth performance in goats fed a grass-based diet (Brachiaria or Cenchrus) compared with a concentrate-based diet. (manuscript)

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* Corresponding author

The contribution of Peter Rogers Ruvuga to the papers included in this thesis was as follows:

I. Conceptualisation of the research question, designed study together with other co-authors, data collection and analysis. Wrote and review the manuscript in collaboration with all co-authors.

II. Planned and designed the study with other co-authors, collected and analysed data. Wrote and review the manuscript in collaboration with all co-authors.

III. Conceptualisation of the research question and designed study with other authors. Analysed data, wrote the manuscript in collaboration with all co-authors.

# List of tables

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# Abbreviations

| | |
|---|---|
| ADF | Acid detergent fibre |
| AIA | Acid-insoluble ash |
| BW | Body weight |
| CP | Crude protein |
| CPMSR | Calculated possible monthly stocking rate |
| CS | Close to settlement |
| CV | Coefficient of variation of annual precipitation |
| DM | Dry-matter |
| DMD | Dry-matter digestibility |
| DMI | Dry-matter intake |
| FS | Far from settlement |
| IVDMD | In-vitro dry-matter digestibility |
| ME | Metabolisable energy |
| MP | Metabolisable protein |
| NBS | National Bureau of Statistics |
| NDF | Neutral detergent fibre |
| NIR | Near infrared reflectance |
| PCQ | Point-centred quarter |
| RSR | Reported stocking rate |

| | |
|---|---|
| SEAG | Small East African goat |
| SSA | Sub-Saharan Africa |
| TALIRI | Tanzania Livestock Research Institute |
| TFS | Tanzania Forest Services |
| TLU | Tropical livestock unit |
| UNSDGs | United Nations Sustainable Development Goals |

# 1. Introduction

## 1.1 Global rangelands

Rangeland is a semi-natural, uncultivated landscape used for extensive grazing or browsing by wildlife and livestock. It differs from pastureland in terms of agronomic inputs and management level (Sandhage-Hofmann, 2016). Globally, rangelands cover about 50% of the ice-free land surface, or 74 million $km^2$ area (Sayre *et al*., 2017). They include biomes such as savannah, grassland, steppe, tundra, shrubland, desert and woodland (Cauldwell *et al*., 1999; Homewood, 2004; Sayre *et al*., 2017). Rangelands supply different regulatory and provisional ecosystem services, such as carbon sequestration, nutrient recycling, water catchment, wildlife habitats and biodiversity conservation (Tian *et al*., 2016; Bailey *et al*., 2019; Olsson *et al*., 2019; Reda *et al*., 2020). They also contribute to achievement of several of the United Nations Sustainable Development Goals (SDGs), such as poverty reduction, food security, climate action and life on land (Sandhage-Hofmann, 2016; Espeland *et al*., 2020).

Rangelands provide a livelihood for more than 2.5 billion people worldwide (Reynolds *et al*., 2007; Engler & von Wehrden, 2018), through provision of grazing resources for livestock production, edible food products (honey, mushrooms, wild fruits, game meat etc.), non-timber forest products, recreational activities (*e.g.* tourism) and many more direct and indirect benefits (Cauldwell *et al*., 1999; Ryan *et al*., 2016; Kazungu *et al*., 2020). Livestock grazing is important in utilising dry rangelands for food production, since crop cultivation has limited potential in the areas (Philipsson *et al*., 2011; Treydte *et al*., 2017). It is estimated that around 50% of global livestock production relies on rangelands, which support 600 million rural households (Thornton, 2010; Briske *et al*., 2020). By 2030, ongoing population growth in sub-Saharan Africa (SSA) is expected to increase food demand by 55% compared with the year 2000 (Thornton, 2010; Philipsson *et al*., 2011; Godde *et al*., 2018). This, coupled with projected growth in household purchasing power, means there will be a ready market for livestock products as more families can afford animal-source protein in their diet (Thornton, 2010; Philipsson *et al*., 2011). However, livestock production in SSA is currently performing poorly due to challenges relating to rangeland productivity, *e.g.* seasonal variations in forage growth and a decline in rangeland area available for grazing (Thornton, 2010; Treydte *et al*., 2017; Godde *et al*., 2018).

The rangeland area used for livestock grazing is declining due to reallocation of land for other uses, such as crop production, conservation and expansion of settlements with increasing urbanisation (Godde *et al*., 2018; Kilawe *et al*., 2018; Kazungu *et al*., 2020). Rangeland reallocation places a strain on the remaining grazed resources and leads to reduced rangeland sustainability and productivity as a result of overgrazing (Egeru *et al*., 2015; Pfeiffer *et al*., 2019). Poor rangeland productivity due to overgrazing and ongoing climate change effects are threatening food security and livelihoods among extensive livestock keepers on open rangeland in SSA. These factors, and increased demand for animal-source foods due to population and economic growth, are driving traditional livestock keepers to seek new grazing lands (Thornton, 2010; Philipsson *et al*., 2011). This has led to livestock grazing in miombo woodlands, which were formerly less used as a grazing resource.

## 1.2 Miombo woodlands

Miombo woodlands are biomes defined and dominated by *Brachystegia*, *Isoberlinia* and *Julbernadia* tree species, with herbaceous plant species providing understory cover. These woodlands have unique ecosystems and harbour a number of endemic flora and fauna (Ryan *et al*., 2016). Miombo woodlands occupy over 2.7 million km$^2$ of land and are distributed in the central, eastern and southern African countries of Angola, Congo DRC, Malawi, Mozambique, Tanzania mainland, Zambia and Zimbabwe (Shirima *et al*., 2011; Gumbo *et al*., 2018) (Figure 1). They can be categorised into dry miombo (annual rainfall less than 1000 mm) and wet miombo (annual rainfall more than 1000 mm) (Frost, 1996; Abdallah & Monela, 2007; Nduwamungu *et al*., 2009). Miombo woodlands in SSA are either protected woodlands covered by defined policy and legislature or general woodlands governed by formal or informal local community agreements (Mapedza, 2007; Kilawe *et al*., 2018; Mtimbanjayo & Sangeda, 2018). Protected miombo woodlands form part of national parks and game or nature reserves and are mostly used for tourism. In contrast, general miombo woodlands have high levels of human interference and are used directly to support the livelihoods of surrounding communities by providing different forest products and some grazing (Chidumayo & Kwibisa, 2003; Ryan *et al*., 2016; Handavu *et al*., 2019). General miombo woodlands face degradation due to human activities, with gross deforestation rate in miombo estimated to be 3.5% in the period 2000-2014. The rate of degradation is estimated to be even higher in Tanzania, with 372,871 ha of general miombo woodlands lost annually (TFS, 2015; Ryan *et al*., 2016).

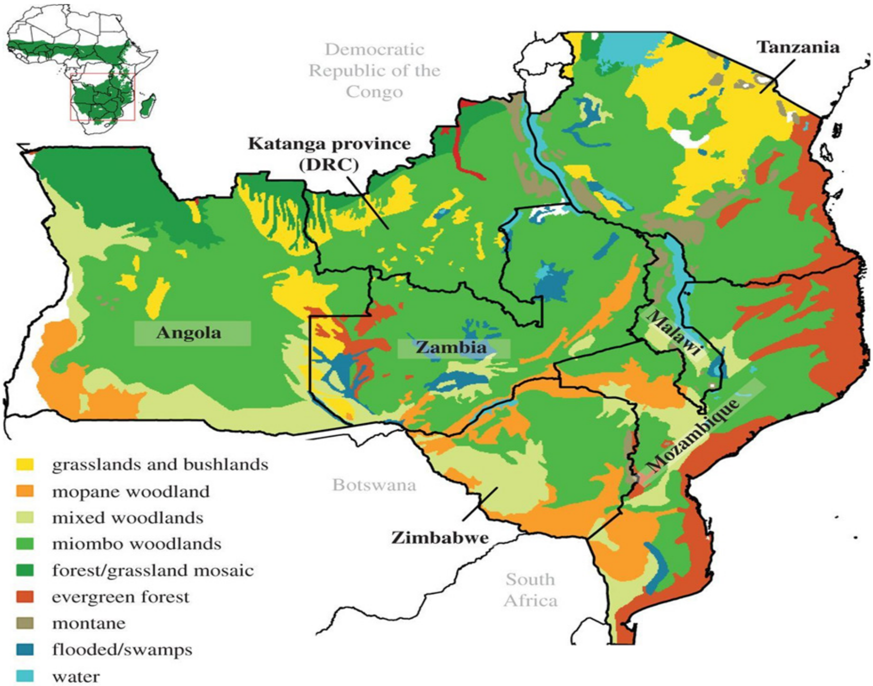


*Figure 1*. Map showing the distribution of miombo woodlands in central, eastern and southern African countries. The green zone around Sahel represents other types of dry woodland (source: Ryan et al., 2016)

In order to facilitate forest resource conservation in general miombo woodlands in Tanzania, a land use plan was introduced in Kilosa district, Eastern Tanzania, in 2012. The plan was developed using a participatory approach whereby village land was assigned different uses, such as grazing, residence, farming, charcoal making and conservation (Gmünder *et al*., 2014; Sangeda & Maleko, 2015; Mtimbanjayo & Sangeda, 2018). All miombo woodland allocated for grazing in Kilosa is collectively grazed by herders, *i.e.* pastoralists (livestock only) and agro-pastoralists (livestock and crop cultivation) (Kilawe *et al*., 2018; Mtimbanjayo & Sangeda, 2018). Unlike open rangeland, miombo biomes have both understory herbaceous forage species and dense tree cover. It is important that livestock and grazing management practices maintain rangeland condition and tree cover in miombo woodlands, but there is a lack of detailed information on the current status and management of allocated miombo grazing land among herders in Kilosa district. The work described in this thesis was conducted to address this knowledge gap and to inform decision making and policies for sustainable miombo woodland management.

# 2. Background

## 2.1 Pastoralist systems in Sub-Saharan Africa

In SSA, pastoralism and agro-pastoralism are extensive low-input systems used generally to rear ruminants. Agro-pastoralist systems are characterised by transhumance livestock production and sedentary crop cultivation. In pastoralist systems, some household members, *e.g.* young men, migrate seasonally with the livestock in search of forage and water, while women and children remain behind in permanent settlements (Butt *et al*., 2009; Selemani *et al*., 2013a; Sangeda & Maleko, 2018; Safari *et al*., 2019). Agro-pastoralists and pastoralists graze their ruminants on rangeland in different tenure systems, either with open access to everyone living in an area (*e.g.* a village) or with collective ownership under control of traditional institutions (Treydte *et al*., 2017; Sangeda & Maleko, 2018). Traditional institutions are social entities established by herders to solve recurring problems, *e.g.* seasonal forage variability and grazing disputes over dry rangeland (Glowacki, 2020). Herders in agro-pastoral and pastoral systems in SSA generally keep indigenous livestock breeds. Local breeds of cattle (*Bos indicus*) are characterised by small to medium body size, humped back, shiny hair coat and varied colour pattern (Rege & Tawah, 1999; Mwacharo *et al*., 2006). Performance of these breeds is generally low, with milk yield <2 L/day, 235-270 days lactation length and mature body weight of around 350 kg (Rege *et al*., 2001; Mwacharo & Rege, 2002). Indigenous small ruminants (goats and sheep) in the region are also characterised by small body size and low mature body weight (around 25 kg) (Mushi *et al*., 2009b; Safari *et al*., 2009; Chenyambuga & Lekule, 2014). Despite their low performance, these livestock breeds are kept due to their resilience to livestock diseases and ability to withstand harsh conditions, such as variable forage availability and prolonged dry periods (Chenyambuga *et al*., 2012; Chenyambuga & Lekule, 2014; Mwacharo & Rege, 2002). However, crosses between indigenous and exotic livestock breeds are increasingly being used by herders, due to their higher productivity and reasonable resilience to harsh conditions. Livestock are kept by herders for subsistence and commercial purposes (Mwacharo & Rege, 2002).

Ruminant management in agro-pastoral and pastoral households is gender-based, with men acting as head of the family and owning and making all decisions related to large livestock (cattle and small ruminants) (Truebswasser & Flintan, 2018). Herding of livestock is the responsibility of adult males, while boys and girls are responsible for taking care of calves, kids and lambs. Additional labour (herders or milkers) can be hired by the household head if the herd is large or if family labour is lacking (Mwacharo & Rege, 2002). Women in the household are mainly responsible for milking, processing and marketing dairy products, and also own small farm animals such as poultry (Mwacharo & Rege, 2002; Truebswasser & Flintan, 2018). Households rely on livestock as a source of food and income, draught power, insurance during emergencies, capital accumulation and manure. Ruminants also have high cultural value among herders in SSA and are used for rituals, payment of dowry and cultural traditions (Kosgey *et al*., 2008; Chenyambuga & Lekule, 2014). Herders generally rank cattle more highly than goats and sheep, but camels are becoming increasingly important in arid and semi-arid regions of SSA due to their adaptation to hot conditions and to the increasing drought frequency in the region (Mwacharo & Rege, 2002; Kosgey *et al*., 2008; Liao *et al*., 2016).

Table 1. Amount of daily nutrients required by different species of growing ruminants (adapted from Luo et al. (2004a, 2004b) and Salah et al. (2014))

| Species | Breed* | Maintenance requirement | | Requirement per g live weight gained | |
|---|---|---|---|---|---|
| | | MP ($g/kg\ BW^{0.75}$) | ME ($kJ/kg\ BW^{0.75}$) | MP (g/kg BW) | ME (kJ/kg BW) |
| Cattle | West African Zebu | 4.35 | 662.6 | 0.446 | 18.03 |
| Goats | Meat [a] | 3.07 | 488.5 | 0.404 | 23.09 |
| | Indigenous [b] | 3.07 | 488.5 | 0.290 | 19.81 |
| Sheep | Indigenous [c] | 3.51 | 495.5 | 0.446 | 18.03 |

MP = metabolisable protein; ME = metabolisable energy; BW = body weight.

*Data for indigenous breeds in miombo are unavailable, so data for closely related breeds are shown: [a] Meat goat, >50% Boers. [b] Indigenous goats, neither meat nor dairy. [c] Indigenous sheep found in India, with some similarity to those in East Africa

Pastoralist production systems in SSA are facing several major challenges, one of which is poor nutritional quality of local forage species due to low protein content and poor digestibility (Butt *et al*., 2009; Selemani *et al*., 2013b; Treydte *et al*., 2017). Ruminants need protein and energy for maintenance and production, but different species have different nutritional requirements depending on breed and production potential (Luo *et al*., 2004a, 2004b; Salah *et al*., 2014) (Table 1). Inability to meet these requirements leads to poor livestock performance and threatens food security and herder livelihoods (Said & Tolera, 1993; Njie & Reed, 1995; Nazli *et al*., 2018). Another challenge facing herders is infectious livestock diseases, which are prevalent due to lack of biosecurity measures among herders, as livestock from different herds come into contact with each other during grazing (Kimaro *et al*., 2017; Omondi *et al*., 2021). Livestock diseases are also a threat to public safety in the case of zoonotic diseases, *e.g. Brucellosis*, and increase production costs per unit through the need for veterinary services and lowered productivity (Mwacharo & Rege, 2002; Asakura *et al*., 2018). In addition, livestock diseases pose a challenge to food security and herder livelihoods by causing livestock deaths (Calkins & Scasta, 2020).

