STATUS AND POTENTIAL ROLE OF RANGELAND INSECT POLLINATORS FOR PASTORALIST LIVELIHOOD DIVERSIFICATION IN NORTHERN TANZANIA

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A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy in Life Sciences of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

Pollinators provide ecosystem services that support other living organisms. However, they are currently threatened by land use changes including habitat fragmentation. In Tanzania, Maasai rangelands are under pressure from population increase, habitat fragmentation and decline in grazing areas that cause overgrazing. Little is known about local Maasai knowledge on pollinator communities and how they are affected by grazing management in semi-arid rangelands in Tanzania. Semi structured questionnaires, key informant interviews and focus group discussions were used during the survey in order to understand local knowledge of insect pollinators. Findings revealed varied pollinator identification skills, with males having higher skills (χ^2 = 6.319, P = 0.042) compared with females. Honey bee, *Apis mellifera* was the most important pollinator as reported by 93% of males and 78% of females. Beekeeping contributed to livelihood diversification for 61% of respondents, with women participating more frequently in this activitiy than men (χ^2 = 46.96, P = 0.0001). Ultraviolet (UV) white, yellow and blue pan traps were used to trap insects in four different grazing management, namely private and communal enclosures, wet and dry season grazing areas. Pan trapping was further supplemented by a standardized sweep netting method. Findings showed that environmental factors and grazing management affected insect pollinators. Insect abundance, diversity and richness varied with seasonality, whereby the mean number of insect abundance was significantly higher (χ^2 = 136.77, P < 0.0001) during the wet (148 ± 70.57) compared with the dry season (17 ± 7.14). Moreover, flower abundance (χ^2 = 3.5, P = 0.05) and percentage herbaceous cover (χ^2 = 5.99, P = 0.015) influenced pollinators. Private enclosure management category contained significantly more pollinators (χ^2 = 27.63, P < 0.001) compared with the communal dry grazing area. The study also investigated pollinator-plant interactions to understand the foraging preference of bees and other pollinators. *Aspilia mossambiensis* and *Justicia debile* were the most preferred plants. The most common visitors were honey bees and butterflies. Pollinator networks showed that enclosures contained larger networks compared with open rangelands. The study concludes that the Maasai community have limited knowledge of pollinator ecosystems services. In addition, traditional range management especially the use of enclosures is an important tool towards the conservation of insect pollinators in semi-arid rangelands threatened by overgrazing and degradation.

DECLARATION

I, Faith Thomas do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted elsewhere for degree award in any other institution.

Faith Thomas

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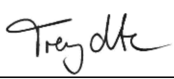
Name and Signature of the Candidate Date

The above declaration is confirmed by:

Prof. Anna C. Treydte



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Prof. Patrick Alois Ndakidemi

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Senate of the Nelson Mandela African Institution of Science and Technology a dissertation entitled "*Status and Potential Role of Rangeland Insect Pollinators for Pastoralist Livelihood Diversification in Northern Tanzania*" in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy in in Life Sciences at the Nelson Mandela African Institution of Science and Technology, Arusha Tanzania.

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DEDICATION

To my parents: Mrs. Matilda A. Mpondo and my late Mr. father Cornel Thomas Mpondo. To my late brother, Mr. Godgave C. Mpondo. This work is also dedicated to my lovely husband, Mr. Shelard Mukama, and my kids Christian Mukama, Jibhai Mukama, Maureen Nyachiro Mukama and Vivian Nyabuki Mukama.

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LIST OF ABBREVIATIONS AND SYMBOL

%	Percentage
^{0}C	Degree centigrade
AIC	Akaike Information Criterion
ATC	Arusha Technical College
CITES	The Convention on International Trade in Endangered Species of Wild Fauna and Flora
COSTECH	Tanzania Commission for Science and Technology
CREATES	Centre for Research, Agricultural Advancement, Teaching Excellence and Sustainability
FAO	Food and Agricultural Organization
GLMM	Generalized Linear Mixed Models
Ha	Hectare
Km	Kilometre
NHT	National Herbarium of Tanzania
NM-AIST	Nelson Mandela African Institution of Science and Technology
NBS	National Bureau of Statistics
mg	milligram
mL	millilitre
SD	Standard Deviation
SE	Standard Error
TANAPA	Tanzania National Parks Authority
TARI	Tanzania Agricultural Research Institute
TAWIRI	Tanzania Wildlife Research Institute
TPRI	Tanzania Pesticide Research Institute
TPW	Tanzania People and Wildlife
TSN	Total Soil Nitrogen
UDOM	University of Dodoma
UDSM	University of Dar es Salaam

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

Pollinators are animals that aid pollen transportation from anthers to the receptive stigma of the same or different plant (Food and Agricultural Organization [FAO], 2007). In so doing, they increase genetic diversity (Potts *et al*., 2010); and in such, maintain global biodiversity for both crops (Munyuli, 2011) and native plant species (Kosior *et al*., 2007; Zurbuchen *et al*., 2010; Munyuli, 2011). It is estimated that about 87% of all flowering plants from different ecosystems depend on pollinators, including 35% of crops that make up the world's food supply (Tuell *et al*., 2008; Kimoto *et al*., 2012; Senapathi *et al*., 2015). The world is endowed with diverse pollinators such as insects, birds, bats, lizards and small mammals estimated to reach about 200 000 species (Harmon *et al*., 2011).

Insects represent the most significant pollinators, with bees being the primary pollinators (Potts *et al*., 2010; Patrício, 2014; Elisante *et al*., 2017). Other insect pollinators include moths, flies, wasps, beetles, and butterflies (Allen-wardell *et al*., 2016). However, honey bees (*Apis mellifera*) are considered one of the most important pollinators in the ecosystems compared with other insects and bee species (Kosior *et al*., 2007; Munyuli, 2011); mainly due to their morphological and foraging adaptation (Patrício, 2014). With increasing reports of honeybee mass mortality throughout the world (Winfree, 2010), there is a change in reliance on only a few species of bees, primarily honeybees of the genus *Apis*, for pollinating the majority of cultivated crops globally (Goulson, 2003; Garibaldi *et al*., 2013). Wild bee pollinators are recently recognized as essential pollinators for wild plants (Potts *et al*., 2010).

Angiosperms provide pollen and nectar resources that commonly serve as food (Manincor et al., 2020), for larval development, adult maintenance and sexual maturation for bees and many other flower visitors (Cook *et al.,* 2003; Danner *et al.,* 2017; Nicholls & Hempel de Ibarra, 2017). However, pollen serves as the most important food source for both consumption and collection by flower visiting insects (Nicholls & Hempel de Ibarra, 2017). Proteins, lipids, carbohydrates, starch, sterols, vitamins and minerals are the nutritional contents of pollen, with the quality of pollen nutrition usually determined by its protein (Cook *et al.,* 2003). The assessment of pollen rewards by pollinators and how they shape pollinator–plant interactions are not fully understood (Nicholls & Hempel de Ibarra, 2017).

The ecosystem service of pollinators ensures the sustainability of rangelands and their ability to support livelihoods by increasing plant species diversity (Stein *et al*., 2017) and essential grassland functioning (Black *et al*., 2011). Therefore, the health and ecological functioning of rangelands depend on the presence of both diverse insects and flowering plants (Patrício, 2014). The interaction between rangeland flowering plants and pollinators can potentially support crop production (Vanbergen & Initiative, 2013; Elisante *et al*., 2017; Mkindi *et al*., 2017), improve livestock forage and beekeeping activities (Fakir & Babalik, 2009), which may consequently improve the pastoralist livelihoods.