## 2.2 Open rangeland management

Herders in Africa have extensive experience in livestock production and in grazing rangeland with seasonal variations in forage biomass and quality. They use indigenous knowledge transferred through story telling by elders or experienced herders to develop different management strategies for utilising limited grazing resources, thus sustaining their livelihood (Tefera *et al*., 2007; Selemani *et al*., 2012; Liao *et al*., 2016; Treydte *et al*., 2017). Small and large ruminants are grazed by herders in different systems, including continuous grazing with livestock migration during dry periods, when herders search for forage over a large area, or a rotational grazing system applied in a relatively small grazed area (Butt, 2010; Selemani *et al*., 2013a). The rotational grazing system involves intensive management, with forage reserves (enclosures) established within the grazed area. Forage reserves are plots of lands set aside for dry-season livestock grazing, with reported area ranging between 2 and 179 hectares (Selemani *et al*., 2012; Safari *et al*., 2019). These forage reserves are maintained through restrictions set by social and traditional institutions to keep livestock out during the rainy season and are opened up for grazing during forage scarcity. They are known as *ngitiri* among Sukuma agro-pastoralists and as *olalili* among Maasai pastoralists in Tanzania (Verdoodt *et al*. 2010; Treydte *et al*. 2017; Safari *et al*. 2019). Forage reserves have been shown to be useful on dry rangeland, *e.g.* the Hifadhi Ardhi Shinyanga (HASHI) programme in Tanzania used forage reserves to restore degraded rangelands, protect existing rangelands and conserve soil (Selemani *et al*., 2012; Safari *et al*., 2019; Wainaina *et al*., 2021). The HASHI programme incorporated indigenous rangeland practices by promoting rotational grazing among herders on open rangeland. This restored about 500,000 ha of degraded rangeland, enhanced biodiversity conservation and improved livelihoods in the participating households (Wainaina *et al*., 2021).

Land tenure system differences due to land use policies and governance influence rangeland management and improvement practices among herders (Selemani *et al*., 2013a; Treydte *et al*., 2017). Traditional institutions in herding communities usually make decisions and manage communal grazed resources (Sangeda & Maleko, 2018; Wainaina *et al*., 2021). Successful restoration of rangeland by the HASHI programme in Tanzania was facilitated by presence of these institutions, which comprised a community assembly (*dagashida*) responsible for inception of by-laws, grazing decisions and conflict resolution, and community guards (*sungusungu*) responsible for enforcing by-laws and grazing decisions (Selemani *et al*., 2012; Wainaina *et al*., 2021). Absent or weak traditional institutions often lead to poor management and overgrazing of communal rangeland (Tefera *et al*., 2007; Verdoodt *et al*., 2010). This, coupled with an unclear land tenure system, can cause disputes among herders and between different land users, especially during forage shortages, when livestock are vulnerable (Benjaminsen *et al*., 2009; Nindi *et al*., 2014). Poor rangeland management can also lead to rangeland degradation and declining livestock performance, threatening herders' livelihoods (Verdoodt *et al*., 2010; Treydte *et al*., 2017; Ondier *et al*., 2019). Increasing frequency of land use conflicts and open rangeland degradation are increasing the importance of miombo woodlands as an alternative grazing resource for some herders (Nduwamungu *et al*., 2009; Mtimbanjayo & Sangeda, 2018).

## 2.3 Miombo woodlands as rangeland

Miombo woodlands have diverse vegetation that can be used as livestock forage (Gambiza *et al*., 2000; Ryan *et al*., 2016). Potential forage species include woody plants (*Brachystegia* spp., *Acacia* spp., *Harrisonia abyssinica*, *Flueggea virosa* etc.) and herbaceous plants (*Cynodon* spp., *Hyparrhenia* spp., *Andropogon* spp., *Urochloa* spp.), which have the capacity to support both browsing and grazing animals (Nyathi & Campbell, 1994; Cauldwell *et al*., 1999; Mtimbanjayo & Sangeda, 2018). The quantity of aboveground herbaceous biomass in dry miombo woodlands is estimated to range between 67 and 162 $g/m^2$ (Chidumayo, 1997; Chidumayo & Kwibisa, 2003), while open dry rangelands can supply an annual forage quantity of 29-135 $g/m^2$. Miombo forage is thus sufficient to support a low to moderate stocking rate (Selemani *et al*., 2013a; Mtimbanjayo & Sangeda, 2018; Sangeda & Maleko, 2018).

Livestock are grazed throughout the year in general miombo woodlands by pastoralists and agro-pastoralists (Figure 2). There is occasional livestock migration to and from open rangelands in cases of forage depletion during the dry season (Nduwamungu *et al*., 2009; Mtimbanjayo & Sangeda, 2018). Livestock grazing within the ecological capacity of miombo woodlands provides several benefits to herders and the miombo ecosystem. Ecologically, livestock grazing simulates the wildlife foraging pattern and lowers the available fuel load (herbaceous biomass), which reduces fire intensity and frequency in miombo woodlands (Gambiza *et al*., 2000; Chinder *et al*., 2020). High fire intensity and frequency in miombo can reduce its potential for carbon sequestration and other ecosystem functions such as water cycling (Gumbo *et al*., 2018; Chinder *et al*., 2020). Livestock are also responsible for nutrient recycling and distribution of herbaceous and woody plant seeds in miombo woodlands (Reid & Ellis, 1995; Mouissie *et al*., 2005; Mayengo *et al*., 2020).

*Figure 2*. Livestock grazing in miombo woodland in Kilosa district, eastern Tanzania.

Grazing beyond ecological capacity is associated with degradation of miombo woodlands due to reduced vegetation cover and reduced woodland sustainability, and can convert miombo woodland into open rangeland (Gambiza *et al*., 2000; Nduwamungu *et al*., 2009). In particular, high grazing intensity for long periods reduces the number of sprouting trees and seedlings due to trampling, leading to tree cover losses (Chinder *et al*., 2020). This can lead to bush encroachment if the tree species are succeeded by short woody plants (Gambiza *et al*., 2000; Alkemade *et al*., 2013). Other effects of overgrazing include soil degradation, biodiversity losses and conflicts with other land users with different management objectives, *e.g.* farming and conservation (Gambiza *et al*., 2000; Nindi *et al*., 2014). For sustainable use of miombo woodlands, livestock grazing should be within the ecological limit, *i.e.* it should not have negative effects on other ecosystem services (Gambiza *et al*., 2000; Mtimbanjayo & Sangeda, 2018).

Tsetse fly (*Glossina morsitans*) poses a challenge to livestock grazing in miombo woodlands. These biting flies are a nuisance to grazing livestock and herdsmen and are also responsible for transmission of African trypanosomiasis, a disease of humans and livestock (Ducheyne *et al*., 2009; Simukoko *et al*., 2011). Tsetse fly is the reason for limited livestock distribution and grazing activities in miombo to date. However, factors such as displacement of herders from their traditional grazing land due to population growth and increased demand for food are leading to increasing use of miombo woodlands in SSA for grazing (Nduwamungu *et al*., 2009; Nindi *et al*., 2014; Mtimbanjayo & Sangeda, 2018). In Zimbabwe, deforestation of miombo woodlands has been tested as a strategy to control tsetse fly and trypanosomiasis, but with negative effects on miombo sustainability and other ecological services (Mapedza, 2007). Tsetse flies tend to be most abundant in dense woodlands during the early rainy season, so avoiding these areas or use of prophylactic treatments in that period is advised (Ducheyne *et al*., 2009; Simukoko *et al*., 2011). Another alternative is to keep indigenous trypanotolerant livestock breeds (Small East African (SEA) goats, Red Maasai sheep and N'Dama cattle), as was done by herders (Geerts *et al*., 2009; Yaro *et al*., 2016). These livestock breeds can survive and remain productive with minimum managerial interventions in areas with high trypanosomiasis prevalence (Geerts *et al*., 2009).

## 2.4 Rangeland condition

Sustainable rangeland condition is described as the state at which soil integrity and rangeland ecological processes are sustained (Whitford *et al*., 1998). It reflects landscape capacity to perform ecosystem functions, ability to support biodiversity conservation and potential for livestock production (Whitford *et al*., 1998; Van Der Westhuizen *et al*., 2005). There is a direct relationship between rangeland condition and productivity. Good rangeland condition can support and improve livestock performance, while livestock grazed on degraded rangeland perform poorly (Fynn & O'Connor, 2000; Odadi *et al*., 2017). Trade-offs arise in miombo woodlands between sustainable rangeland condition for optimum livestock production and sustainable forest management aiming to protect tree cover. Reducing tree cover may increase livestock production without having negative effects on herbaceous forage distribution, but it is not suitable for miombo sustainability (Chidumayo, 1997; Chidumayo & Kwibisa, 2003; Chinder *et al*., 2020). Overall, dry rangeland condition varies due to abiotic and biotic factors such as annual rainfall, fire occurrence and grazing livestock distribution (Tessema *et al*., 2011; Lohmann *et al*., 2012; Ondier *et al*., 2019; Pfeiffer *et al*., 2019).

Coefficient of variation (CV) of annual precipitation can be used to categorise dry rangelands into equilibrium or non-equilibrium systems (Engler & von Wehrden, 2018). The threshold CV value is 33%, with systems below that value being in equilibrium and systems above in non-equilibrium. Systems in equilibrium show lower variations in inter-annual precipitation and can be improved with controlled stocking rate (Vetter, 2005; Ferrer *et al*., 2019). In addition to grazing, high inter-annual rainfall variation influences plant species composition and aboveground biomass in the non-equilibrium system (Vetter, 2005; Engler & von Wehrden, 2018). The systems have different management implications for dry rangeland. In equilibrium systems, local management and control of stocking rates may maintain rangeland condition, while in non-equilibrium systems livestock mobility and adaptive grazing are more important (Vetter, 2005). Livestock mobility in non-equilibrium systems is intended to rest rangeland during dry periods when plants have low growing capacity (Müller *et al*., 2007).

### 2.4.1 Vegetation structure

Plant communities respond differently to livestock grazing, and plant distribution and composition can be used to assess rangeland quality. Ecologically, grass species can be divided into different groups (Table 2), based on their succession and response to grazing intensity on dry rangelands (Cauldwell *et al*., 1999; Tefera *et al*., 2007). Grass species prevalence differs due to variations in rangeland type and botanical composition and can be used to indicate rangeland health, *e.g.* species categorised as Increaser 2a (see Table 2) indicate good rangeland condition (Cauldwell *et al*., 1999; Tefera *et al*., 2007; Egeru *et al*., 2015). In open rangeland systems, it has been shown that grass species life forms (ratio of annual to perennial grasses) can also be used to determine rangeland condition. Perennial grass species are usually preferred by rangeland managers, due to their persistence, productivity and year-round availability (Verdoodt *et al*., 2010; Pfeiffer *et al*., 2019). Annual grass species have large specific leaf area but thinner leaves than perennial grasses, and also have low biomass and a short life cycle, making them less suitable for rangeland grazing (Pfeiffer *et al*., 2019). Overall, the ratio of annual to perennial grasses increases with increasing grazing intensity until perennials are exhausted, after which available annuals are selected by grazing animals (Verdoodt *et al*., 2010; Lohmann *et al*., 2012; Pfeiffer *et al*., 2019). The condition of dry rangeland can be categorised as very poor (0%), poor (1-25%), fair (26-50%), good (51-75%) or excellent (76-100%), based on available grass cover (Sangeda & Maleko, 2018).

Table 2. Ecological status categories of rangeland grass species in response to different grazing intensity (adapted from Cauldwell et al. (1999) and Tefera et al. (2007)

| Ecological status | Description |
|---|---|
| Decreaser | Highly preferred by livestock; decrease in abundance with an increase in grazing intensity. |
| Increaser 2a | Present in low abundance in undergrazed or overgrazed rangeland; increase in abundance in moderately grazed rangeland. |
| Increaser 2b | Rare in undergrazed rangeland; increase in abundance in heavily grazed rangeland. |
| Increaser 2c | Less preferred by livestock; low abundance in undergrazed rangeland and very high abundance in overgrazed or degraded rangeland. |

Weeds (unpalatable herbaceous plant species) and bush encroachment are other indicators of rangeland condition, with weeds and bush usually being abundant in overgrazed rangeland (Tefera *et al*., 2007; Lohmann *et al*., 2012). They compete with palatable herbaceous species for space, light and nutrients, affecting their distribution and the overall productivity of rangeland (Fuhlendorf *et al*., 2009; Verdoodt *et al*., 2010). Good rangeland is characterised by diverse plant species, as plant diversity is important for different regulatory and provisional ecological services supplied by rangeland. Overgrazing is associated with biodiversity loss, including loss of important flora and displacement of fauna on rangeland (Alkemade *et al*., 2013; Odadi *et al*., 2017). This disrupts existing ecosystems, threatening rangeland sustainability and reducing the potential of rangeland for grazing, game hunting and tourism (Odadi *et al*., 2009).

### 2.4.2 Grazing management

Grazing management involves controlling the number of grazing livestock and their distribution, foraging period and visiting frequency on grazing land. Ideal grazing practices are those which sustain livestock production and maintain rangeland ability to provide other ecosystem services (Teague & Barnes, 2017; Godde *et al*., 2018; di Virgilio *et al*., 2019). Rangeland condition is not affected by livestock grazing when stocking is low to moderate (within rangeland regeneration capacity). Moderately grazed rangeland is dominated by desirable grass species (perennials), good vegetation cover and high forage biomass (Tefera *et al*., 2007; Pfeiffer *et al*., 2019). Heavy grazing for long periods is associated with an increase in undesirable plant species, low forage biomass, biodiversity losses, soil erosion and rangeland degradation (Selemani *et al*., 2013a; Odadi *et al*., 2017). This is because forage offtake eventually exceeds forage regeneration rate, so some soil patches are left exposed to the forces of erosion, *e.g.* water, wind and livestock hooves. Excessive grazing of desirable forage species can also reduce their competitive ability over undesirable species, *e.g.* weeds and annual grasses, reducing overall rangeland condition (García *et al*., 2012; Lalampaa *et al*., 2016).

Grazing management varies depends on the season, condition and area of available grazing land. In SSA, livestock may be moved over long distances from forage-depleted rangeland during the dry season to other grazing land if available. Herders migrate with much of their herd and establish temporary camps on grazing lands with water and forage that can be up to 80 km away from their permanent settlement (Adriansen & Nielsen, 2005; Butt *et al*., 2009). The livestock are brought back to the original grazing land if conditions become favourable or if the grazing resources in the new area become depleted. This grazing system is common in non-equilibrium rangeland systems where annual rainfall and forage biomass are highly variable, where livestock migration is important for rangeland recovery and herder livelihoods (Fynn & O'Connor, 2000; Müller *et al*., 2007). If migration is not possible due to lack of alternative grazing land, a rotational (deferred) grazing system can be employed. Under this grazing system, part of the grazing land available is rested and made inaccessible to grazing livestock, which gives the rested area time to regrow, recruit new plant species and restore biodiversity (Verdoodt *et al*., 2010; Selemani *et al*., 2013a). Resting grazed rangeland can increase the abundance of palatable forage species and available forage biomass, although not necessarily biodiversity in non-equilibrium ('alternative steady state') systems (Müller *et al*., 2007; Seymour *et al*., 2010; di Virgilio *et al*., 2019). Alternative steady state is a form of non-linear succession whereby lost plant species in degraded rangeland are not restored, due to rainfall variability, invasive species and soil erosion (Fuhlendorf *et al*., 2009; Bailey *et al*., 2019).

### 2.4.3 Rangeland carrying capacity

Rangeland carrying capacity is defined as the number of grazing animals that can be supported without serious effects on vegetation cover and other ecosystem services (De Leeuw & Tothill, 1990). It is determined by biomass availability at a given time and by the forage demand from livestock. Hence, it varies over time and between different rangelands (De Leeuw & Tothill, 1990; Gusha *et al*., 2017). In estimating carrying capacity, it is advised that some of the available biomass be left behind after grazing bouts, to support regeneration and avoid rangeland degradation (Benjaminsen *et al*., 2006; Mulindwa *et al*., 2009; Meshesha *et al*., 2019). Forage utilisation efficiency (30% for African dry rangeland) is generally used in estimating carrying capacity, so as to retain part of available biomass for rangeland regeneration and to account for uneaten forage due to trampling, urine and faecal contamination, and presence of thick shrubs or other grazing barriers (Dunne *et al*., 2011; Meshesha *et al*., 2019). The carrying capacity of African dry rangeland is commonly estimated using tropical livestock units (TLU), with 250 kg live weight taken as the standard TLU unit. Livestock species have different TLU conversion factors, *e.g.* 1.0 for camels, 0.8 for cattle and 0.2 for goats and sheep (FAO, 1988). Daily dry matter intake is estimated to be 2.5% of live weight, which is equivalent to 6.3 kg/TLU (Mulindwa *et al*., 2009; Meshesha *et al*., 2019). The carrying capacity is calculated per unit area and it is used to plan grazing activities in an area (Benjaminsen *et al*., 2006; Sangeda & Maleko, 2018). The carrying capacity of African dry rangeland is reported to be 0.1-1.0 TLU/ha/year, depending on the season and rangeland condition (Sangeda & Maleko, 2018; Meshesha *et al*., 2019).

The concept and calculation of carrying capacity focuses on herbaceous forage cover and grazing livestock, and thus shrub-dominated rangeland may have low estimated carrying capacity values due to lack of herbaceous biomass, since shrubs browsed by goats are not counted as part of total forage biomass yield (Meshesha *et al*., 2019; Mohammed *et al*., 2020). The carrying capacity concept is only applied to a limited extent by herders on African dry rangeland, since a trained rangeland expert is needed to perform the calculations. In addition, carrying capacity as a management tool may not be sufficient to maintain rangeland condition in non-equilibrium systems, since botanical composition is influenced by other factors such as inter-annual rainfall variation and prolonged droughts (Vetter, 2005; Benjaminsen *et al*., 2006).

## 2.5 Livestock foraging behaviour

Foraging behaviour in animal species involves actively seeking, identifying, selecting and swallowing plant materials (Odadi *et al*., 2009; Safari *et al*., 2011). Different livestock species have different foraging behaviours, *e.g.* cattle are primarily grazers and prefer understory herbaceous forage species. Sheep are also grazers and eat understory forage species, but compared with cattle (bulk feeders) they are more selective and prefer tender grasses (Dumont & Petit, 1995; Odadi *et al*., 2009). Goats are primarily browsers and their flexible lips enable them to selectively pick and eat leaves from shrubs and woody plants (Liao *et al*., 2016; Schroeder *et al*., 2019). Livestock species can change their feeding behaviour, *e.g.* goats may graze on understory forage species and sheep or cattle may browse on woody plants, when their preferred forage types are exhausted (Baloyi *et al*., 1997; Pontes *et al*., 2010; Mohammed *et al*., 2020). These changes are temporary, and livestock resume their usual foraging behaviour when their desired vegetation type becomes available.

Livestock foraging pattern is the result of rangeland managerial decisions such as landscape selection and individual livestock patch selection (Odadi *et al*., 2009; Hilario *et al*., 2017). Grazing land management and condition determine the available forage species, which influences forage intake and selection by grazing animals (Dumont & Petit, 1995; Mohammed *et al*., 2020). Grazing cattle tend to select forage patches dominated by perennial grass species due to their thick leaves and high biomass, in order to fill the rumen with nutrient-dense forage and reach satiety rapidly (Pfeiffer *et al*., 2019; Schroeder *et al*., 2019). The amount of forage ingested by grazing animals is determined by bite size and rate. Bite size is directly affected by available plant species diversity in the selected patch, with higher diversity resulting in smaller bite size and decreasing diversity causing an increase in bite size (Agreil *et al*., 2005; Pontes *et al*., 2010). It is postulated that diverse patches have additive effects on energy and protein quantity, overcoming shortcomings of individual grass species such as low digestibility and anti-nutritional factors. The larger bite size in less diverse patches can thus be attributed to a decline in nutrient consumption per bite, causing the animal to take larger bites to get the same amount of nutrients (Agreil *et al*., 2005). Forage height and forage stem strength (which vary with stage of maturity or species) are major factors affecting bite size in rangeland grazers. Bite size is lower in animals grazing tall forage species and increases with an increase in forage stem strength (Benvenutti *et al*., 2009; Geremia *et al*., 2018). Bite rate depends on bite size and is adjusted to ensure that the grazing animal consumes sufficient nutrients to meet its body requirements (Agreil *et al*., 2005; Benvenutti *et al*., 2009; Geremia *et al*., 2018).

Total forage intake and nutrient intake by livestock depend on the nutritional quality of the selected patch and ingested forage species (Odadi *et al*., 2009; Geremia *et al*., 2018). Low forage intake can lead to an increase in time spent searching for forage, at the expense of ruminating, resting and social behaviours (Odadi *et al*., 2009). It also increases the distance walked by grazing livestock in search for forage, leading to energy loss to support locomotion instead of using it for body maintenance or production (Jung *et al*., 2002; Odadi *et al*., 2009). Overall, livestock foraging behaviour can be influenced by improving rangeland condition and sustainable grazing plans that also include protection of plant diversity as a rangeland management goal (Agreil *et al*., 2005; Odadi *et al*., 2009).

## 2.6 Dry season mitigation strategies by herders

Destocking, livestock migration in search of forage and use of enclosures for forage conservation are the main management strategies used by herders to mitigate the effects of declining forage quantity in dry rangeland during dry periods (Butt *et al*., 2009; Verdoodt *et al*., 2010; Treydte *et al*., 2017). Livestock migration and use of enclosures face several challenges, such as changes in land use policies and land tenure systems resulting in a decrease in area of available grazing land (Said *et al*., 2016; Godde *et al*., 2018; Kilawe *et al*., 2018). Herders may also use alternative feedstuffs such as crop residues, *e.g.* maize stover and rice straw, to supplement livestock diets during dry periods, in order to mitigate the effects of feed shortages on their livestock (Njie & Reed, 1995; Treydte *et al*., 2017). Crop residues are characterised by low nutritional value due to high fibre content, so feeding these residues to livestock may ensure their survival during dry periods, but may not necessarily improve or maintain animal performance (Said & Tolera, 1993; Njie & Reed, 1995; Nazli *et al*., 2018).

Concentrates such as maize bran and seed cakes from agricultural mills are preferred by intensive livestock keepers as alternative feeds during dry periods, due to their high nutritional value and good effects on livestock performance (Mushi *et al*., 2009a; Safari *et al*., 2009). The main factors limiting wider use of concentrate as a ruminant feed by extensive herders are the high price and competition for raw materials from other animals and humans (Balehegn *et al*., 2020). These limitations increase the importance of using available grazing land to produce alternative feedstuffs that can be used during dry periods. *Cenchrus ciliaris* grass is cultivated on Tanzanian semi-arid rangeland and used successfully as an alternative feed during dry periods, due to its biomass yield (1-3 t DM/ha) and protein content (49-99 g/kg DM) (Bwire *et al*., 2003; El-Kharbotly *et al*., 2003; Patidar & Mathur, 2017). Recently, a new grass variety, *Brachiaria brizantha* cv. Piatã, bred specifically for high yield and drought resilience in Brazil, has been tested as a potential feed resource on dry rangeland during dry periods (Santos *et al*., 2018; Epifanio *et al*., 2019; Balehegn *et al*., 2020). This species has biomass yield of up to 4 t DM/ha and a protein content of 83-158 g/kg DM (Geremia *et al*., 2018; Mutimura *et al*., 2018; Santos *et al*., 2018).

There are limited studies done on effects of a *B. brizantha* cv. Piatã diet on the growth performance of indigenous livestock breeds in Africa. A study on crossbred cows showed no differences in feed and nutrient intake compared with an indigenous grass species (*Pennisetum purpureum*) (Mutimura *et al*., 2018). Studies on several *B. brizantha* varieties have reported improved dry matter intake, digestibility and weight gain in Brazilian indigenous cattle (Morais *et al*., 2011; Santos *et al*., 2018). Feeding *C. ciliaris* to indigenous livestock also results in high feed intake, nutrient digestibility and daily gain compared with other forage mixtures (Goromela *et al*., 1997; Bwire *et al*., 2003; Komwihangilo *et al*., 2005). The nutritional values of *B. brizantha* cv Piatã and *C. ciliaris* are similar, indicating good potential of both as supplementary dry season feeds. However, data on livestock performance in African breeds fed *B. brizantha* cv Piatã are lacking, so comparative studies on this and other supplementary feedstuffs are needed.

# 3. Aims of the thesis

The overall aim of this thesis was to assess herder management of assigned grazing land in miombo woodlands for sustainable livestock production, to improve livelihoods and food security without affecting woodland ecosystems.

Specific objectives of the studies described in Papers I-III were to;

- Describe indigenous rangeland and livestock management practices among traditional herders in miombo grazing land (I).
- Assess the role of livestock for the livelihoods of traditional herders using miombo grazing land (I).
- Evaluate seasonal variations in herbaceous species composition and vegetation structure in miombo grazing land (II).
- Evaluate variations in biomass production and nutritional values in herbaceous forage species on miombo grazing land (II).
- Evaluate forage species and alternative feedstuffs that can be fed to livestock as supplementary feeds during dry periods (III).

# 4. Materials and methods

## 4.1 Study area (Papers I-III)

Three field studies were conducted, two in Kilosa district (6-8ºS, 36º30'-38ºE) in Morogoro region, eastern Tanzania (Papers I and II) and one at the Tanzania Livestock Research Institute (TALIRI) in Kongwa district (6º-6º6'S, 26º22'-36º30'E), Dodoma region, central Tanzania (Paper III) (Figure 3). Kilosa district was chosen for a baseline survey and rangeland condition studies because it has a land use plan implemented by the 'Transforming Tanzania's Charcoal Sector' project in 2012 (Gmünder *et al*., 2014; Sangeda & Maleko, 2015; Kilawe *et al*., 2018). Choice of this study area was also motivated by presence of grazing activities in miombo woodlands by herders and regular conflicts among different land users in the district (Benjaminsen *et al*., 2009; Mtimbanjayo & Sangeda, 2018). Kongwa district has semi-arid conditions, with mean annual temperature of 26.5ºC and annual rainfall of between 254 and 660 mm (Asimwe *et al*., 2015; Chitimbe & Liwenga, 2015).

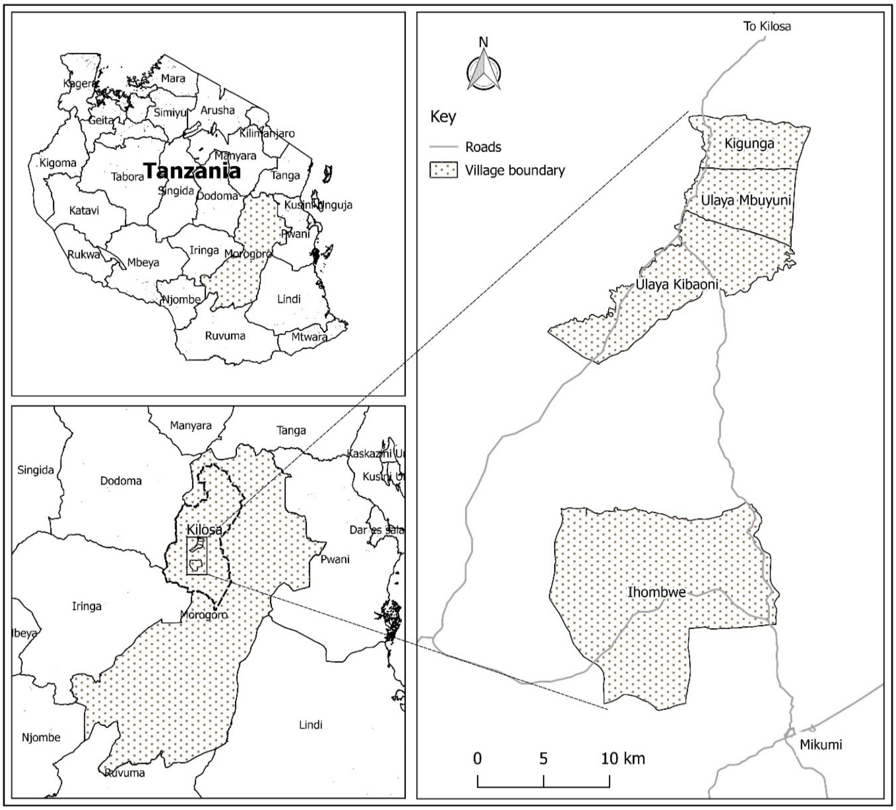


*Figure 3*. Location of the selected miombo villages in Kilosa district, eastern Tanzania (Papers I and II).

## 4.2 Study design

Household and key informant interviews and focus group discussions were used to investigate rangeland and livestock management practices among agro-pastoralists and pastoralists (Paper I). Seasonal rangeland condition in relation to distance from settlements, categorised as close (CS, 0-400 m from settlement) (Figure 4), and far (FS, >400 m from settlement), was evaluated using botanical composition, vegetation structure and forage condition (Paper II). In Paper III, growing goats (Tanzanian dual-purpose goat, a cross of 55% Kamorai, 30% Boer and 15% Small East African goat) were used in an on-station feeding trial (Paper III) to evaluate feedstuffs for *in vivo* dry matter digestibility, feed intake and growth performance. The data collection procedures employed are summarised in Table 3.

Table 3. Description of procedures used for data collection in Papers I-III

| | Paper I | Paper II | Paper III |
|---|---|---|---|
| Type | Qualitative and quantitative | Quantitative | Controlled experiment |
| Study area | Kilosa district | Kilosa district | Not applied |
| Villages | Ihombwe, Kigunga, Ulaya Kibaoni, Ulaya Mbuyuni | Ihombwe, Kigunga, Ulaya Mbuyuni | TALIRI research station, Kongwa |
| Study design | Household survey | Transect line | Complete randomised block design |
| Data collection | Household and key informants' interviews, focus group discussion, chemical analysis | Line intercept method, point centred method, chemical analysis, secondary rainfall data | Chemical analysis, in-vivo digestibility, feeding trial |
| Population | Agro-pastoralists and pastoralists | Allocated grazing lands | Tanzanian cross-bred goats |
| Sample size | 70 households | 3 grazing areas | 24 growing goats |
| Sample distribution | 36 agro-pastoralists and 34 pastoralists (54 males, 16 females) | 7,552 ha in Ihombwe, 206 ha in Kigunga, 120 ha in Ulaya Mbuyuni | 12 males and 12 females |
| Remarks | Permanent presence of herders and land use plan in the villages | Permanent grazing land, no permanent watering points and fire burning not allowed. | Dual-purpose goats bred for resistance to drought and diseases. |

*Figure 4.* Livestock resting around a boma (settlement) in miombo grazing land in Kilosa district, eastern Tanzania, during the dry season.

## 4.3 Data collection

### 4.3.1 Baseline survey

Agro-pastoralist and pastoralist households registered as permanent residents in the respective village registry were interviewed. The respondents were asked questions relating to rangeland and livestock management (Paper I). Age and gender were used as criteria when selecting some of the herders interviewed for further focus group discussions. Land use, grazing land management and livestock products were among the issues covered in these discussions. Key forage species mentioned in focus group discussions were sampled during the dry season and analysed for nutritional value (Paper I). One influential elder and one village official were interviewed as key informants in each selected village. Interviews were conducted following a set of prepared questions relating to environmental conservation, grazing and prospects for a land use plan.

### 4.3.2 Botanical composition and vegetation structure

Herbaceous forage distribution and vegetation structure (grasses, weeds, litter, tree canopy and bare ground) were assessed monthly, using the line intercept method (Godínez-Alvarez *et al*., 2009) (Figure 5). The Tanzanian forage species identification manual (Kayombo *et al*., 2016) was used to identify herbaceous forage species. The point-centred quarter (PCQ) method (Bryant *et al*., 2004) was used to measure tree density once, at the start of the study. For this, a steel cross was thrown randomly and the nearest trees in all four directions of the cross were identified and their distance measured (Figure 5).