The role of pollinators in rangeland functioning has received little attention from the community (Patrício, 2014) and is not well known by most local people residing in rangeland areas. The majority of African communities have little awareness of the pollinators benefits, especially ecosystem services, compared with communities in Europe and America (Munyuli, 2011). According to Huntington (1998), community-based knowledge is more practical and relevant to environmental challenges and ecological impact assessments than many other sources of data. Furthermore, community based knowledge may bring new insights for strengthening existing scientific understanding (Angassa & Oba, 2008). Pollinator awareness, benefits and management studies have been conducted to focus mainly on agricultural landscapes (Allen-wardell *et al*., 2016) in the tropical areas include (Munyuli, 2011(a); Munyuli, 2011(b); Otieno *et al*., 2015, Kiatoko *et al*., 2014; Melin *et al*., 2014) with little aligning on native landscapes, mostly of which are outside Africa including that of Sjödin (2007), Brenton (2015) and Bhattacharyya and Acharya (2017).

In Africa, rangelands cover about 43% of the continent's land surface, with woodlands, shrubs or grasslands as the primary vegetation composition (Sangeda & Malole, 2014). According to Selemani (2017), most African rangelands are threatened by human activities, especially overutilization resulting in a decline in forage quality. Currently, livestock grazing has been the dominant land use activity in the tropical rangeland, and about 800 million people depend on this occupation for their livelihoods (Neilly *et al*., 2017). The large-scale loss of rangelands with a concurrent decline in natural resources has been described in various biodiversity areas in tropical and subtropical regions, including East Africa.

The Simanjiro plains, located east of Tarangire National Park in northern Tanzania, are a critical wildlife dispersal area crucial to Maasai pastoral livelihoods, which are rapidly diversifying (Woodhouse & McCabe, 2018). Although Tanzanian rangelands are still under communal management, most groups including the Maasai, are gradually changing due to the transfer of private holdings to individuals and villages (Mccabe *et al*., 2010). Maasai have always dealt with resource availability variations by moving within and beyond territorial parts (*olosho*) on a daily and seasonal basis, aided by social systems that enable outsiders to access natural resources during times of stress (Homewood, 2008). Moreover, like other pastoral groups in East Africa, *Maasai* are increasingly utilizing traditional enclosures known as *Alalili* for dry season grazing (Abebe *et al*., 2006). These are areas set aside for only sick and young animals to graze, while other animals travel long distances for grazing (Abebe *et al*., 2006; Haftay *et al.*, 2013). Napier and Desta (2011) identified four forms of enclosures: private, government, communal and enclosures established by the initiatives of Non-Governmental Organizations (NGOs).

Enclosures help to minimize rangeland degradation and increase the amount and diversity of vegetation species (Abebe *et al*., 2006; Angassa *et al*., 2010; Habtemicael *et al*., 2015). However, because arthropods are more negatively affected by grazing than plants, the positive contribution of enclosures to herbaceous vegetation enhancement may not always be a good predictor of insect pollinator variety in grazing areas (van Klink *et al*., 2015). Moreover, as pollinators are essential for rangeland health, the impact of different grazing regimes on insect pollinator groups must be considered.

Understanding the influence of grazing disturbances on pollinator networks in rangelands is also essential for conserving pollinators in rangelands as grazing form dominant land uses (Yoshihara *et al*., 2008; Elisante, 2017). Pollinator networks possess conserved properties, including low connectance, asymmetric distribution of interactions, nestedness and modularity (Oleques *et al*., 2019). Compared with traditional analyses which focus only on quantifying species abundances (Bascompte & Jordano, 2007), plant-pollinator network analyses provide a more functional perspective by identifying species that interact within a community, the frequency of their interaction, and how these interactions are structured. Recent studies have shown that network structure can be influenced by anthropogenic disturbances, including grazing even when species richness within a community is unaffected (Aizen *et al.,* 2008; Yoshihara *et al.,* 2008). Pollination networks offer the chance to understand the relative importance of each component (Yoshihara *et al*., 2008), the degree of specialization (Kelly & Elle, 2020), and even the robustness when structural components become extinct (Memmott *et al*., 2004). Therefore, the importance of understanding plant-pollinator interactive structures for conservation purposes is mounting (Bascompte & Jordano, 2007).

1.2 Statement of the Problem

Rangeland ecosystems are essential for biodiversity conservation and livelihoods (Dettenmaier *et al*., 2017). Pollinators are among the critical component of rangeland functioning as they offer vital ecosystem services including increasing plant species diversity, maintenance of soil conditions for crop production and livelihoods (Klein *et al*., 2007; Stein *et al*., 2017). The decline in flower-visiting insect pollinators is currently reported in several parts of the world across various ecosystems, including rangelands (Potts *et al*., 2009). This decline might be caused by increased grazing pressure, reducing the abundance and diversity of plant species attractive to pollinators, and this can potentially affect pastoralist livelihoods. The Maasai steppe in northern Tanzania is a rangeland system, where pastoralism and agro-pastoralism form the primary sources of livelihood (Msoffe *et al*., 2011). Significant changes in land use have been reported in the Maasai steppe, especially the shift from small-scale agriculture to large-scale farming, resulting in reduced grazing land, loss of native rangeland vegetation, and a decline in the quality of the remaining rangeland forage (Msoffe *et al*., 2011). This decline might negatively affect associated pollinator species in the Maasai steppe. To rehabilitate degraded rangelands and speed up vegetation recovery in this rangeland system, traditional enclosures, common in East African rangelands, have been part of the grazing management (Angassa *et al*., 2010). However, the influence of these traditional management on insect pollinators abundance, composition and diversity are not well understood. Many studies conducted in the Maasai steppe have focused on large wildlife species (Msoffe *et al*., 2011), while insect pollinators are yet inadequately studied. It is still not clear how traditional grazing management in the Maasai steppe affects pollinator dynamics, pollinator forage plants and local livelihoods in the Simanjiro rangelands of Northern Tanzania.

1.3 Rationale of the Study

Information on the influence of rangeland clearing and traditional rangeland management strategies in Tanzania is limited. Observational and experimental studies to understand these impacts on pollinators have been rare with much focus on large animals. Furthermore, plants preferred by pollinators and how they are affected by grazing is not well documented in Simanjiro. However, reports from other parts of the world acknowledge grazing to impact plant species, including plant flowering (Debano, 2006; Shapira *et al.*, 2020). This study will focus on understanding the current status of insect pollinators, including species composition, abundance and diversity with respect to environmental factors and grazing management, i.e. enclosures versus open rangelands used for wet and dry season grazing, understanding pollinator forage plants and networks as well as local knowledge on pollinators and its implication on pastoralist livelihoods.

1.4 Research Objectives

1.4.1 Main Objective

To provide a baseline and assess the current status of pollinator species (abundance, diversity and species richness) and their potential role in pastoralists' livelihood diversification under different rangeland management in Simanjiro District, Nothern Tanzania.

1.4.2 Specific Objectives

(i) To assess the knowledge of the local pastoralist community about insect pollinators and understand the pollinators' role in local livelihood diversification in Simanjiro district.

(ii) To evaluate the influence of environmental characteristics including soil, seasonality (rainfall, temperature) and vegetation cover on pollinator species abundance, composition and distribution in Simanjiro rangelands.

(iii) To determine bee foraging preferences and their interactions with different plant species in Simanjiro rangelands.

(iv) To evaluate the influence of different grazing management strategies on pollinator communities, abundance and diversity in Simanjiro district.

1.5 Research Questions

(i) What is the level of knowledge of local pastoralist communities about the importance of insect pollinators and their role in rangelands?