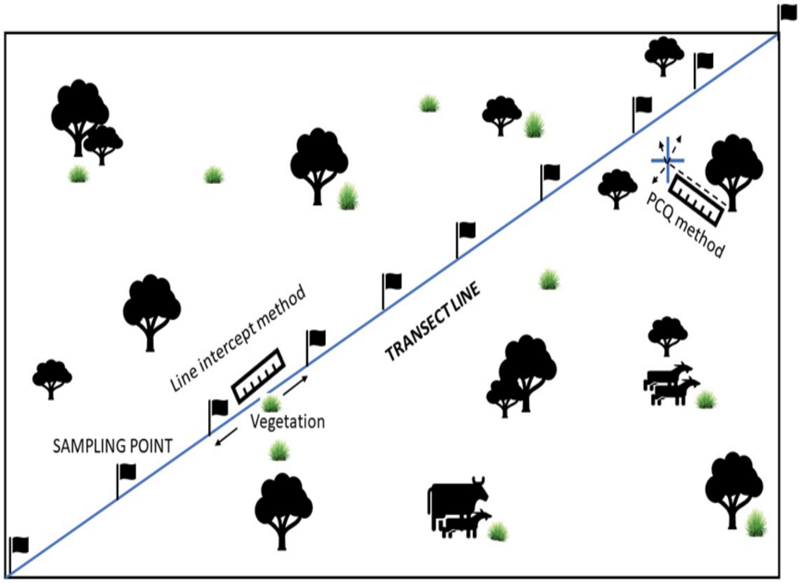


*Figure 5*. Illustration of methods used to collect data on herbaceous forage distribution and vegetation structure.

### 4.3.3 Forage condition and grazing management

A 0.5 m x 0.5 m quadrat was used to sample herbaceous forage species for nutritional analysis. Sampled forages were a mix of mature, young and dry forages, in order to imitate cattle foraging behaviour (Dumont & Petit, 1995; Benvenutti *et al*., 2009). A disc pasture meter (Zambatis *et al*., 2009) was used to measure herbaceous forage biomass monthly (Figure 6). Disc readings were calibrated at the start of the study and a linear equation was created to estimate herbaceous forage biomass (Paper II). Herbaceous forage biomass was used to determine calculated possible monthly stocking rate (CPMSR), calculated as available herbaceous forage biomass divided by estimated monthly livestock demand. Secondary data collected from the District Livestock Office were used to determine livestock grazing density (Paper II), which was expressed as reported stocking rate (RSR).

*Figure 6*. Disc pasture meter used to measure herbaceous forage biomass in grazed miombo woodland.

### 4.3.4 Supplementary feed evaluation

The supplementary diets evaluated were 'Brachiaria' (80% *B. brizantha* cv. Piatã, 20% *Gliricidia* leaf meal), 'Cenchrus' (80% *C. ciliaris*, 20% *Gliricidia* leaf meal) and 'Concentrates' (40% rice polish, 40% maize bran, 20% *Gliricidia* leaf meal). These feeds were selected due to their high nutritional values, drought resilience and good accessibility (concentrates) to farmers in the study region (El-Kharbotly *et al*., 2003; Tlili *et al*., 2018; Balehegn *et al*., 2020). The goats used in the study were fed their assigned diet individually at 5% of their body weight (amount changed weekly), twice a day, and were given water *ad libitum*. Average daily intake in individual goats was estimated weekly by collecting refused feed portions daily. Average daily weight gain was determined by weighing individual goats weekly. Faeces samples were analysed for acid-insoluble ash (AIA), for digestibility estimation, and individual diets were analysed for their chemical composition (Paper III).

## 4.4 Chemical analysis

Proximate methods established by the Association of Official Analytical Chemists (AOAC, 1997) were used for analysis of dry matter (DM; method ID 930.15) and crude protein (CP; method ID 954.01) in Papers I and II. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were analysed using the methods of Van Soest *et al*. (1991). The Tilley & Terry (1963) procedures and a regression model (Mbwile & Udén, 1991) were used to determine *in vitro* dry matter digestibility (IVDMD) and metabolisable energy (ME, MJ/kg DM) in Paper I. A near infrared reflectance (NIR) spectrometer (Perkin Elmer, DA 7250™), calibrated following the manufacturer's instructions, was used to determine DM, CP, NDF and ADF in Paper III, Dry matter digestibility (DMD) was estimated from AIA values. The model developed by Bwire *et al*. (2003) was used to calculate ME content in the concentrate and forage diets in Paper III.

## 4.5 Data analysis

Statistical Package for the Social Sciences version 20 (SPSS, IBM, Chicago, IL) for Windows was used to analyse collected household interview data (Paper I). Pearson's chi-square was used to compare the responses of agro-pastoralists and pastoralists. The Mann-Whitney U test was used to analyse demographic data, while content analysis was used in analysis of focus group discussion and key informant data. R Program version 4.0.1 (R Core Team 2020) was used to analyse vegetation structure, forage condition, CPMSR, feed intake, DMD and growth performance data in Papers II and III. The

Tukey test was used for mean pairwise comparison of the independent variables at $p<0.05$. In Paper II, coefficient of variation (CV) of annual precipitation in Kilosa district was determined using secondary rainfall data for the period January 2009-December 2019 (Figure 7). The CV value was used to categorise grazed land into equilibrium system (CV <33%) or non-equilibrium system (CV >33%).

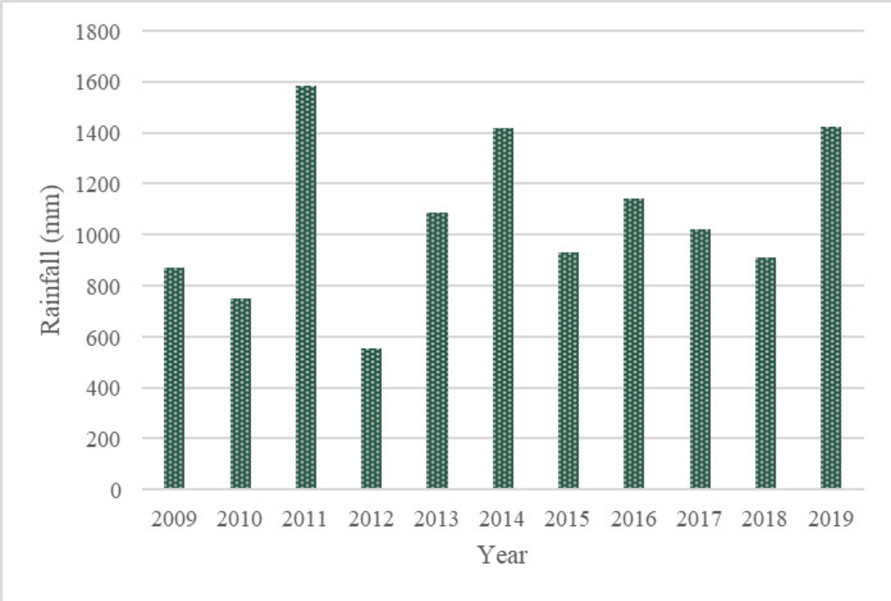


Figure 7. Total rainfall distribution 2009-2019 in Kilosa district, eastern Tanzania (source: Tanzania Meteorological Agency).

# 5. Main results

## 5.1 Socio-economic characteristics of herders (Paper I)

Level of education did not differ between the groups, with 55.6% of agro-pastoralists and 61.8% of pastoralists interviewed having no formal education (Table 4). Household size (8 members for both agro-pastoral and pastoral households) also did not vary between the groups. However, the role of livestock in livelihoods differed between agro-pastoralists and pastoralists (Table 4).

Table 4. Education level and role of livestock in the livelihoods of agro-pastoralists and pastoralists in Kilosa district, eastern Tanzania

| | Agro-pastoralists (n=36) | Pastoralists (n=34) |
|---|---|---|
| Formal education level (%) | | |
| None | 55.6 | 61.8 |
| Primary | 36.1 | 32.4 |
| Secondary | 2.8 | 2.9 |
| Tertiary education | 2.8 | 2.9 |
| Role of livestock (%) | | |
| Food | 58.3 | 76.5 |
| Income | 30.6[a] | 85.3[b] |
| Insurance | 80.6[a] | 52.9[b] |
| Draught power | 75.0[a] | 11.8[b] |
| Capital | 2.8 | 20.6 |
| Manure | 5.6 | 0.0 |
| Tradition | 2.8 | 17.6 |

Values within rows with different letters are significantly different ($p<0.05$).

## 5.2 Herd composition and health (Paper I)

Cattle, goats and sheep were the most common livestock reared by agro-pastoralists and pastoralists. Participants in the focus group discussions reported keeping indigenous livestock breeds due to their resilience to harsh conditions (diseases and drought), good temperament (draught animals), low management requirements, good market price and cultural values. Some of the miombo villages represented by interviewees had by-laws limiting herd size to 50 cattle per household. Herd size was reported to increase through birth, purchase, gift, inheritance and dowry. Some diseases were mentioned as reasons for livestock death and decline in herd size owned by agro-pastoral and pastoral households (Figure 8). Key informants mentioned high disease prevalence due to lack of disease prevention programmes in the area. In cases of livestock disease, herders reported use of unprescribed drugs to treat animals, selling sick animals and consulting a livestock advisor.

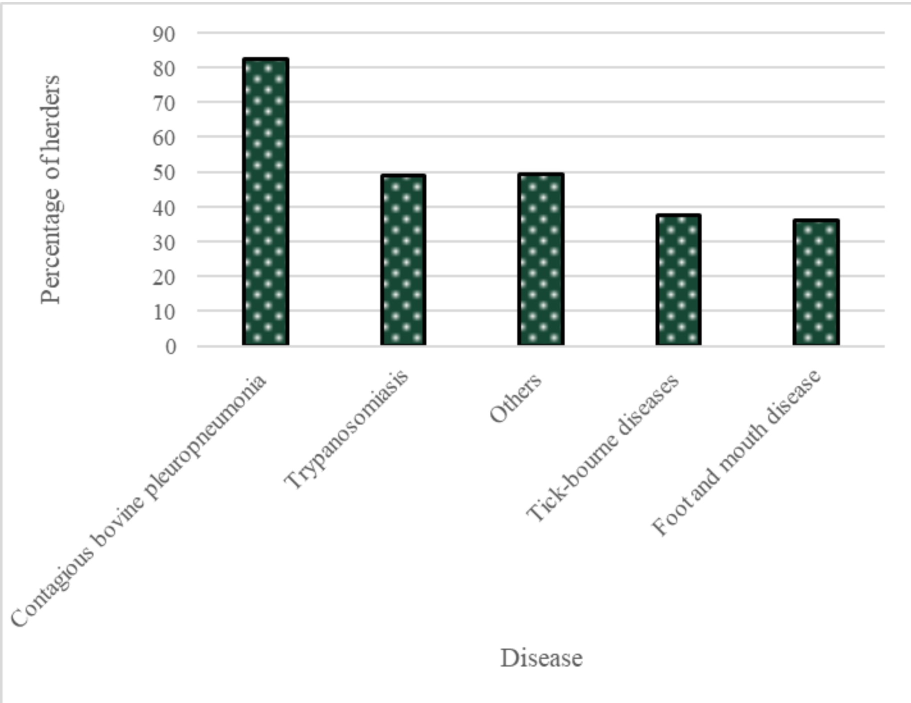


*Figure 8*. Main livestock diseases mentioned by agro-pastoralists and pastoralists in Kilosa district miombo woodlands.

## 5.3 Livestock and their products (Paper I)

Agro-pastoralists and pastoralists reported selling their live animals in livestock markets within Kilosa district. The price of live animals was determined by live body weight, age, health and season of the year (prices low in dry season). Cows were milked twice per day and the milk was used mostly for home consumption. Surplus milk was either sold fresh/raw or processed into fermented milk, ghee or butter for home consumption. Fresh/raw milk was sold daily (68% of herders) within the villages and to restaurants or other consumers in urban centres (Mikumi and Kilosa). There were no milk collection centres in the area and herders mentioned fluctuations in the price of fresh/raw milk depending on season. Herders also mentioned difficulties with fermentation of raw milk that led to spoilage and ultimately loss of milk during processing. These losses were reported to occur mainly during the dry season. Meat and hides/skin were sold by a very few herders (5.4%). Livestock were slaughtered and the meat was sold during public holidays or occasionally at livestock markets held every two weeks.

## 5.4 Rangeland management (Paper I)

Agro-pastoralists and pastoralists perceived the condition of their grazing land to be poor, due to a decline in forage quantity and, according to agro-pastoralists, to increased seasonal immigration of livestock from other areas. Pastoralists mentioned reallocation of their former grazing land for charcoal and conservation uses by the Transforming Tanzania's Charcoal Sector project as the main reason for poor grazing land quality. Despite bans, herders reported grazing their livestock in charcoal plots, conservation areas and farm areas during the dry season, due to a decline in forage quantity on their allocated land. Most traditional herders reported no to low bush encroachment, but pastoralists reported high weed infestation in their grazing area. A limited number of the respondents engaged in grazing land improvement practices such as bush clearing, fire control and controlled grazing around their households. None reported using traditional enclosures (*olalili*, *ngitiri*) for forage conservation. Unclear land tenure system, lack of technical knowledge and presence of other herders on grazing land were mentioned as the major barriers to improving grazing land condition (Figure 9).

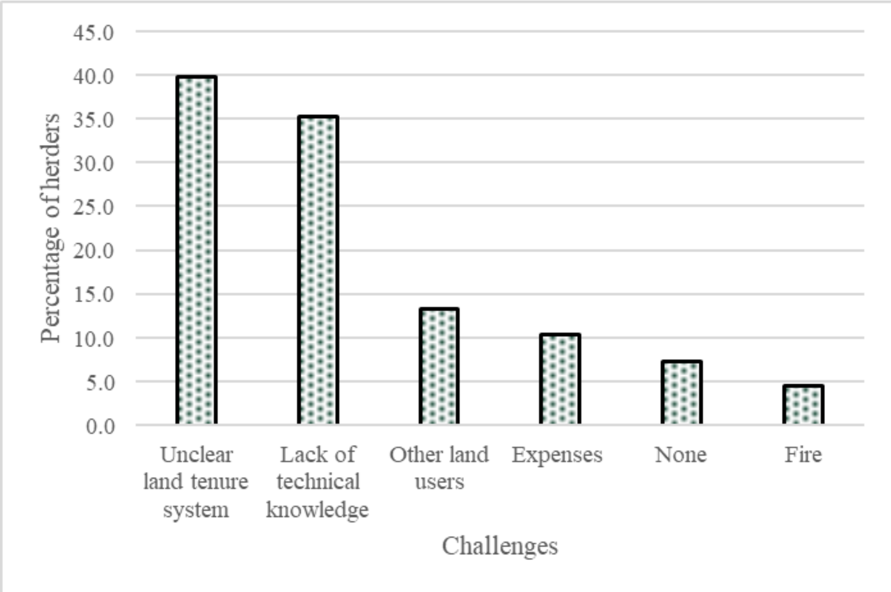


*Figure 9*. Rangeland improvement challenges reported by herders using miombo grazing land in Kilosa district, Tanzania.

Agro-pastoralists and pastoralists reported that their forage quality was good, based on available forage species, their palatability and livestock performance. Herders mentioned species such as *Panicum maximum*, *Cynodon nlemfuensis*, *Commelina benghalensis* and *Heteropogon contortus* as their preferred forages for livestock production. Herders' reasons for mentioning these species were availability throughout the year due to drought resilience and good nutritional qualities.