(ii) How do environmental characteristics including soil, seasonality (rainfall, temperature) and vegetation affect pollinator species abundance, composition and distribution?

(iii) What are the most important plant species that serve as bee forage in the study area and what is their protein and fatty acids proportion?

(iv) What are appropriate rangeland grazing management strategies that maximize pollinator populations and networks in rangelands?

1.6 Hypotheses

(i) Pollinator knowledge varies between gender (i.e. men and women) and occupation (agropastoralists vs pastoralists) within the local Maasai population.

(ii) Maasai can associate rangeland management practices with the abundance of pollinators and they can identify the favourite rangeland plants for bees.

(iii) Range management practices and seasonality influence insect pollinators, specifically:

- Insect species richness and abundance will be greater in enclosure sites compared with open rangelands due to the expectation of more flowering plants and higher vegetation cover in the former than in the latter.
- The higher the herbaceous cover and flower abundance, the higher the insect pollinator species abundance and diversity.
- This study expected higher pollinator abundance during the wet season than during the dry season.

(iv) The higher the protein and fatty acids contents, the higher the bee visitation to flowering plants in rangelands.

(v) The study expected higher visitation and robust networks in enclosures compared with communal open rangelands.

1.7 Significance of the Study

Insect pollination is vital to ensure the functioning and sustainability of terrestrial ecosystems; however, pollinator populations are reported to decline in different parts of the world (Stein *et al*., 2017). Local knowledge and awareness about the type of pollinator species abundance, diversity and distribution are essential towards promoting conservation. This study provides information on local knowledge of pollinators for pastoral communities and therefore, justification for training the local Maasai community on different pollinator groups and their rationale. Moreover, the study serves as a baseline for pollinator studies and their conservation in Simanjiro rangelands as it managed to link grazing and pollinator conservation; therefore, this study informs policy makers and range managers on how traditional grazing management may influence the pollinator population in the area.

In addition, the study provides knowledge of preferred bee plants, which are crucial for sustainable livelihoods diversification in the area as beekeeping is an environmentally friendly livelihood activity which may be practised alongside livestock keeping while conserving native plant species on rangelands and generating alternative income among Maasai pastoralists. The study also forms an opportunity for academicians and researchers on further research on insect pollinators, conservation and management in semi-arid rangelands in East Africa, where rangelands are threatened by increasing population, habitat fragmentation and degradation.

1.8 Delineation of the Study

This study focused on the current status of pollinators in Simanjiro rangelands through sampling in four sites under different grazing management categories and therefore each management was represented by one site and blocks were used to replicate sites. It would have been more practical to conduct a more intensive study with multiple sites for each grazing management category to capture potential confounding factors of landscape heterogeneity or soil differences. However, due to limited funds and village authorization, replication of sites in the field was not possible. The study also studied pollinator plant interaction in permanent blocks within grazing management categories. However, studying plant interactions across different land uses including farm lands, grazing lands, and wetlands would make more sense to accommodate large diversity of plants and pollinators.

CHAPTER TWO

LITERATURE REVIEW

2.1 Conceptual Framework

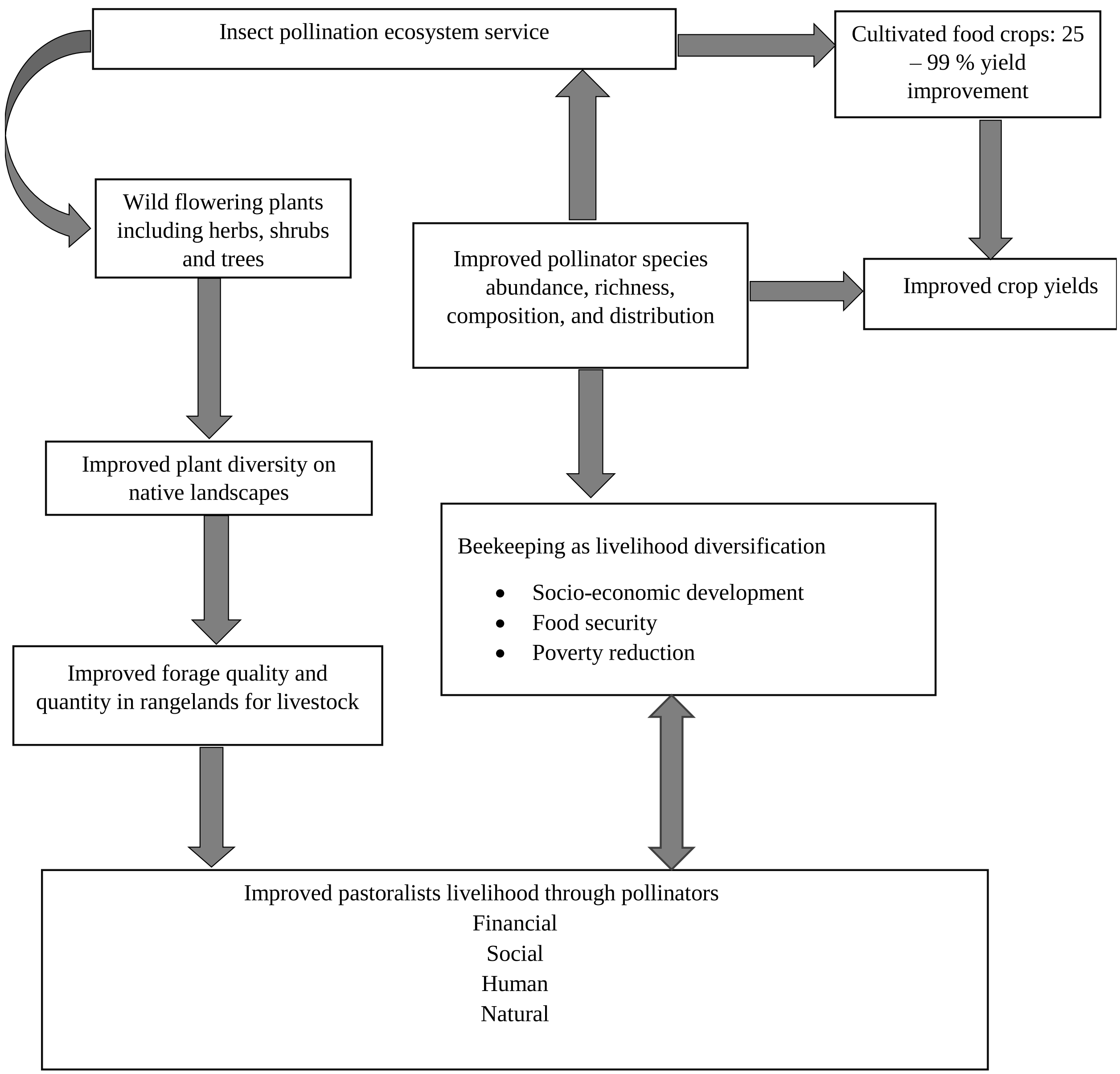


Figure 1: Conceptual framework of roles played by pollinators in ecosystem and local Livelihoods

2.2 Roles of Pollinators in Human Wellbeing and Livelihoods

Livelihood refers to assets or means that enable people to earn a living (Chambers & Conway, 1992). The sustainable livelihoods framework consists of five significant assets which are physical, social, human, financial and natural capital (Ellis, 2000). The contribution of insect pollinators to human well-being can either be economic or non-economic. They contribute to essential ecosystem services including nutrient cycling, soil mixing, and the well-being of local food webs (Schwartz *et al*., 2000). In so doing, they promote human wellbeing through livelihoods improvement, nature conservation, and improving agriculture production (Kassa & Regasa, 2020). Insect pollinators provide an essential ecosystem service of pollination for both wild species and cultivated crops, with bees pointed out to be the most efficient pollinating insects (Klein *et al*., 2007).