## 5.5 Herbaceous forage quality and quantity (Papers I and II)

Among the key forage species in miombo, *C. benghalensis* was found to have the highest CP content (248 g/kg DM) and *Brachystegia boehmii* the lowest (73 g/kg DM). The NDF content was highest in *H. contortus* (730 g/kg DM) and lowest in *C. benghalensis* (429 g/kg DM). Dry matter digestibility of key forage species ranged between 16 and 49 %, while the ME content range was between 2 and 5 MJ/kg DM. Seasonal evaluation of miombo forage quality included analysis of mixed forage species in varying proportions (Table 5). These samples included *Aristida* spp., *Bothriochloa* spp., *C. benghalensis*, *Cynodon* spp., *Digitaria* spp., *H. contortus*, *Hyparrhenia* spp., *P. maximum* and *Urochloa mosambicensis*. There was no seasonal variation ($p>0.05$) in CP or ADF content throughout the year, but the NDF content in miombo forages was affected by season, with lower values in the early dry season than in other seasons

Table 5. Forage quantity and quality in miombo woodland in Kilosa district, eastern Tanzania

| Key forage species | Plant type | Ecological group | DM (g/kg) | ME (MJ/kgDM) | CP (g/kgDM) | NDF (g/kgDM) | ADF (g/kgDM) | IVDMD (%) |
|---|---|---|---|---|---|---|---|---|
| Ihombwe village | | | | | | | | |
| *Cynodon nlemfuensis* | Grass | Decreaser | 371.4 | 2.1 | 117.4 | 717.4 | 406.5 | 32.5 |
| *Pennisetum puerperium* | Grass | Decreaser | 134.2 | 2.1 | 126.6 | 689.0 | 412.3 | 33.5 |
| *Heteropogon contortus* | Grass | Increaser 2a | 318.1 | 1.8 | 93.5 | 729.8 | 390.3 | 29.4 |
| *Panicum maximum* | Grass | Decreaser | 169.5 | 3.3 | 145.8 | 699.9 | 400.1 | 38.8 |
| *Commelina benghalensis* | Forb | NA | 126.0 | 4.1 | 247.8 | 442.4 | 306.5 | 44.7 |
| Ulaya Mbuyuni village | | | | | | | | |
| *Panicum maximum* | Grass | Decreaser | 157.9 | 3.7 | 98.7 | 664.8 | 395.1 | 43.0 |
| *Commelina bengalensis* | Forb | NA | 116.7 | 3.5 | 133.2 | 429.4 | 288.7 | 49.2 |
| *Cynodon nlemfuensis* | Grass | Decreaser | 272.2 | 4.9 | 178.7 | 681.4 | 349.6 | 48.9 |
| *Panicum destum* | Grass | Decreaser | 131.0 | 4.3 | 177.2 | 573.2 | 344.3 | 47.6 |
| *Heteropogon contortus* | Grass | Increaser 2a | 317.5 | 1.8 | 143.2 | 683.3 | 409.9 | 26.3 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ulaya Kibaoni village | | | | | | | | |
| *Cynodon nlemfuensis* | Grass | Decreaser | 277.6 | 5.0 | 180.3 | 681.9 | 321.6 | 48.7 |
| *Cyperus involucratus* | Forb | NA | 149.4 | 3.8 | 115.7 | 624.0 | 320.1 | 38.1 |
| *Panicum maximum* | Grass | Decreaser | 265.5 | 3.2 | 91.0 | 675.1 | 395.8 | 38.7 |
| *Brachystegia boehmii* | Tree | NA | 259.5 | - | 73.3 | 632.4 | 538.3 | 16.3 |
| Kigunga village | | | | | | | | |
| *Panicum maximum* | Grass | Decreaser | 153.2 | 2.3 | 134.9 | 691.8 | 403.2 | 36.4 |
| *Urochloa mosambicensis* | Grass | Increaser 2a | 170.2 | 4.4 | 137.9 | 641.4 | 341.6 | 48.2 |
| Seasonal forage quality | | | | | | | | |
| Nutrients | | Late rainy | Early dry | | Late dry | | Early rainy | |
| DM (g/kg) | | 307.1±31.7$^{a}$ | 528.5±25.9$^{b}$ | | 558.3±25.9$^{b}$ | | 285.7±25.9$^{a}$ | |
| CP (g/kg DM) | | 71.4±3.6 | 73.1±3.0 | | 74.0±3.0 | | 73.3±3.0 | |
| NDF (g/kg DM) | | 688.9±12.0$^{a}$ | 531.8±9.7$^{b}$ | | 703.5±9.7$^{a}$ | | 704.5±9.7$^{a}$ | |
| ADF (g/kg DM) | | 406.3±13.5 | 402.1±11.1 | | 423.1±11.0 | | 419.0±11.1 | |
| Seasonal forage quantity (kg DM/ha) | | | | | | | | |
| Distance [a] | | Late rainy | Early dry | | Late dry | | Early rainy | |
| CS | | 667.6±234.8$^{\ddagger}$ | 553.8±232.0$^{\ddagger,\dagger}$ | | 298.7±232.9$^{\S}$ | | 418.6±232.5$^{\S,\dagger}$ | |
| FS | | 798.3±224.0$^{\ddagger}$ | 866.4±221.0$^{\ddagger}$ | | 408.5±222.0$^{\dagger}$ | | 570.8±222.0$^{\S}$ | |

[a] CS = close to settlement (0-400 m); FS = far from settlement (>400 m).
DM = dry-matter; ME = metabolisable energy; CP = crude protein; NDF = neutral detergent fibre; ADF = acid detergent fibre; IVDMD = *in-vitro* dry-matter digestibility.
Means within columns and rows with different symbols or letters are significantly different.

Herbaceous forage quantity was not significantly different between the close (CS) and far (FS) distances, but it varied significantly due to season (Table 5). It was generally higher in the late rainy and early dry season, and lower in the late dry and early rainy season, for both distances from settlement (Table 5).

## 5.6 Herbaceous forage distribution (Paper II)

A total of 69 different herbaceous species of grasses, forbs and legumes were found on miombo grazing land. The grass species *Bothriochloa pertusa* showed high prevalence at CS and FS distances throughout the year in the grazed miombo area in Kigunga village. Similarly, *B. pertusa* was the most prevalent grass specie in grazed miombo area in Ulaya Mbuyuni village for both distances and all seasons except the late rainy season, when *Digitaria sanguinalis* was more prevalent for the CS distance. Grazed miombo area in Ihombwe village had a high prevalence of *Hyparrhenia rufa* (FS, throughout the year), *Urochloa mosambicensis* (CS, early and late rainy season), and *Cynodon plectostachyus* (CS, early and late dry season).

## 5.7 Vegetation structure (Paper II)

Grass cover, ratio of annual to perennial grasses, area of bare ground and litter cover did not vary significantly between distances CS and FS and there was no distance-season interaction (Table 6). Weed cover was affected by distance, being higher at CS compared with FS in the two rainy seasons and during the early dry season. Season ($p<0.05$) had an effect on grass, weed and litter cover, as expected (Figure 10). Litter cover was lowest during the rainy seasons, while grass and weed cover were higher during the rainy and early dry season and lowest during the late dry season. The properties of trees in miombo grazed area did not differ significantly between distances CS and FS (Table 6).

Table 6. Vegetation structure (mean±SE) in miombo grazing land in different seasons in relation to distance from settlement (CS = close to settlement (0-400 m); FS = far from settlement (>400 m)). Means with different letters and symbols are significantly different.

| Distance | Late rainy | Early dry | Late dry | Early rainy |
|---|---|---|---|---|
| Grass cover (%) | | | | |
| CS | $37.7\pm5.0^{\S}$ | $34.3\pm4.7^{\S,\dagger}$ | $30.4\pm4.7^{\dagger}$ | $35.9\pm4.7^{\S,\dagger}$ |
| FS | $39.0\pm4.7^{\S}$ | $36.2\pm4.5^{\ddagger,\S}$ | $25.1\pm4.5^{\dagger}$ | $32.7\pm4.5^{\ddagger}$ |
| Annual:Perennial grass ratio | | | | |
| CS | 0.07±0.04 | 0.02±0.03 | 0.04±0.03 | 0.07±0.03 |
| FS | 0.05±0.03 | 0.07±0.03 | 0.09±0.03 | 0.04±0.03 |
| Weed cover (%) | | | | |
| CS | $10.4\pm1.4^{\ddagger,a}$ | $8.0\pm1.3^{\S,\ddagger,a}$ | $3.6\pm1.3^{\dagger}$ | $6.3\pm1.3^{\S,a}$ |
| FS | $4.7\pm1.1^{b}$ | $2.7\pm1.0^{b}$ | 1.1±1.0 | $2.8\pm1.0^{b}$ |
| Bare ground (%) | | | | |
| CS | 24.8±3.3 | 24.3±2.9 | 31.0±2.9 | 28.2±2.9 |
| FS | 23.9±2.7 | 26.5±2.4 | 27.8±2.4 | 24.3±2.4 |
| Litter (%) | | | | |
| CS | $2.7\pm5.1^{\ddagger}$ | $20.8\pm4.8^{\S}$ | $26.7\pm4.8^{\S,a}$ | $10.6\pm4.8^{\ddagger}$ |
| FS | $5.4\pm4.6^{\ddagger}$ | $22.2\pm4.4^{\S}$ | $36.5\pm4.4^{\dagger,b}$ | $16.2\pm4.4^{\S}$ |
| Tree properties | | | | |
| | Density (trees/ha) | Height (m) | Crown diameter (m) | Canopy cover (%) |
| CS | 923±254 | 4.4±0.4 | 4.1±0.5 | 36.5±6.6 |
| FS | 1136±237 | 4.3±0.3 | 3.6±0.4 | 41.6±5.6 |

Figure 10. Vegetation structure (bare, litter and tree cover) in miombo grazing land during the dry season.

## 5.8 Livestock grazing management (Paper II)

Calculated possible monthly stocking rate (CPMSR) varied between miombo grazed areas in the different villages (Figure 11). The values in Ihombwe were higher ($p<0.05$) than in Kigunga and Ulaya Mbuyuni grazed areas during the early dry and rainy season. The CV of annual precipitation was 29.3% in Kilosa district. Reported stocking rate (RSR) during the study period was 7.7 TLU/ha/year in Ulaya Mbuyuni, 2.6 TLU/ha/year in Kigunga and 0.6 TLU/ha/year in Ihombwe.

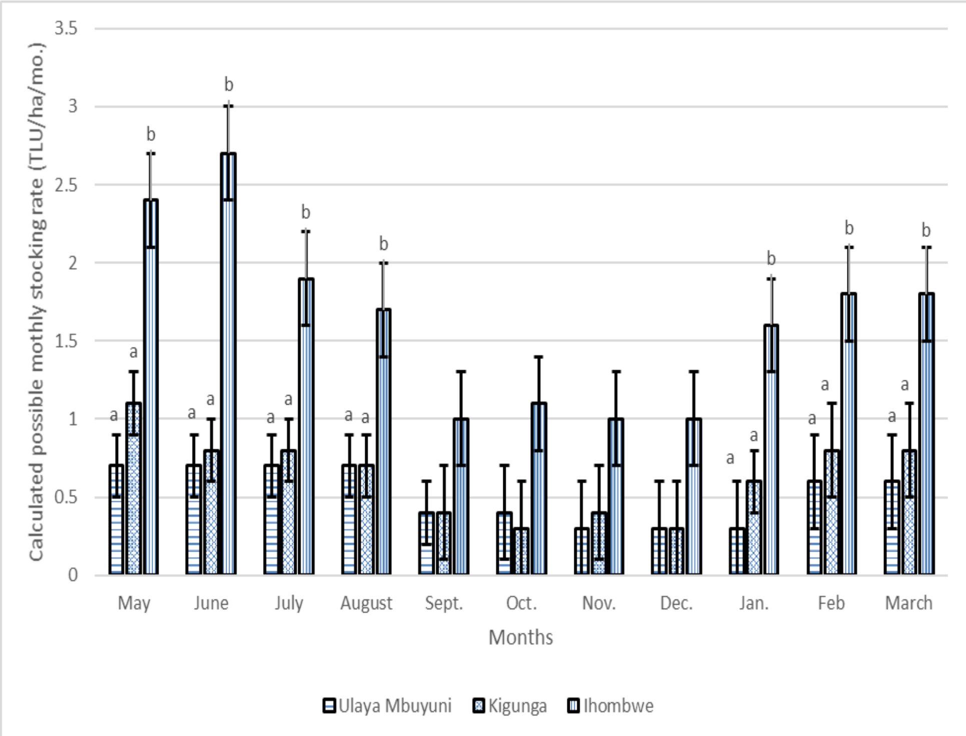


Figure 11. Calculated possible monthly stocking rate (CMSR, expressed as tropical livestock units (TLU) per ha and month) on miombo grazing land in eastern Tanzania during the study period. Different letters indicate significant difference within months. Reported stocking rate (RSR) during the period according to the district authority was 7.7 TLU/ha/year in Ulaya Mbuyuni, 2.6 TLU/ha/year in Kigunga and 0.6 TLU/ha/year in Ihombwe.

## 5.9 Alternative livestock feedstuffs (Paper III)

The Concentrates, Brachiaria and Cenchrus experimental diets examined in Paper III had a CP content of 183, 73 and 66 g/kg DM, respectively, and an ME content of 10.6, 7.4 and 9.2 MJ/kg DM, respectively. The NDF content was 342 g/kg for the Concentrates diet, 533 g/kg for the Brachiaria diet and 553 g/kg for the Cenchrus diet. The Concentrates diet (38.9%) had significantly lower digestibility than the Brachiaria diet (55.4%) or Cenchrus diet (67.7%).

Goats fed the Concentrates diet had lower dry matter intake (DMI) (508 g/day) and lower overall live weight gain (0.118 kg) compared with goats fed the Cenchrus diet (DMI 549 g/day, overall live weight gain 2.069 kg). Goats fed the Brachiaria diet had intermediate DMI and overall live weight gain values. Type of diet fed had no effect on daily average weight gain during the study period, with goats gaining 10.7, 9.9 and 22.8 g/day on the Concentrates, Brachiaria and Cenchrus diet, respectively.

# 6. General discussion

## 6.1 Miombo grazing land condition

Miombo biomes are unique as grazing land due to presence of both understory herbaceous forage and relatively dense tree cover, unlike in open rangeland (Paper II). Livestock grazing while maintaining the tree cover is a recent practice in miombo woodlands. The tree clearing and overgrazing that were common practice earlier among herders in Zambian and Tanzanian miombo woodlands resulted in conversion of miombo to open rangeland (Chidumayo & Kwibisa 2003; Nduwamungu *et al*. 2009). Thus, the land use plan developed for Kilosa district included measures aiming to reduce practices destructive to trees, while some miombo villages introduced by-laws to keep herd size below 50 cattle per household (Paper I). The herd size restrictions limited grazing intensity, which can reduce livestock trampling of regenerating trees in miombo grazing land according to Gambiza *et al*. (2000) and Chinder *et al*. (2020). Miombo trees contribute to different ecosystem services, such as carbon sequestration and water catchment, and support livelihoods through supplying timber and non-timber forest products (Ryan *et al*., 2016). The tree density in miombo woodland grazed in this study (923-1136 trees/ha; see Table 6) is similar to that reported for undisturbed miombo woodlands (Shirima *et al*., 2011; Lupala *et al*., 2015). This indicates potential for using miombo for grazing without significant negative effects on the available tree cover, as targeted by the land use plan. However, miombo grazing under the Kilosa land use plan had only been active for about six years when this study was conducted, so long-term effects (>10 years) of current grazing practices on tree cover need to be evaluated in future studies.

The grazing areas studied in this thesis had diverse herbaceous cover (69 plant species), including different grasses (both perennials and annuals), legumes, and forb species (Paper II). Herbaceous plant diversity is important for grazing land condition because plant species differ in their resilience to pests, diseases, climate change and grazing. Thus, plant heterogeneity ensures that some forage species are available all year round. Herbaceous plant diversity is also important to grazing ruminants because forage species, *e.g.* grasses and legumes, have different digestibility, anti-nutritional factors and nutrient content (energy and protein), and hence have complementary effects in livestock nutrition (Agreil *et al*., 2005; Dunne *et al*., 2011). It is important to include herbaceous plant biodiversity as a management goal for miombo grazing land and as a rangeland condition indicator, in order to ensure livestock productivity and provision of other ecosystem services. High grazing intensity can reduce diversity, but the current grazing intensity in the study region seems to maintain both tree cover and available plant species diversity (Papers I and II).