Pollinators contribute to food production through honey production and pollination of crops to improve yields (Biesmeijer *et al*., 2015), consequently supporting livelihoods for the majority of people in Africa, especially those residing in rural areas who depend on agriculture for subsistence (Munyuli, 2011). According to Klein *et al*. (2007), more than 75% of the world crops benefit from pollinators through increased fruit or seed set. Various analysis has also been conducted to evaluate the contribution of pollinator to crop production in different regions. For example, more than 130 crop species in USA depend on pollinators especially bees (James & Pitts, 2008); while in the European region, it was reported that 84 % of crop species depend on bees (Devkota *et al*., 2016). In Africa, many indigenous crops are also pollinator dependent (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES], 2016), however, the exact percentage of dependence is not yet calculated. These crops include African nightshades, African Kale, amaranths, spider plant, slender leaf, jute mallow, strawberries, green pepper (IPBES, 2016) and African eggplant (Gemmil-Herren *et al*., 2014). With the diversity in agricultural crops in Africa coupled with high reliance on agriculture of the African people, there is a high a need to understand how pollinators interact with other crops in the region.

Pollination service providers vary with regions, for instance, in the temperate regions, most animal pollination is provided by the honey bees (*Apis mellifera*), bumblebees (*Bombus spp*), solitary bees, wasps and hoverflies while in the tropics the significant players include butterflies, moths, birds and bats (Klein *et al*., 2007). Regardless of this useful information, studies on the same for African region is still a grey area with most of pollinator research done in South Africa (Eardley *et al*., 2009).

Insect pollinators can further contribute to livelihoods through diverse ways including beekeeping, which is a potential environmentally friendly activity that might be practised in a varied environment including forests, savannah and semi-arid areas (Chemurot, 2011; Jeil *et al*., 2020). These areas are very rich in flowering plants that are preferred and visited by bees (Abdullahi *et al*., 2011). Thus, efforts should be made to ensure residents of marginalized semi-arid lands recognize the potential of these areas and appropriate actions are taken to conserve them. Beekeeping plays an important role in improving biodiversity conservation, socio-economic development, food security and poverty reduction in many parts of the world. According to Mwakatobe *et al*. (2005), beekeeping is estimated to generate about 1.7 million USD annually to Tanzanian GDP. The activity also contributes to household financial income. For instance, in Inyonga, Mlele district beekeeping contributes about 1 200 000 Tanzanian shillings to household income annually (Ntawila *et al*., 2017).

The combination of pollination services and beekeeping can further provide a good means of livelihoods improvement. Economic evaluation revealed pollination to be more valuable compared with honey and beeswax production. According to Devkota *et al*. (2016), the production of mustard crop in Nepal was highly boosted by the inclusion of *A. mellifera* within the plots and the yields were more valuable than honey harvested from beehives. This suggests that a combination of the two activities can economically boost farmers' livelihoods since the African honeybee, *A. mellifera* is well adapted to the environment and needs very little care (Jeil *et al*., 2020).

Pollinators are essential for human health in several ways, for example ecosystem service of pollination supports the survival of many wild and cultivated plants some of which have medicinal value (Munyuli, 2011). Pollinator-dependent plants can recycle CO_2, regulate climate, and improve air and water quality, which are all critical for human wellbeing. The pollination of many fruits and vegetable plants which are good sources of nutrients, including vitamin A is another contribution of pollinators to human health (Ellis *et al*., 2015). Bees have been reported to have a significant contribution to health due to their products like honey and propolis which have pharmacological use against infections and improvement of healing for burn wounds (Sluijs & Vaage, 2016). According to Sluijs and Vaage (2016), the contribution of pollinators to human diet cannot be undermined due to the fact that a large proportion (90%) of vitamin C, 100% of Lycopene and majority of antioxidants especially $_\beta$ - cryptoxanthin and tocopherol – cryptoxanthin, majority of lipids all depends on pollinated plants. However, Ellis *et al.* (2015) describes a healthy and pollinator relationship as a complex phenomenon, arguing that pollinator loss can only affect human health under certain scenarios (Kideghesho, 2009). Therefore, concerted efforts should be done to ensure a clear understanding of the relationship between human health and pollinators including all the scenarios under which human health might be affected (Fig. 1 for more details).

2.3 Pollinator Species Abundance, Composition, Diversity and Threats

The abundance and diversity of pollinator species show spatial variation with some species restricted to specific localities and others with a broader distribution. The distribution is attributed to variation in adaptations of different pollinator groups like butterflies, beetles and bees in diverse aspects such as pollen collection (Rathcke *et al*., 1993). The African continent, for instance, is reported to have rich pollinator diversity with Sub-Saharan Africa being more diverse with about 21% of the world's bee genera (102 from a total of about 476) (Connal *et al*., 2009). However, only 2600 species are already described which comprise about 13% of the global fauna (Connal *et al*., 2009). Globally it is estimated that about 20 000 bee species exist including solitary and parasocial bees; which are considered the majority (Patrício-Roberto & Campos, 2014; Michener, 2007). More research is needed to explore pollinator species available in other regions of tropical Africa to facilitate their conservation.

Abundance and diversity of pollinators are to a greater extent influenced by habitat and landscape factors including floral abundance, plant diversity, patch size and amount of wood vegetation (Bates *et al*., 2011; Kearns & Oliveras, 2009). Generally, heterogeneous habitats are believed to increase the abundance and diversity of pollinators (Munyuli, 2011). Potts *et al*. (2003) reported a positive relationship between floral resources and pollinator diversity. The aforementioned factors not only influence abundance and diversity, but also determine other activities such as foraging (Kearns & Oliveras, 2009).

The importance of wild bee pollinators is currently pronounced, and it has been reported that the condition of the surrounding landscape is of vital importance as it can affect pollinator populations consequently promoting ecosystem services, especially pollination (Kennedy *et al*., 2013; Garibaldi *et al*., 2014). Pollinators are highly sensitive to disturbance including pesticide use, habitat destruction and loss, grazing intensity, intensification in land-use systems and farming practices (Munyuli, 2011; Otieno *et al*., 2015; Sjödin *et al*., 2008). Habitat loss and fragmentation affect pollinator diversity due to increased isolation of habitat patches as well as reduced landscape complexity with a consequent decline in flowering plants and associated resources (Ferreira *et al*., 2013). A study by Kearns and Oliveras (2009), revealed that pollinators can be affected by urbanization because species diversity positively correlated with distance from urban areas. Therefore, more work is needed to assess the impact of urbanization on pollinators. This assessment is particularly critical in tropical Africa, where rapid population growth creates the need for more land and, consequently, leads to the conversion of more natural lands into settlements.

The response of diverse pollinator species to disturbances is not uniform. For instance, while the wild bee abundances and diversity were reported to decline with anthropogenic disturbances, the honey bees did not show a similar response (Xie *et al*., 2016). Within landscapes, pollinators are affected by several threats including pesticides, invasive species, climate change, habitat loss and fragmentation. To prevent decline in pollinator population, it is crucial to preserve aspects of traditional farming practices, develop policies and affordable legal measures that will ensure adequate protection of pollinators within landscapes (Kosior *et al*., 2007; Munyuli, 2011).

2.4 Pollinator - Plant Interactions and Ecological Roles of Pollinators

Pollinator - plant interaction is one of the most complex and essential phenomena in conservation of pollinators (Ollerton *et al*., 2011). The interaction between pollinators and target plants can either be generalized or specialized (Gous *et al*., 2017; Elisante, *et al*., 2017). Specialization occurs when plants possess flowers attracting a single pollinator species while generalized interaction involves many pollinator species (Gous *et al*., 2017). Wild and managed bees provide essential ecosystem services to cultivated and wild plants worldwide because they are obligate flower visitors (Ritchie *et al*., 2016). According to Michener (2007), bees derive all their energy and nutrition from flowering plants. The visitation of insects to flowering plants provides two key services, namely pollination and pest control (Kearns *et al*., 1998; Potts *et al*., 2005). When an insect pollinator visits different plant materials to gather resources such as pollen, nectar and oils, the activity is known as foraging (Patrício-Roberto & Campos, 2014). Pollen and nectar form essential food resources for bees with the quality and quantity of pollen reported to impact larval growth, adult bee size, and overall survivorship (Roulston & Cane, 2002).

In-depth knowledge of plant-pollinator interaction is necessary for the conservation of pollinators for both agricultural and natural ecosystems (Klein *et al*., 2007; Elisante *et al*., 2017). More information about these interactions is summarized in Table 1. Empirical work on pollinator-plant interaction reveals that knowledge on pollinator plant interactions is still a grey area, especially in Africa (Eardley *et al*., 2009). Some research in agricultural ecosystems revealed that pollinator diversity has a high potential of promoting crop yields for sunflower (Greenleaf & Kremen, 2006), watermelon (Kremen *et al*., 2002) and coffee (Klein *et al*., 2003). Thus, there is great possibility of boosting agricultural productivity of communities residing in Africa. However, this requires intensive research on pollinators as well as awareness creation at local levels.

The importance of pollinator-plant interaction is not limited to agricultural areas. Studies on natural ecosystems revealed that pollinators presence is vital for the sustainability of natural systems because plant community diversity positively correlated with pollinator community diversity (Potts *et al*., 2003). Understanding perennial plants that are suitable for providing foraging resources for bees during different seasons throughout the year can be a significant milestone towards the conservation of wild bee pollinators (Tuell *et al*., 2008). Adequate information and data on foraging ability and preference of insect pollinators are necessary to understand population dynamics and community structure for securing the development of conservation strategies (Gathmann & Tscharntke, 2002). This is of vital importance amid current crisis of decline in pollinators and formation of baseline ecological data for pollinator plant relationships (Kearns *et al*., 1998; Potts *et al*., 2003; Albano *et al*., 2009).

Ecosystem wellbeing, to a more considerable extent, relies on pollinator-plant interactions. These interactions are crucial in the spread and succession of non-native plants, commonly referred to as invasive species (Stout & Tiedeken, 2016). In most scenarios, invasive plant species have been reported to compete with native co-flowering plants consequently disrupting pollination network (Morales & Traveset, 2009; Dietzsch & Stout, 2011; Ojija *et al*., 2019). Furthermore, plant - pollinator interaction networks are critical to the maintenance of ecosystems stability and functioning (Memmott *et al*., 2004; Manincor *et al*., 2020). Therefore, understanding the structure and functioning of these networks especially species interactions and dynamics is among the current important goals of ecology (Lázaro *et al*., 2019; Manincor *et al*., 2020). Livestock grazing in rangelands affect plant pollinator interactions due to interference in plant, insect abundance and diversity as well as reproductive success of plants (Vanbergen *et al*., 2003; Yoshihara *et al*., 2008a; Oleques *et al*., 2019). Regardless of the potential effects of grazing on pollinator networks, the effects of this disturbance on the structure of pollination interactions remain poorly understood (Lázaro *et al*., 2019).

Pollinators possess different foraging strategies whereby some are specialists, adapted to feed on a single plant species (Gous *et al*., 2017) and others are generalists feeding on a wide range of plant species (Memmott *et al*., 2004). Specialist pollinators are more vulnerable to changes that occur in their landscapes that are more likely to affect plants they depend on. A summary of studies on pollinator plant interaction for both wild and cultivated crops is provided in Table 1. With the current trend of pollinator decline, there is an urgent need to understand native plants that are important for pollinator foraging in order to target conservation strategies to different habitat in the landscapes. Understanding the extent of competition between invasive and native plants for pollination is crucial in maintaining quality rangelands with consequent improvement in livestock forage.

Pollinator-plant interactions are influenced by various biotic and abiotic factors. Biotic factors include the quantity and quality of pollen as well as floral resources availability. On the other hand, abiotic factors include temperature, wind, light and distance between food source and nesting site (Elisante *et al*., 2017). In addition, soil quality has been studied for impacts on pollinators due to its direct influence as reported by Cardoza *et al*. (2012) whereby vermicomposting influenced the behaviour and physiology of bumblebees (*Bombus impatiens*) by increasing bee visits and reducing the time of flower discovery. However, research is still needed to understand the nutrients supplied by vermicomposting to the soil (Huang & Giray, 2012). It is fundamental to understand pollinator interactions in semi-arid rangelands and factors likely to influence foraging inorder to promote pollinator conservation in semi-arid rangeland.

Table: A summarized Pollinator-plant interactions for wild and cultivated plant species

S/n	Pollinator	Order/ Family	Plant preferred	Plant Family (ies)
1	Bees other than honey bees, wasps	Hymenoptera	*Acacia tortilis*	*Fabaceae*
2	Stingless bees (e.g. *Meliponini sp*, *Trigona sp*)	Hymenoptera	Various flowering plants	*Fabaceae*, *Acanthaceae*, *Asteraceae, Cucurbitaceae, Commelinaceae, Lamiaceae, etc.*
3	Bees other than honey bees, small butterflies	Hymenoptera/ Coleoptera	Indigofera (*Mangifera indica*)	*Anacardiaceae*
4	Fig wasps (e.g. *Ceratosolen capensis, Ceratosolen grandii, Dolichori sp*)	Hymenoptera (*Agaonidae*)	One or a few closely related *Ficus* species. e.g. *Ficus microcarpa, Ficus sur, Ficus maxima*, *Ficus salicifolia*, *Ficus sycomorus, etc.*	*Moraceae*
5	Other wasps, e.g. *Tiphia* sp, *Hemipepsis* sp.	*Tiphiidae*, *Pompilidae*	Various flowering plants	*Asteraceae*, *Lamiaceae, Fabaceae*
6	Honey bees (*Apis mellifera* L.)	Hymenoptera (*Apidae*)	Various crops and wild flowering plants	*Fabaceae*, *Asteraceae, Acanthaceae, Cucurbitaceae, Lamiaceae.*
7	Carpenter bees, *Xylocopa spp*	Hymenoptera	Passion fruit (*Passiflora edulis*)	*Passifloraceae*
8	Flies (e.g. Syrphids and bee flies)	Diptera (e.g. Syrphidae)	Various crops and flowering plants .	*Fabaceae*, *Asteraceae, Lamiaceae*
9	Butterfly (e.g. Common eyed pansy)	Lepidoptera (e.g. *Nymphalidae*)	Various flowering plants	*Rubiaceae* and *Asteraceae.*
10	Flies, ants, bees	Diptera, Hymenoptera	Cashew nuts, *Anacardium occidentale*	*Anacardiaceae*
11	Hawkmoths, skipper butterflies, Xylocopa bees	Lepidoptera, Hymenoptera	Papaya (*Carica papaya*)	*Caricaceae*

Elisante *et al.* (2017) and Rodger *et al.* (2004)

2.5 Local Knowledge, Perceptions on Pollinators and Implication for Conservation

Local ecological knowledge has been conceptualized differently by various researchers. Hall and Close (2007) describes it is as a component of social capital for promoting economic progress and supplying environmental services which are neglected by planners and policymakers. On the other hand, Berkes *et al*. (2010) defines it as cumulative and adaptive by nature, tested by trial and error and transmitted through generations orally or by shared practical experiences. There is growing interest by scientists to understand local knowledge due to recognition of an important role it plays in decision making, specifically on the use of biodiversity and its management (Berkes *et al*., 2010; Smith *et al*., 2017). With the current concern on pollinator population declines, assessment of local ecological knowledge is critical because the gathered information can be shared with scientific knowledge and develop more effective conservation strategies (Marques *et al*., 2017).