The miombo biome in Kilosa district is at the borderline between dry and wet miombo woodland, as can be seen from the inter-annual rainfall distribution (Figure 7). Annual rainfall variations (CV=29.3%) indicate that the landscape is in an equilibrium system, rather than a non-equilibrium system. This means that rainfall is sufficient and variation between years is relatively low, therefore, management and livestock stocking rate determine good rangeland conditions (Vetter 2005). Calculated possible monthly stocking rate (0.2-2.7 TLU/ha/month; Figure 11) can ensure good rangeland condition because grazing would be within forage regeneration potential. Stocking rate beyond the calculated values can lead to degradation of grazing land condition and poor rangeland productivity despite sufficient rainfall. However, climate change could lead to systems previously in equilibrium changing to non-equilibrium systems due to an increase in rainfall variation and prolonged droughts (Vetter, 2005; Ferrer *et al*., 2019). Sustainable rangeland management recognises the importance of controlled grazing and resting periods on all dry rangeland, which allow rangeland condition to be ensured if the rate of forage offtake (grazing intensity) by livestock does not exceed the rate of forage regeneration (Oluwole *et al*., 2008; Dunne *et al*., 2011).

The condition of the miombo grazing land studied in this thesis could be interpreted as good, due to dominance of perennial grass species (Table 6).

The ratio of annual to perennial grasses has been found to be a good indicator of rangeland health and degradation in more open rangeland (Linstädter *et al*., 2014; Pfeiffer *et al*., 2019). This ratio was very low in the study area (0.02-0.09) and there were no seasonal or distance to settlements differences (Table 6, Paper II). This confirmed that the condition was good, since the ratio was lower than the critical threshold (<0.5) identified by Lohmann *et al*. (2012). It could also indicate that the ratio of annual to perennial grasses is not a relevant indicator of rangeland health for shaded environments such as miombo and that other indicators should be used.

Perennial grass species such as *Bothriochloa pertusa*, *Hyparrhenia rufa*, *Urochloa mosambicensis* and *Cynodon plectostachyus* were prevalent in all the studied grazing areas (Table 6, Paper II). *H. rufa*, *U. mosambicensis* and *C. plectostachyus* are categorised as Increaser 2a species (Cauldwell *et al*., 1999; Tefera *et al*., 2007; Egeru *et al*., 2015) because they occur in low frequency in undergrazed or overgrazed rangeland and are abundant in moderately grazed open rangeland or dry miombo. *Bothriochloa pertusa* is a native forage species in African open rangelands, but its ecological response to grazing in the region is not clearly established. According to Selemani *et al*. (2013a), *B. pertusa* is prevalent in open rangelands in Tanzania, with good vegetation cover. In Australia, *B. pertusa* is considered an invasive species and grows in areas with low soil fertility and it is of low grazing value (Mcivor *et al*., 1995, 1996). Succession of *B. pertusa* by annual grass *Digitaria sanguinalis* in Ulaya Mbuyuni close to settlement during late rainy period (Paper II) suggest that *B. pertusa* could be an Increaser 2b in this miombo area. This is because succession of grazed grass is linear from Decreaser to Increaser 2a, 2b and 2c whereby *D. sanguinalis* is Increaser 2c due to its high prevalence in degraded and severely grazed African rangelands (Doumbia, 2006; Mudongo *et al*., 2016). Overall, grazing intensity in Ihombwe grazing land studied in this thesis could be described as intermediate or moderate because of the observed high seasonal prevalence of Increaser 2a (7-20%) compared to Increaser 2b and 2c (0.1-6.1%) grasses. The condition in Kigunga and Ulaya Mbuyuni grazed areas could be described as relatively poor and leaning towards degradation due to high prevalence (7-25%) of Increaser 2b and 2c. Increaser grasses could be possible to use as an indicator of rangeland condition in miombo because of their growth habit and response to grazing. They could also be used to reflect soil health and grazing intensity, since high prevalence of Increaser 2a (*H.*

*rufa*, *U. mosambicensis* and *C. plectostachyus*) species could indicate moderate grazing, their replacement by Increaser 2b (*B. pertusa*) species could be an early sign of degradation, and Increaser 2c (*D. sanguinalis* and *Dactyloctenium aegyptium*) species dominance could indicate rangeland degradation.

Interestingly, *B. pertusa* and *H. rufa* were not mentioned by herders as key forage species during interviews (Table 5), despite their high prevalence in miombo villages where herders mentioned preferring forage species that have good nutritional quality and are abundant and palatable (Paper I). In terms of nutritional values, mature *B. pertusa* and *H. rufa* are reported to have an ME content of 4.2 and 7.4 MJ/kg DM, respectively, and a CP content of 38 and 40 g/kg DM, respectively (Grimaud *et al*., 2006; Mlay *et al*., 2006). The energy level in key forage species mentioned in Ulaya Mbuyuni and Kigunga villages was 2.3-5.0 MJ/kg DM. Herders could have omitted mentioning *B. pertusa* as it is less preferred by livestock and *H. rufa* could have been left out intentionally, because of its low protein content compared with the 73-180g/kg DM found for key miombo forages in the study villages. Keba *et al*. (2013) reported a positive relationship between herder perceptions of grass quality in dry rangeland and laboratory protein value, as also seen in this thesis (Table 5). Except for *Heteropogon contortus* and *U. mosambicensis*, the key miombo forage species mentioned by herders (see Table 5) are Decreaser species, which means they could be highly desired by livestock compared with some abundant Increaser 2a or 2b species present. This shows that the herders have ethnobotanical knowledge in determining what is best for their livestock, preferring Decreaser or Increaser 2a forages with high CP content. Dominance of any forage species in dry rangeland should not be encouraged, because of possible nutritional limitations such as low palatability and protein values. Herbaceous forage diversity in miombo grazing land could reduce the limitations of individual forage species and improve rangeland nutrition, as discussed above.

The estimated ME value of 2-5 MJ/kg DM in miombo forages preferred by the herders interviewed can meet the nutritional requirements of growing indigenous goats and sheep (Luo *et al*., 2004a; Nsahlai *et al*., 2004; Xu *et al*., 2015). However, it is lower than the minimum energy requirement for cattle body maintenance estimated by Salah *et al*. (2014). This was contradictory to herders' perceptions, as they reported selecting key miombo forage species based on their nutritional quality and ability to support the productivity of indigenous cattle (Paper I). The ME of key miombo forage species such as *Panicum maximum* (2.3-3.7 MJ/kg DM; Table 5) was lower than the 5.5-9.4 MJ/kg DM reported in the East African nutritional table (Mgheni *et al*., 2013). The differences between two ME values can be attributed to forage sampling season, since sampling of individual grasses was carried out during the dry season (Paper I), and to differences in the model used to estimate ME. Mgheni *et al*. (2013) used a model that accounted for individual organic compounds (CP, fat and carbohydrate) digestibility, whereas the Scandinavian model used in this thesis only considered organic matter content and its in vitro digestibility. Also, high energy and low protein in the diet during estimation of nutritional requirements could cause overestimation of cattle energy requirements, since low protein can limit body metabolism despite high energy intake (Patterson *et al*., 2009; Salah *et al*., 2014). All these considerations, combined with the fact that cattle grazing in miombo were able to survive and grow, indicate that key miombo forages present were able to meet cattle energy requirements. The CP content of key miombo grasses such as *Cynodon nlemfuensis* was higher than in herbaceous forage samples in grazing areas in Paper II (Table 5). This is because key miombo forage species were individually sampled and analysed (Paper I), whereas the analysis of seasonal herbaceous forage (Paper II) included different grass species and a mixture of fresh, standing hay and matured grass, in order to imitate cattle foraging behaviour as bulk feeders (Papers I and II). The CP content of some miombo forages was sufficient to support the maintenance and performance requirements of different livestock species (Salah *et al*., 2014; Dias Ferreira *et al*., 2015).

The highest herbaceous forage quantity observed on miombo grazing land, 866 kg DM/ha far from settlements during the early dry season (Table 5), was close to the 743 kg DM/ha reported for open dryland (Selemani *et al*., 2013a; Meshesha *et al*., 2019) but in the lower range of biomass values found in dry miombo woodlands (Chidumayo & Kwibisa, 2003). The difference between the values found in this thesis and in earlier studies on miombo could be because herbaceous forage biomass was estimated in continuously grazed areas in this thesis. Herders mentioned overall low forage quantity and the low forage biomass observed in the study villages during the dry season was at the level expected within dry rangelands. Low forage quantity could limit livestock production potential during the dry season. Use of supplementary feed resources or introduction of high-yielding and nutritious forage species on miombo grazing land could improve forage biomass and ensure livestock productivity throughout the year (see section 6.4). Herders could also increase herbaceous forage biomass through different indigenous rangeland improvement practices.

## 6.2 Miombo grazing land management

Rangeland improvement activities to increase forage biomass were only used to a limited extent among interviewed herders. Improvement practices were conducted on areas around settlements by 31% of the agro-pastoralists and 12% of the pastoralists interviewed. The grazing land improvement measures mentioned were controlled grazing, bush clearing and fire control (Paper I). Fire control is very important to avoid sudden loss of accumulated forage biomass after the growing period (Solomon *et al.*, 2007; Alkemade *et al.*, 2013). It was hypothesised in the longitudinal grazing land evaluation study (Paper II) that rangeland condition would be worse closer to settlements, because of trampling due to livestock traffic. This was not seen during the study period and mean grass cover did not differ between the two distances from settlement (far and close), but grass cover was categorised as poor (<26%) at distances far from settlements during the late dry season (Table 6). This could be due to an increase in grazing pressure far from settlements as a result of livestock immigration (Papers I and II). The majority of the herders interviewed mentioned insecure land tenure system and immigration of other herders not living in the village as the major reasons for not improving their grazing land or establishing forage reserves (Paper I). The lack of forage reserves and grazing land improvement practices for miombo reported by the interviewees contradict findings by Selemani *et al*. (2013a) and Treydte *et al*. (2017), who observed presence of forage reserves in communal open rangelands. These differences are mainly due to the presence of strong traditional institutions in the open rangelands, in which villages improved communally owned grazing land.

Insecure land tenure system was mentioned as a barrier to grazing land improvements (Figure 8), despite the herders having the right to graze in miombo woodlands. This is because all land is owned by the state in the Tanzanian land tenure system. The Village Land Act of 1999 recognised customary land and gave village councils (democratically elected every five years) the mandate to administer it on behalf of the people (Massay, 2016; Biddulph, 2018). Under the land use plan for miombo in Kilosa district, village councils are the governing body and make all decisions relating to miombo grazing land, including by-laws that ban other activities (cutting trees, farming, fire burning). The herders (Maasai and Sukuma) interviewed in this thesis showed good stockmanship and ethnobotanical knowledge, but the by-laws banning tree cutting or burning limited herders wider application of these practices in improvement of grazing land condition (Paper I). In addition, Kilawe *et al*. (2018) reported poor representation of herders in the miombo village councils. They found that village councils were mostly made up of farmers (crop cultivation), who vastly outnumber herders in the region (NBS 2013). Hence herders have little chance of influencing decisions relating to the land use plan.

An increase in herder representation in village councils seems warranted, but might not address the land tenure question or encourage herders to engage in rangeland improvement practices, due to the "paradox of pastoral land tenure" (Kilawe *et al*., 2018; Ono & Ishikawa, 2020). Herders want a secured tenure system for all customary land that guarantees their grazing rights without risking being expelled or punished. They also want grazing rights to be granted only to herders living in a particular village and to include respect for private property. This is to ensure that rangeland improvement practices, such as saving forage for the dry season, benefit the resident herders and not other herders entering the area (Papers I and II). However, herders also require flexibility in the land tenure system that can support livestock mobility, due to seasonal forage variations and climate change effects (Sendalo, 2009; Turner *et al*., 2016). These are contradictory ends, since herders do not have both a private and open-access customary land system. Moreover, land area is limited, so multiple users such as other herders and farmers cultivate crops in their allocated areas within the same customary land in the land use plan (Paper I). In Kilosa district, this paradox of pastoral land tenure has been the cause of conflict among different users, *e.g.* farmers and herders (Benjaminsen *et al*., 2009; Nindi *et al*., 2014). This could ultimately lead to a tragedy of commons in miombo grazing land, with individuals refraining from improving grazing land due to lack of incentives and secured land use rights, hence risking mismanagement and degradation (Moritz *et al*., 2015; Glowacki, 2020).

Degradation of miombo grazing land due to extreme mismanagement could be indicated by loss of tree and grass cover, replacement of Increaser 2a and 2b by Increaser 2c grass species, herbaceous plant diversity loss and soil erosion, converting miombo from woodland to open rangeland to bare land (Gambiza *et al*., 2000; Nduwamungu *et al*., 2009). Alternatively, an increase in grazing intensity, decline in rangeland condition and little livestock mobility options during the dry season could make herders opt for intensive management of miombo in order to utilise available resources effectively and sustain their livelihood. Herders could strengthen their traditional institutions to manage grazing land with formal or informal grazing arrangements among themselves (Glowacki, 2020; Wainaina *et al*., 2021). Absent or weak traditional institutions could be explained by current land tenure and governance of miombo grazing land (Papers I and II). There is a need for more flexible land governance in land use plans in order for intensive grazing land management to occur and succeed. Village authorities should change some of their current by-laws, in order to integrate and consider other products (animal-source food from livestock). A compromise could be reached between some of the ecological services performed by tree cover in miombo and maintaining herder livelihoods. This compromise could include allowing herders a certain degree of input use, such as use of forage reserves, rangeland seeding to increase forage biomass and setting a minimum number of trees that could be used to maintain other miombo ecological services. This thesis did not address the relevance of such compromises. Further studies are needed to investigate the effect of different tree covers in miombo grazing land on forage biomass yield and woodland capacity for carbon sequestration.

Lack of technical knowledge on rangeland improvement was mentioned by herders during interviews (Paper I). It has arisen because grazing in miombo woodlands, while maintaining existing tree cover, is a new practice for many herders, who previously used open rangeland for grazing their cattle. Most of the herders interviewed were originally from open rangeland in Kilosa or neighbouring districts, with some immigrating seasonally and others settling permanently. The number of herders migrating and settling permanently in miombo could have increased after introduction of the land use plan, due to the secured grazing rights and relatively good rangeland condition (Strömquist & Backéus, 2009; Nindi *et al*., 2014). This increase in the number of herders due to immigration could further strain miombo grazing land in the future, due to absence of rangeland improvement practices. Nonetheless, these herders have an accumulated wealth of indigenous knowledge transmitted through oral traditions and experience in managing open rangeland (Liao *et al*., 2016; Selemani, 2020). An example of an indigenous practice is prescribed burning during the late dry season every three years, to recycle nutrients and increase forage biomass in the following rainy season (Oluwole *et al*., 2008; Toledo *et al*., 2014). Fire during the late dry season can be more intense, due to accumulation of herbaceous biomass. Alternatively, early burning has been shown to reduce forage biomass drastically, cause losses of soil nutrients (organic carbon, nitrogen, phosphorus) and expose bare soil to wind erosion (Sandhage-Hofmann, 2016). Prescribed burning could be relevant for open rangeland, but when too intense or frequent it could reduce the cover of woody plants.

Multi-species livestock production in miombo grazing land seems to be used by herders to utilise the area that is also covered by woody plants. Although cattle (grazers) are the main livestock species in miombo, presence of relative dense tree cover and a possible decline in herbaceous forage biomass due to overutilisation in some miombo villages (Paper II) might elevate the importance of goats (browsers) as a key livestock species among herders. This is because woody plants could provide foraging materials for browsing goats. Goats could support herder livelihoods and ensure food security because of their short generation interval, prolificacy and low forage intake due to their relatively small body size (Kosgey *et al*., 2008; Liao *et al*., 2016). Low forage intake by goats could increase forage availability on the grazing land per animal.