Studies on local knowledge of insect pollinators in South America and Africa revealed scarce information and thus a need for sharing scientific knowledge between their communities (Marques *et al*., 2017; Munyuli, 2011; Elisante *et al*., 2017). For instance, in evaluating local knowledge on pollinators in Southern Brazil, Marques *et al*. (2017) exposed the need for sharing scientific knowledge to community because the majority of respondents expressed little knowledge on pollinators. Most respondents reported the honey bee (*Apis Mellifera)* and *Trigona spinis* as the only pollinators and the remaining insects as harmful, and consider them as pests or vectors of disease (Marques *et al*., 2017). Enhancement of local knowledge can be accomplished through training local communities on insect pollinator and their benefits as suggested by Elisante *et al*. (2019).

Scarcity on pollinator knowledge among local community is not only limited to farming communities, but even pastoral and agro-pastoral communities have shown a similar trend (Mpondo *et al*., 2021). Generally, the majority of studies revealed *Apis mellifera* as the most popular pollinator which might highly be attributed to their honey production capability (Bhattacharyya & Acharya, 2017; Mpondo *et al*., 2021).

Most communities are still however blind to the contribution of other pollinators on the ecosystem. Studies from different ecosystems have reported the efficiency and importance of bee species other than *Apis* on pollination (Bhattacharyya *et al*., 2017). According to Junqueira *et al*. (2021), the value of pollination services from non-Apis bees is estimated to be around 3 billion USD globally over the year 2007. Therefore, it is essential to bridge local knowledge on ecosystem services from a pollinator, particularly pollination inorder to promote community awareness on other pollinator groups.

Knowledge on pollinator varies among communities depending on location and efforts of authorities and other stakeholders to enhance community awareness on pollinators. Smith *et al*. (2017) reported sufficient knowledge among communities residing in the state of Orissa in India as they were able to recognize most groups of pollinators including *Amegilla spp*, *Apis dorsata*, *Apis cerana*, *Ceratina sp*, *Xylocopa sp*, lime butterfly and peacock pansy (*Junonia almana*). The *A. mellifera*, the western honey bee was the least recognized insect pollinator may be due to their low abundance as they are non-native. Majority of respondents were aware of the role of insects in pollination and the associated benefits such as an increase in crop yields. The respondents also associated the decline in pollinator abundance with the application of pesticides (Smith *et al*., 2017). The people's knowledge can be integrated with scientific knowledge to develop sustainable species management strategies. Most communities are aware of their environment including the species available within their areas and plants that they prefer to visit and their phenology, especially flowering time. Inorder to ensure effective pollinator conservation, protection of fodder plants is of vital importance (IPBES, 2016).

Despite great efforts to understand local knowledge on pollinators in tropical areas, limited information exists on how most pastoral or agro-pastoral communities from different areas in tropical Africa understand the importance of pollinators, specifically on ecosystem services (Dressang, 2018). This is also important since most of the rangelands have been converted to croplands as most pastoral communities such as Maasai of East Africa have become sedentary, integrating livestock keeping and crop production (Msoffe *et al*., 2011). There is a need to conduct research that will assess and build the knowledge gap of pastoral communities since pollinators have equal importance in grazing lands as in agricultural lands. Moreover, the wellbeing of grazing lands in terms of plant diversity highly depends on pollinators. This calls for the need to facilitate pollinator knowledge in these communities.

2.6 Pollinator Conservation and Management Strategies

Human pressure on the ecosystem is among the factors that create pressure on pollinators and the need for their conservation and management. Pollinators in tropical regions are facing real and pressing threats, and reliable data on their decline is still lacking (Aizen, 1994; Freitas *et al*., 2009). Pollinator abundance data including managed bees, *A. mellifera*, is still lacking in most regions of Tropical Africa compared with other regions globally with some information from few countries, including Ghana, South Africa and Kenya (IPBES, 2016). The limited taxonomic and geographic coverage for most of the species relies on sparse occurrence data or inference from environmental impact studies (Vanbergen & Initiative, 2013). According to Eardley *et al*., (2009), information on habitat specificity and occurrence of most pollinators is still scanty. Conservation of pollinators is therefore necessary for the successful conservation of both native and cultivated plants (Kelly & Elle, 2020).

Generally, management of present pollinators' habitat is crucial in conservation as it favours diverse pollinator communities due to food availability, mating and breeding sites (Brosi *et al*., 2008; Raina *et al*., 2011; Elisante *et al*., 2017). Agricultural and native landscapes with multiple vegetation (i.e. heterogenous) promote pollinator diversity (Munyuli, 2011). Rangelands are also rich in biodiversity including pollinators and provide significant ecosystem services globally (Kimoto *et al*., 2012). Livestock grazing by sheep, cattle and goats form the dominant utilization and common disturbance in rangeland ecosystems worldwide (Debano, 2006; Elwell, 2012; Kimoto *et al*., 2012). Grazing can potentially cause decline in percent cover of shrubs and bare soil which can negatively impact biodiversity (Elwell, 2012). Most studies on the influence of grazing on insect pollinators indicate that grazing impacts on floral and pollinator communities are variable and may depend on several factors, including the type of grazers, the habitat type, the historical disturbance e.g. how long grazing has occurred, habitat type and the intensity of grazing (Elwell, 2012; Kimoto *et al*., 2012; Shapira *et al*., 2020). This variability in findings suggests that more studies, especially in understudied geographic regions such as Africa are needed. The appropriate utilization of rangelands such as prescribed burning, seeding and other mechanical treatment may assist in promoting diverse plant species suitable for pollinators and other wild and domesticated animals (Gilbert & Vaughan, 2010). A study by Sjödin *et al*. (2008) in Sweden revealed that pollinator management in native rangelands should include grazing management at the landscape level to accommodate different groups like beetles, butterflies, flies and bees (Sjödin *et al*., 2008). These findings are vital for tropical Africa where rangelands cover a large part of the region. Pollinator conservation knowledge of pastoral communities residing in tropical Africa rangelands should therefore be enhanced for maximum pollinator habitat management.

Conservation strategies for pollinators in Africa should emphasize the need to identify areas with high bee diversity and endemism (Eardley *et al*., 2009). Comprehensive assessment of the status and trends of pollinators and pollination services is still lacking (Melin *et al*., 2014; IPBES, 2016). Most research on pollinators especially in the southern part of Tropical Africa and other parts of the world focused on the honey bee, *A. mellifera* L (Hepburn & Guye, 1993). Information regarding other pollinators like stingless bees is minimal (Eardley *et al*., 2009; Elisante, *et al*., 2017). Likewise, information regarding other wild pollinator taxa is still unclear. This situation creates difficulty in implementing successful pollinator conservation programs.

Pollinator conservation strategies require combined efforts between policymakers, conservationists and local communities. Diverse knowledge contributes to understanding pollinators in different aspects including economic, environmental and socio-cultural values (IPBES, 2016). To a large extent, conservation measures should consider living standards and economic conditions of local people in order to be effective (Eardley *et al.*, 2009). In most of tropical Africa, government laws currently cover pollinator conservation within protected areas regardless of the fact that many species exist outside protected areas in croplands and natural landscapes (Eardley *et al*., 2009). According to Elisante *et al*. (2020), implementation of agro-ecological principles could help to restore damaged pollinators' habitat in croplands and promote habitat heterogeneity. These include hedgerow margins and sowing of flower strips (Briggs *et al*., 2013; Kennedy *et al*., 2013; Feltham *et al*., 2015; Elisante *et al*., 2017).

There is an increasing awareness towards conservation of pollinators (Martins *et al*., 2013). Analysis of pollination studies in Africa by Germill-Herren *et al*., (2014) revealed an increase of 62 studies between 2004 and 2013. Furthermore, the formation of the African Pollination Initiative (API) whose main goal is to promote pollination as an important ecosystem service for sustainable livelihood and maintenance of pollinator diversity is another step towards the sconservation of pollinators (Martins *et al*., 2003; IPBES, 2016). In addition, implementation of pollinator studies by some institutions located within Tropical Africa forms another milestone towards Pollinator conservation. For instance, the current research projects hosted by the African College of Wildlife (MWEKA) and Tanzania Wildlife Research Institute (TAWIRI) will document the pollinators available in Tanzania, specifically in northern and eastern parts of Tanzania, respectively. The projects will promote pollinator knowledge in the region as well as their conservation. Despite these efforts, more research should be directed towards understanding varied pollinators in both natural and agroecosystems lands.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

The study was conducted in Simanjiro district, northern Tanzania (3° 33’ 42.55” S and 36° 58’ 44.22” E). According to the Tanzanian National Census of 2012, the population of the district was 178 693 people, with a 2.4% annual increase and a population density of 8.967 per km^2 (National Bureau of Statistics [NBS], 2017). The area has a bimodal rainfall, averaging 650 mm per year, with short rains between October and December and long rains between March and April (Woodhouse & McCabe, 2018). Social data were collected in the three villages of Loiborsiret, Narakauo and Kimotorok (Fig. 2). Study sites for other data involved four grazing areas under different management categories in Loiborsiret village. The areas included private enclosures having a total area of 100 ha, communal enclosures measuring 1200 ha, called *Alalili*. Furthermore, the study investigated communal wet season grazing land that is open to all livestock during the wet season having a total area of 1032 ha and communal dry season grazing land with an area of 500 ha.

The principal residents of the district are Maasai pastoralists, and livestock keeping is the most dominant source of income, followed by crop cultivation, as Maasai have recently become sedentary (Msoffe *et al*., 2011). Crops cultivated include maize (*Zea maize*), mainly for subsistence, and the cash crops, hyacinth beans (*Dolichos lablab*) and sesame (*Sesame indicum*). Grassland (51%) is the most common vegetation type, with short *Digitaria macroblephara* and *Panicum coloratum* species. Wood vegetation, mostly *Acacia stuhlmannii* and *Acacia drepanolobium* covers 26% of the vegetation. Bushlands cover 13% of the ground, while bushed grasslands cover the remaining 10% (Mbinile *et al*., 2020a).

During the wet season, Simanjiro plains provide a critical grazing and calving area for wildebeest, *Connochaetes taurinus* and zebra, *Equus quagga*, and its fertile pastures support coexistence between humans, livestock and wild animals (Woodhouse & McCabe, 2018). Although most Maasai have now settled in permanent villages, reducing movement within village lands and across village boundaries, the plains still have varied grazing management that rotates between wet and dry season grazing areas (Woodhouse & McCabe, 2018). In Simanjiro rangelands, grazing resources are still communal. However, in most villages, individuals have recently been assigned private holdings (Mccabe *et al*., 2010). As a response to range degradation, Maasai have recently adopted the use of traditional enclosures which are known as *Alalili* that helps recovery of rangeland vegetation and preventing range degradation, consequently promoting conservation of pollinators (Mpondo *et al*., 2021). These grazing lands are either privately owned by individuals or communally owned by the entire village. Only young or sick goats, sheep, and cattle are allowed access to these grazing areas. The maximum number of grazing animals that can be allowed in these enclosures is thirty animals per boma (Mpondo *et al*., 2021).

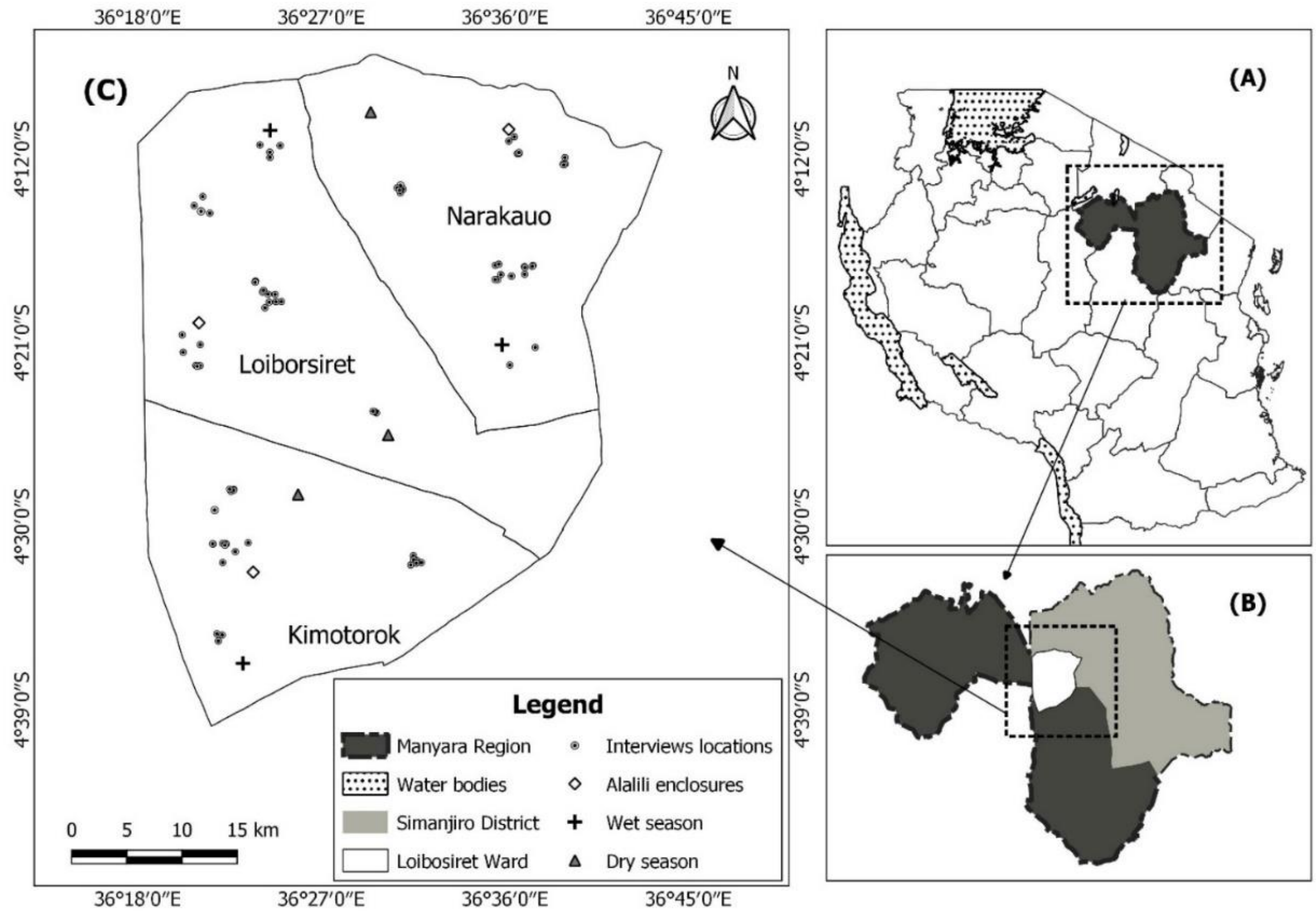


Figure 2: **Map of the three study sites in Loiborsiret ward, Simanjiro district, showing the location of 181 interviews, as well as the location of sample sites in seasonal enclosures called *Alalili* and on wet and dry season open rangelands during field assessment in 2019**