## 6.3 Livestock grazing in miombo

Calculated possible monthly stocking rate (CPMSR) based on available forage biomass was 0.2-2.7 TLU/ha/month, with values being lower during months in the late dry and early rainy season (September-January) than in the late rainy and early dry season (February-August) (Paper II). The CPMSR was within the carrying capacity reported for other dry rangeland (Mulindwa *et al*., 2009; Meshesha *et al*., 2019). However, aboveground herbaceous biomass used to determine CPMSR was measured in continuously grazed areas, which may have skewed the value since forage biomass could have accumulated or could have been ingested by livestock between monthly measurements, resulting in underestimates and overestimates, respectively. Also, the forage biomass used to calculate CPMSR did not account for woody plants, *e.g. Brachystegia boehmii*, which was mentioned as a key forage by herders and was one of the dominant miombo tree species (Papers I and II). Woody plants were not included because of their height (Table 6), which renders them inaccessible to most browsing livestock. The reported stocking rate (RSR) from district livestock data for Ulaya Mbuyuni was 7.7 TLU/ha/year, which was higher than the 5.4 TLU/ha/year estimated using livestock data for other open dry rangeland (Sangeda & Maleko, 2018; Meshesha *et al*., 2019). The difference in stocking rate between Ulaya Mbuyuni village and other open rangeland can be because Ulaya Mbuyuni had a small grazing area hence had high grazing pressure. Also, lower carrying capacity (expressed as CPMSR) than grazing intensity (expressed as RSR) observed in Kigunga and Ulaya Mbuyuni village during the study period could indicate that the two areas were being overutilised.

The calculated possible monthly stocking rate (CPMSR) in Kigunga and Ulaya Mbuyuni grazed areas during rainy and early dry months was lower than that estimated in Ihombwe grazed area (Figure 11). Lower possible stocking rate seen throughout the year under the current grazing pressure means that the two grazed areas had lower capacity to support additional livestock production as was described by De Leeuw & Tothill (1990) and Gusha *et al*. (2017). The grass cover observed in the two villages' grazing land during early rainy and late dry seasons (19-21%) can be categorised as poor (Paper II). Weed cover (undesirable herbaceous species) in studied miombo was between 1 and 10% (Paper II) which was lower than 18-28% reported by van der Westhuizen *et al*. (1999) and Mseddi *et al*. (2016) in degraded open dry rangelands. The level and distribution of weed cover was lower than what is considered as degraded, but low CPMSR, poor grass cover and high prevalence of Increaser 2b and 2c in Ulaya Mbuyuni and Kigunga indicates that their areas could be overgrazed and at an early stage of degradation (Paper II). Also, there is a risk that weed cover could increase in the future due to lack of rangeland improvement practices and continued increase in grazing pressure from an immigration of other herders from open rangelands (Papers I and II). High grazing pressure and poor management practices can reduce the competitiveness of desirable forage species (Decreaser and Increaser 2a) and replace them with unpalatable grass species

(Increaser 2b and 2c) and weeds. High weed cover reduces rangeland productivity by lowering herbaceous forage biomass and could affect other ecosystem services due to plant biodiversity losses (Odadi *et al*., 2009; Alkemade *et al*., 2013). Sustainable grazing land management requires that the current rangeland condition in the studied area is improved since increased pressure on grazed resource could lead to weed takeover and complete loss of desirable forage species (Paper II). It is therefore important to promote grazing practices that improve or maintain good rangeland condition in miombo grazing land.

There are several grazing systems that could be employed to ensure that grazing intensity does not exceed forage regeneration capacity, and thus to maintain or improve rangeland condition in miombo grazing land. Stocking rate should be set at the lowest available monthly forage biomass in dry rangelands such as miombo if grazing is constant and there is no resting period between grazing bouts. This will ensure that grazing lands are not overstocked during the dry season, when forage resources are depleted (Table 5 and Figure 11). The village authority managing Ulaya Kibaoni's grazing land seems to have opted for this approach, by limiting herd size to 50 cattle for each household throughout the year (Paper I). It was unclear how this stocking rate limit was determined, but regular inspections of herd size should be conducted by the village authority to enforce the grazing arrangements. A lower stocking rate could be suitable during the dry season but might result in underutilisation of miombo during the rainy season, when there is an abundance of forage (Table 5). Underutilisation of grazing land could lead to selective grazing and accumulation of standing hay, which could lower the nutritional value (*e.g.* CP, see Table 5) in individual patches and limit nutrient recycling in the absence of fire (Oluwole *et al*., 2008; McGranahan *et al*., 2014; Yoshihara *et al*., 2015). This could lead to wastage of valuable forage resources and ineffective utilisation of miombo grazing land for maximum livestock production during rainy periods, and hence affect animal-source food production.

Another grazing option could be to adjust the stocking rate on miombo grazing land following CPMSR (Figure 11). The stocking rate could be lowered during dry months by reducing the number of grazing livestock through destocking and increase again in rainy months. Such adjustment could also be done seasonally, to avoid monthly mobility, by encouraging herders to set stocking rate using the lowest CPMSR of the respective season, *e.g.* early rainy, late rainy, early dry and late dry (Paper II). The greatest challenge in adopting this grazing system on miombo grazing land could be finding areas for livestock to graze in between forage regeneration periods. Mtimbanjayo & Sangeda (2018) proposed partial livestock grazing (during the dry season) in miombo charcoal plots without affecting tree regeneration and charcoal production sustainability in Kilosa district. The condition of available herbaceous forage species, their biomass and carrying capacity in miombo charcoal plots are currently unknown. These need to be evaluated before the start of grazing in the area, so as to monitor grazing land condition and avoid overgrazing. Another challenge lies in estimating rangeland carrying capacity, as this requires specialist training (Benjaminsen *et al*., 2006; Zambatis *et al*., 2009). This could be resolved by using livestock advisors to monitor available herbaceous forage biomass using Equation 1 developed in Paper II. Large miombo grazing area makes it difficult to estimate stocking rate monthly, so to reduce the labour intensity it could be done seasonally instead. However, the poor availability of livestock advisory services in most African countries means that livestock advisors are not widely available (Gustafson *et al*., 2011; Mutambara *et al*., 2013). Livestock advisory services for livestock keepers could be provided through the mass media (radio and television) or by affiliating the land use plan with universities such as Sokoine University of Agriculture in Morogoro as part of field training for students. In the meantime, grass and weed species prevalence could be used as indicators of grazing capacity and intensity. However, political will from village authorities is important overall for rotational grazing between miombo grazing land and charcoal plots to occur.

## 6.4 Livestock supplementary feeds

In addition to rotational grazing, supplementary feed resources can be an option to feed livestock during the dry season. The feedstuffs used should be nutritious and palatable (easily accepted by livestock), and should be available during the dry season or show drought resilience (Balehegn *et al*., 2020; Sala *et al*., 2020). In this thesis, diets based on *Brachiaria brizantha* cv Piatã, *Cenchrus ciliaris* and concentrates were evaluated as potential supplementary feeds based on these criteria. Chemical analysis of the Brachiaria, Cenchrus and Concentrates diets showed that their ME was 7.4, 9.2 and 10.6 MJ/kg DM, respectively and their CP content was 73, 66 and

183 g/kg DM, respectively (Paper III). These compound diets contained 20% *Gliricidia sepium* leaf meal and therefore had higher ME than the key miombo forage species (Table 5). All three diets had sufficient ME to meet the requirements of different indigenous livestock species (Luo *et al*., 2004a, 2004b; Salah *et al*., 2014). The good nutritional qualities, availability (concentrates) and high biomass yield of *B. brizantha* and *C. ciliaris* make them suitable for dry rangelands as supplementary feedstuffs. There were no significant differences in average daily weight gain when the diets were fed to goats (Paper III). This indicates that the new (in Tanzania) *B. brizantha* cv. Piatã grass variety as well as *C. ciliaris* grass can be fed to livestock to obtain similar daily weight gain as obtained with other supplement feeds used elsewhere, such as concentrates.

Dry matter intake (DMI) was lower for goats fed the Concentrates diet (508 g/day) than for goats fed the Cenchrus diet (549 g/day). This difference could be because the experimental goats were foraging in *Cenchrus*-dominated rangeland prior to the start of the experiment (Paper III), which could have increased their acceptance and adaptation rate to the Cenchrus diets. Goats on the Concentrates diet were offered a small amount of hay in the beginning of the study, in order to facilitate transition from a forage-based to a concentrate diet. Goats fed the Concentrates diet had lower DMI in the early weeks of experiment (Paper III), as seen previously in goats suddenly changing to a high-concentrate diet (Sun *et al*., 2010; Serment & Giger-Reverdin, 2012). The lower initial DMI in goats fed the Concentrates diet, despite receiving hay during transition period, was likely because the transition period was too short (2 weeks) or because the concentrate level in the diet (80%) exceeded the 65% recommended by Hua *et al*. (2017). High concentrate inclusion in the diet could alter the microbial population in the rumen, with fibrolytic microbes replaced by non-fibrolytic species due to the easy fermentation of concentrates. This could lead to an increase in production and accumulation of ruminal lactic acid and hence lower rumen pH to between 5.0 and 5.4, which could lead to subacute rumen acidosis (Sun *et al*., 2010; Hua *et al*., 2017; Giger-Reverdin, 2018). Subacute rumen acidosis can be the reason why goats fed the Concentrates diets had lower initial DMI than goats fed either the Brachiaria or Cenchrus diet (Paper III). Overall estimated live weight gain during the entire study period (12 weeks) was lower in goats fed the Concentrates diet (0.12 kg) than in goats fed the Cenchrus diet (2.07 kg). This indicates that feeding high levels of concentrate-based diet as a dry season supplement to foraging livestock, like those grazing miombo woodland, might not improve DMI or overall live weight gain, since the animals might need a long time to adapt to concentrates. A possible option for herders could be to use grass species such as *B. brizantha* cv. Piatã or *C. ciliaris* with good feed intake and overall live weight gain as supplementary feeds (Paper III).

Introduction of these grass species could increase miombo grazing land productivity and ensure forage availability throughout the year. The forage could be conserved as hay and fed to livestock during forage shortages. However, cultivation of these forages on the whole gazing area and their conservation as hay by herders on miombo grazing land would be labour-intensive and would require high inputs use such as seeds and fertiliser (Coppock, 1991; Sala *et al*., 2020). Their wider introduction and adoption on miombo grazing land would also require much clearer land tenure than the current system (Paper I). There is some scope for small-scale interventions, whereby individual herders could cultivate these forage species in the areas surrounding their settlements where rangeland improvement is practised (Papers I and II). Agro-pastoralists could also sow forage species between crop rows on their existing plots, hence increasing land utilisation efficiency. However, these grass species could compete with cultivated crops for light and space in the same way as weeds, so a better option might be to plant them around the farm borders (Maleko *et al*., 2019; Bell *et al*., 2021). Individual cultivation of grass species could establish a niche market for hay, which could diversify household livelihoods as herders could sell surplus forage to other livestock keepers. A niche hay market could also create a financial incentive by giving a monetary value to the available forage and could convince other herders to adopt forage conservation techniques (Safari *et al*., 2019; Balehegn *et al*., 2020).

In this thesis, *C. ciliaris* grass was planted on five acres of enclosed plot in four different villages but failed to establish in all cases. This failure was due to poor soil tillage, late planting and livestock grazing in enclosed areas because of poor fencing (personal observations). Agronomically, *B. brizantha* cv. Piatã and *C. ciliaris* could still be cultivated on miombo grazing land, based on their ability to grow on soils with low fertility and their potential to be integrated into silvi-pastoral system due to their shade tolerance (Mishra *et al*., 2010; Geremia *et al*., 2018; Balehegn *et al*., 2020). If *C. ciliaris* or *B. brizantha* cv. Piatã is cultivated, herders are advised to use certified seeds, which have a better germination rate (Hare *et al*., 2018; Bhatt *et al*., 2020). Lack of commercial pasture seeds and the recent entry of *B. brizantha* cv. Piatã in Tanzania could limit its use as a forage species for miombo grazing land. Herders could instead use plant cuttings, *e.g. C. ciliaris* tillers, which could be easily made available from established plots in the district and would resprout in plots (Kizima *et al*., 2014). Herders should also harrow the land before planting the tillers and prevent livestock grazing by using enclosures until the grass has established. Ecologically, it could be argued that introduction of *C. ciliaris* and *B. brizantha* cv. Piatã as grass species poses a risk of plant diversity losses in miombo, because these new species may outcompete native herbaceous species and become invasive. However, *C. ciliaris* and *B. brizantha* are native grass species in large parts of Africa, including in dry miombo woodland (Cauldwell *et al*., 1999; Tefera *et al*., 2007; Egeru *et al*., 2015). Absence of these grass species in Kilosa miombo grazing land could be because these are Decreasers on dry rangeland. Therefore, their introduction in enclosed areas might not lower herbaceous plant species diversity in miombo grazing land, but rather enhance it. High livestock preference for introduced grasses would also reduce the risk of them becoming invasive and dominating the whole grazing land.

## 6.5 Livestock and livelihood in miombo woodlands

Livestock grazing in miombo could support livelihoods by providing several services, such as food, income, insurance, draught power and capital accumulation (see Table 4), as mentioned in interview by traditional herders. Many of the agro-pastoralists (58%) and pastoralists (76%) interviewed relied on livestock as a source of food. High human population growth could increase the importance of miombo as a grazing resource, due to an increase in demand for animal-source food and shrinking area of open rangeland (Thornton, 2010; Godde *et al*., 2018). A large proportion of the pastoralists interviewed (85%) relied on livestock as a source of income, compared with only 31% of the agro-pastoralists, who grew crops for sale and had relatively small herd size consisting of small ruminants and cattle (Paper I). The involvement of agro-pastoralists in crop cultivation and its importance as a source of income could also explain why most of those interviewed (75%) used livestock as draught power (Table 4). Use of draught animal power in crop production by agro-pastoralists is reported to improve household resilience during drought by enabling a greater area of land to be cultivated and reducing the work burden on women and children, who are responsible for manual land tillage in households (Abdul Rahman & Reed, 2014; Zampaligré *et al*., 2014). Interestingly, it was found in Paper I that some pastoralists in miombo woodlands were also taking up sedentary crop cultivation, *e.g.* pastoralist women (Maasai) were leasing a small piece of land (2-5 acres) within the allocated farmland and cultivating staple crops (mostly maize). This has also been reported on other dry rangeland, *e.g.* by Tsegaye *et al*. (2013) and Zampaligré *et al*. (2014), as an adaptation strategy to enhance food security. The current dry sub-humid climate in Kilosa district (Figure 7) could support crop cultivation, but this situation could change in the future due to increased aridity index under climate change. Climate change might cause crop failure, so herders will rely more on livestock to support their livelihoods. Livestock could be sold in the event of crop failure among agro-pastoralists, during prolonged drought periods or during health emergencies (Moll, 2005). Livestock provide insurance in this way, as mentioned by herders in this thesis (Table 4). This shows the importance of livestock as stored wealth for herders' livelihoods and the rural economy, as they could be easily sold during emergencies for household support (Moll, 2005; Little *et al*., 2014).

Selling live animals within the district, as mentioned by the traditional herders interviewed in this thesis, is common practice in SSA. The remoteness of miombo grazing land could limit available markets to primary livestock markets within Kilosa district (Paper I). Kadigi *et al*. (2013) and Little *et al*. (2014) found that livestock in dryland areas are bought by middlemen visiting local markets and that the price is influenced by household economic situation and livestock condition, which is similar to the situation in Kilosa (Paper I). The livestock price fluctuations reported during the dry season can be caused by poor forage availability in miombo woodlands, leading to weight loss and poor body condition in livestock. This could threaten the livelihood of most pastoralists using miombo grazing land, since they rely solely on livestock as a source of income and food (Paper I). During the dry season, there is a risk of malnutrition among vulnerable groups (children, elders, pregnant women) in pastoral households due to lack of sufficient protein in the diet, because adult males may migrate with livestock in search of forage (Truebswasser & Flintan, 2018). It is therefore important to improve forage availability and rangeland condition in order to maintain herders' livelihoods and health.

Herders reported selling milk directly in local markets, due to lack of milk collection facilities, which could pose a threat to public health since milk quality is not controlled. Lack of milk collection centres could be explained by local herders' limited overall capacity to produce and supply milk throughout the year (Jans *et al*., 2016). Daily milk yield of 5 L in indigenous cattle was mentioned by the herders using miombo grazing land (Paper I), which was higher than the 2 L/day reported for Zebu cattle on dry rangeland (Mwacharo & Rege, 2002). The higher daily milk yield observed in cattle on miombo grazing land could have been influenced by lactation stage (cows in early lactation produce more milk) or nutrition level, such as forage abundance during the rainy season. High volume of milk on the market was reported by herders for the rainy season, but milk yield is usually low during the dry season (Paper I), so establishment of a milk collection centre might not be feasible (Truebswasser & Flintan, 2018). The lack of a milk collection centre in miombo villages reduces the available market for surplus milk produced during the rainy season. Fluctuating supply and low local demand for milk could explain the price fluctuations mentioned by miombo herders. Low local demand for milk means that a large proportion of milk may not be consumed and may spoil. Spoiled milk, *i.e.* post-harvest losses, occurring throughout the year has multiple negative effects on herder livelihoods, such as loss of food and possible income, while milk contamination could transmit food-borne diseases (Msalya, 2017; Häsler *et al*., 2018). If there is an increase in the current milk price of 600 TSh (0.26 USD) per litre (Paper I) due to an increase in milk demand caused by population growth, herders could be encouraged to engage in more formal markets. Herders on miombo grazing could organise themselves into groups and participate in formal dairy value chain through bulk sales and adoption of production strategies that meet market and seasonal demand, *e.g.* milk collection centres, as reported elsewhere (Chagwiza *et al*., 2016; Tessema *et al*., 2019; Glowacki, 2020). Formal integration of miombo herders into a dairy value chain could reduce post-harvest losses, improve marketing of milk, protect public health through regular quality checks and create an incentive for herders to intensify livestock production on miombo grazing. It could also improve income and empower women, who are responsible for marketing milk in pastoral households (Mwacharo & Rege, 2002; Truebswasser & Flintan, 2018).

Cattle were the livestock species most favoured by herders (Paper I), owing to their multiple uses as draught animals, good market value due to relatively large body size compared with goats and sheep, and other socio-cultural roles (Kosgey *et al*., 2008; Abdul Rahman & Reed, 2014). Herders' choice of indigenous livestock breeds for grazing miombo woodlands due to perceived resilience to diseases is well founded, as explained by Geerts *et al*. (2009) and Yaro *et al*. (2016). Lack of disease prevention programmes in miombo woodlands (Paper I) is due to poor livestock advisory services in SSA. Lack of advisory services also results in herders using unprescribed antibiotics to treat most livestock diseases (Paper I), as reported by Mangesho *et al*. (2021). Poor milk fermentation was mentioned by herders to occur throughout the year, and could be caused by presence of antibiotics residues in the milk (Kang'ethe *et al*., 2005; Mangesho *et al*., 2021). Community-based animal health workers are necessary in miombo woodland areas in order to diagnose livestock diseases and monitor antibiotic use, in the absence of veterinarians in the region. Veterinary policies and service delivery need to be flexible and address the major infectious diseases prevalent in the miombo area (Gustafson *et al*., 2011; Mutambara *et al*., 2013; Musoke *et al*., 2020). Overall, livestock can play a significant role in poverty reduction through enhanced animal food production, despite the marketing and disease challenges faced by herders using miombo grazing land.

# Conclusions

Sustainable management of miombo woodland needs to account for different services, such as ecological benefits and livestock grazing, provided by this landscape. In the studied miombo grazed lands, grazing was continuous and rangeland improvement practices were limited whereby herders conducted bush clearing and avoid fire burning to the areas surrounding their settlements. Unclear land tenure system and lack of technical knowledge were identified as the major reasons for lack of wide improvement of the miombo. Herders in the area of Tanzania studied were mostly keeping indigenous multi-livestock species whereby cattle were the most favoured livestock species. The indigenous livestock species were kept because of their resilience to harsh condition and other socio-economic values. Livestock contributed to the herders livelihoods through the selling of milk and live animals in the local markets within the area. They were also used as the draught animals for crop cultivation and provide insurance during emergencies.

The high number of trees found on miombo grazing land showed that it is possible to use these woodlands for livestock grazing without significant negative effects on the available tree cover. The herbaceous cover was diverse with high prevalence of both annual and perennial grass species. High prevalence of Increaser 2a grass species (during rainy and dry seasons) in Ihombwe miombo villages indicated that the grazing land condition was good and grazing intensity was moderate. Kigunga and Ulaya Mbuyuni grazed areas in the studied miombo were dominated by undesirable Increaser 2b (in all seasons) and Increaser 2c (late rainy season) grass species. Weed cover was too low in all seasons to consider them as complete degraded but poor grass cover during dry and early rainy season with high prevalence of undesirable grass species indicated poor condition and early sign of degradation due to overgrazing in the two villages. The prevalence of Decreaser or Increaser and weed cover can be used as indicator of herbaceous cover condition in miombo to monitor grazing land status.

Forage species selected by herders as key grasses and of randomly sampled herbaceous forage collected in seasonal evaluation of grazing areas showed that some miombo forages have sufficiently high protein and energy values to support maintenance and performance requirements of different livestock species. Aboveground forage biomass varied seasonally and was lowest during the dry season. Potential supplementary feeds (concentrates, *Brachiaria brizantha* cv. Piatã, *Cenchrus ciliaris*) evaluated had enough energy and protein to meet the maintenance and production requirements of different livestock species. Goats fed a diet based on 80% concentrates had lower feed intake and overall live weight change compared with goats fed a Cenchrus-based diet indicating that a high-concentrate diet is not a good supplementary feed for previously foraging livestock. Instead, *B. brizantha* cv. Piatã or *C. ciliaris* grasses could be fed during the dry season, which could increase livestock productivity on miombo and contribute to poverty reduction and household food security.

# Recommendations and future perspectives

- The use and importance of miombo woodlands as an alternative grazing resource for livestock is expected to increase in future, due to projected human population growth, effects of climate change and an increase in demand for animal-source foods. It is important to promote practices that can change or prevent poor rangeland condition observed in some miombo grazed areas in Kilosa district. Herders should keep their livestock stocking rate at the lowest monthly carrying capacity if they graze miombo continuously throughout the year. A better but more difficult management could be to adjust stocking rate to match seasonal variations in forage biomass in miombo.

- Village authorities could enforce proper stoking rate through regular inspection of herd size and allowing rotational grazing between charcoal plots and allocated grazing areas for limited periods during the dry season to allow forage regeneration. Flexible land use system could also be employed by village authorities with a compromise between maintaining tree cover and animal-source food production, by allowing controlled tree clearing in grazed areas. Studies are needed to evaluate the relevance of tree clearing, different grazing systems and carrying capacity of charcoal plots (ungrazed) for grazing in Kilosa district. Grazing studies should assess the effects of grazing duration and intensity on individual livestock performance and per unit of land, and condition of grazed land, using botanical composition and vegetation structure as indicators.

- Some forage species in miombo have good nutritional value, but low forage biomass and poor grass cover in dry season necessitate introduction of new forage species in miombo woodland. Herders could grow *Brachiaria brizantha* cv. Piatã and *Cenchrus ciliaris* grasses from vegetative cuttings (*e.g.* tillers) in enclosed areas surrounding their settlements or around their farm borders. These grass species could be conserved as hay and used during the dry season. Herders could benefit from cost-benefit analyses on introduction of new forage species and use of other rangeland management practices such as enclosures and selective tree clearing. Cost-benefit data could offer herders valuable financial guidance when deciding on management of their grazing land.

- When creating future land use plan in other miombo woodlands or regions, policymakers need to allocate areas for grazing. Grazing areas in the land use plan can provide forage resources and ensure grazing rights of livestock keepers, thus increasing economic growth and animal-source food production in the country.

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# Popular science summary

Future population growth is expected to cause a strain on available resources while causing an increase in food demand. There is a need to use available resources sustainably so that food can be produced more effectively and wisely. One of those resources is grazing lands which provide grasses as feed for livestock in most part of the world poor livestock keepers in particular. The livestock are supporting livelihood of most rural communities and produce food rich in protein. However, some open rangelands in Africa are currently reallocated for other uses such as mining, settlement, crop cultivation and tourism. The remaining grazed areas are often in poor condition to various degree and incapable of meeting an ever increasing in food demand. Livestock keepers have been using alternative grazing land such as miombo woodlands to support their livelihood. Miombo woodlands are unique with many tree species growing only there, and not like other grazing land because they have both trees and grasses. An increase of grazing activities could cause destruction of these trees. It is therefore important to balance between food production from livestock and tree protection for ecosystem services. The current study was conducted to evaluate the status of the grazing area and livestock keepers management of miombo woodlands specifically assigned for grazing in Kilosa district, eastern Tanzania.

The results of this study showed that livestock production in miombo woodlands provided food and income to livestock keepers families. There was a large number of trees which indicated that current grazing activities in miombo were good and maintained tree cover for other uses. Grasses available in miombo were of good quality and are seen as desirable by livestock keepers. There were also undesirable grasses in grazed miombo, which showed an early sign of deterioration on some grazed areas condition that could affect availability of good grasses. Also, available grasses had low quantity especially during dry period and livestock keepers were not doing enough to increase these grasses quantity. The major reason for livestock keepers to not work to increase grass quantity was that village authorities governing the grazed miombo areas did not allow them to intervene. It is advised that village authorities adopt flexible management that could allow livestock keepers to improve grass quantity. Also, livestock keepers are advised to grow buffel (*Cenchrus ciliaris*) and bread (*Brachiaria brizantha* cv Piatã) grasses which are good for livestock and have high quantity. These grasses could be fed to the livestock when other grasses in miombo grazing land are finished during dry period.

It was concluded that it is possible to use miombo woodlands for livestock production without affecting tree cover. Lack of measures to increase desirable grass quantity and presence of undesirable grasses may threaten sustainability of the grazed miombo. In order to use grazing areas more effectively village authorities can promote good grazing practices and allow livestock keepers to grow new type of grasses (buffel and bread) in some of their grazed area. The miombo woodlands could be very important in the future to produce protein rich food from livestock that will be needed by many people.

# Populärvetenskaplig sammanfattning

Jordens befolkning förväntas öka, och det medför ett ökat behov av livsmedel, och samtidigt ett ökat utnyttjande av tillgängliga resurser. Dessa måste därför nyttjas på ett hållbart sätt för att möjliggöra en effektiv matproduktion. Ett exempel på en sådan resurs är de betesmarker som förser boskap med foder, boskap som bidrar med proteinrika livsmedel och utgör stora delar av försörjningen för människor på landsbygden. Många av Afrikas betesmarker används numera för andra syften, så som gruvdrift, bostäder och turism. Då tillgången på betesmark minskar har boskapsskötare använt andra marker för bete, till exempel miomboskogarna som är unika och skiljer sig från traditionella betesmarkerngenom att de är trädbevuxna. Då ett ökande bete i skogsmarken kan ha en negativ påverkan på dessa träd är det viktigt att hitta en lagom nivå av animalieproduktion i miombo som inte hotar skogens andra användningsområden. Syftet med den här studien var att utvärdera status hos, och hur boskapsskötarna sköter delar av miombo som är avsatt för bete i Kilosa i östra Tanzania.

Resultaten visade att boskapsproduktionen i hög grad bidrar med försörjning och inkomst till boskapsskötande familjer. Det höga antalet träd i betesområdet tyder på att betet sköttes väl och att betestrycket inte hade negativ påverkan på träden eller andra användningsområden för skogen. I vissa byar syntes dock tidiga tecken på degradering av betesresursen i att sämre grässlag blev vanligare. De tillgängliga gräsarterna var huvudsakligen av god kvalitet och betraktades som bra av boskapsskötarna. De mindre önskvärda gräsarter som förekom hade ingen påverkan på tillgången av önskvärda gräsarter. Dock var mängden gräs begränsad, särskilt under torrperioden, och boskapsskötarna använde sig inte av några skötselmetoder för att öka mängden av bete. Många åtgärder var förbjudna i de områden som var avsatta för bete vilket gjorde det svårt att försöka förbättra betet med olika metoder. Mer flexibel förvaltning av betesområdena kan möjliggöra för boskapsskötarna att öka mängden foder. Boskapsskötarna skulle också kunna odla till exempel *Cenchrus ciliaris* eller *Brachiaria brizantha* cv Piatã, två produktiva gräsarter som är bra foder för boskap. Dessa kan användas som foder när det är ont om andra gräsarter i miombo under torrperioden.

Slutsatsen är att det går att använda miomboskogen till bete utan att negativt påverka träden. Bristen på åtgärder för att öka mängden gräs kan, tillsammans med förekomsten av mindre önskvärda gräsarter, utgöra hot mot hållbarheten i betade delar av miombo. För ett mer effektivt utnyttjande av dessa resurser kan de styrande i byarna främja bra betesstrategier och även på vissa områden tillåta boskapsskötarna att odla nya gräsarter. Miomboskogarna kan bli ännu viktigare i framtiden för att producera proteinrika animaliska livsmedel som kommer att efterfrågas av en växande befolkning.

# Acknowledgements

The author is grateful to the Swedish International Development Cooperation Agency (Sida) and the University of Dar es Salaam (UDSM) for their financial support through the project "*Sustainable Agricultural Productivity, Processing and Value Chain for Enhancing Food security in Tanzania*". This work would not have been possible without the land use plan introduced in miombo villages by the Tanzania Forest Conservation Group (TFCG). Their contribution and cooperation from the beginning until finalisation of this thesis is highly commended and appreciated. I am also grateful to Kilosa district council, Ihombwe, Kigunga, Ulaya Kibaoni and Ulaya Mbuyuni village councils and Tanzania Livestock Research Institute-Kongwa for granting permission to conduct part of the work in their jurisdictions. The herders in the study villages are gratefully acknowledged for giving their valuable time to participate in interviews.

I am indebted to my research group, led by Prof. Ewa Wredle, for their guidance and advice, which enabled successful completion of this PhD thesis. I am also thankful for the professional support I received from my former and current colleagues at the Swedish University of Agricultural Sciences, UDSM and Sokoine University of Agriculture. You are so many I could not mention each and every one of you here, but your contribution during my studies was immeasurable. I would also like to thank my family, both in Sweden and Tanzania, and especially my partner, for their patience and support during the entire study period. I would also like to acknowledge my friends from all over the world for listening to me talking about nothing but this work for more than four years.

Acta Universitatis Agriculturae Sueciae

Doctoral Thesis No. 2021:35

This thesis investigated current pasture condition and herders' management of allocated miombo grazing land. Herders kept indigenous livestock species and relied on them as a source of food and income. Grazed miombo had good tree cover and diverse herbaceous plant communities. Poor grass cover and undesirable grass species were prevalent in some grazed areas and indicated early stage of rangeland degradation. These results indicated that livestock grazing in miombo supported herders' livelihood without causing negative effects on tree cover.

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Online publication of thesis summary: http://pub.epsilon.slu.se/

ISSN 1652-6880
ISBN (print version) 978-91-7760-748-9
ISBN (electronic version) 978-91-7760-749-6