3.2 Local Pastoralists Knowledge on Pollinators and their Role in Livelihoods

3.2.1 Social Study

Field surveys were conducted between October and December 2019 to study local Maasai perceptions on insect pollinators in three villages of Narakauo, Kimotorok and Loiborsiret. The study villages were selected based on the level of external interventions like participation in conservation projects, land use plans for instance presence of wet and dry season grazing sites, presence of enclosures for dry season grazing, the proximity of villages to each other and resources availability, especially time and funds. The survey adopted purposive sampling whereby only respondents from the Maasai ethnic group were included while people from other ethnic groups such as *Waarusha* and *Warangi* were excluded. The approach was used because the Maasai are the primary residents and dominant pastoralists in the area (Baird & Hartter, 2017). Before commencement of the research, permits were acquired from respective authorities including Tanzania Commission for Science and Technology (COSTECH) and Tanzania Wildlife Research Institute (TAWIRI). The respective permits were later presented to district, ward and village authorities.

The study used a mixed approach involving quantitative and qualitative data collection methods such as focus group discussions and key informant interviews (Chisanga *et al.*, 2019; Ontiri *et al.*, 2019). Data collection commenced with key informant interviews comprising 10 respondents inorder to obtain their views on insect pollinators and livelihoods in the area. The participants included village officers, adult Maasai pastoralists and non-governmental organization employees, including the Tanzania People and Wildlife (TPW) beekeeping officer. Focus group discussions were later conducted with 5 participants from each village, making a total of 15 participants. The participants were selected by considering age, gender balances, and time lived in the respective location for at least 20 years. Inorder to increase the wide sharing of participants views, the discussions were separated between males and females considering the culture of Maasai where women do not speak while in meeting with men (Ontiri *et al*., 2019; Woodhouse & McCabe, 2018).

Finally, a semi structured questionnaire was administered (Appendix 1) to collect quantitative data through household/boma surveys that were located at least 0.5 km apart from each other. Before the interview, the questionnaire was pre-tested, and errors were corrected before commencement of data collection. The survey involved a total of 181 respondents from the three study villages (Loiborsiret 61, Narakauo 60 and Kimotorok 60). The sampling fraction constituted at least 5% of individuals in the population who fit the study criteria (Mbinile *et al.*, 2020b). The interviews were conducted in Swahili language which is widely spoken throughout Tanzania. However, in some cases a Swahili to Maasai language translator was used especially for respondents who were unable to speak Swahili. The first section of the questionnaire consisted of socio-demographic information including age, gender, occupation, education level, household size and sources of household income. The second section included questions on general knowledge about different groups of pollinators and their link to rangeland resources and management (Appendix 1). The last part comprised questions on honey bees, *Apis mellifera,* as the most important pollinator, to determine the pastoral understanding of honeybees and beekeeping possibilities for livelihood diversification (Appendix 1).

The ability of pastoralists to recognize pollinators was assessed by showing each respondent a high resolution A4 coloured picture of adult individuals as well as mounted specimens of six insect pollinators, including *Apis mellifera* (honeybee, *Apidae*), *Lasioglossum spp* of subgenus *Ipomalictus* (solitary bee, *Halictidae*), wasps (*Eumenidae*), hoverfly (*Syriphidae*), *Eurema hecabe* (butterfly, *Pieridae*) and *Cheilomenes sp* (beetle, *Coccinellidae*). Respondents were required to respond with Yes or No to whether they recognized the insect shown in the picture. In addition, they were requested to provide the insect name in Swahili or *Maa* language and further state the benefits of each insect. The insect species were selected based on their abundance in the rangelands from our detailed survey to study the influence of rangeland grazing management on the abundance and diversity of insect pollinators in Simanjiro rangelands.

Plate 1: Household surveys in Loiborsiret and Narakauo villages, Simanjiro during data collection in 2019 (Photo: Joseph Lembaji, 2019)

3.3 The Influence of Environmental and Landscape Characteristics on Pollinators

3.3.1 Characteristics and Description of Sampling Sites

The study used stratified random sampling to select four sampling sites used as grazing areas under different management categories (Abdulatife, 2016). The grazing areas included private and communal enclosures commonly known as alalili; wet and dry season open communal rangelands. Enclosures are used for grazing of small number of goats, sheep, calves and sick or weak cows that range from 10 – 30 per boma during the dry season. Usually, the enclosures are closed during rainy season when neighbouring rangelands are being grazed, a practice that is increasing in use in East African rangelands inorder to reduce rangeland degradation (Angassa *et al*., 2010). On the other hand, communal wet season grazing land that is open to all livestock types during the wet season and lastly, communal dry season grazing land, which is mainly used during the dry season for large cattle herds.

3.3.2 Pollinator Sampling, Storage and Identification

To study insect pollinators, three blocks each measuring 50 m x 80 m (4000 m^2) located 300 m from each other were established in each grazing management category. Within each block, three plots each measuring 20 m x 20 m (400 m^2) were set out systematically at 10 m apart (Stein *et al*., 2017). The study used pan trapping, which is the most effective method of trapping pollinators across different habitats for insect trapping in the study sites (Bates *et al*., 2011) as in Plate 2 (b). Three sets of pan traps, coloured Ultraviolet (UV) fluorescent yellow, blue, and white were installed in each plot at an average vegetation height of approximately 50 cm from the ground resembling available vegetation height, to sample flying insects (Stein *et al*., 2017).

The pan traps were further filled with 200 mL of Sodium Chloride (NaCl) saturated water, mixed with detergent, to break surface tension (Stein *et al*., 2018). The study also used standardized sweep netting to supplement pan trapping inorder to target different pollinator groups including bees, butterflies, hoverflies and beetles (Bates *et al*., 2011). Sweep netting was done for 15 minutes in each plot twice a day, i.e. in the morning (0900 hrs to 1100 hrs) and afternoon (0200 hrs to 0400 hrs) (Winfree *et al*., 2007) to ensure that species with different diurnal patterns have an equal chance of being trapped.

Plate 2: (a) Insect trapping using sweep nets and pan traps (b) (yellow, white and blue) in Loiborsiret grazing areas during data collected in May 2019 (Photo: Shelard Mukama)

Insects were collected from the four grazing management categories from May to early October 2019, covering one wet and dry season, and using a total of 81 pan traps in each site. Traps were installed early in the morning before maximum insect activity (0700 hrs – 0800 hrs) and collected later in the evening (0500 hrs – 0600 hrs), leaving them active in each site for 8 hours (Williams *et al*., 2011). Insect trapping was done for 8 days per month i.e. 2 days in each site. All insect data were collected on sunny days while cloudy days were avoided to reduce differences between sites taking into consideration that bees are very sensitive to environmental changes (Winfree *et al*., 2007; Tuell *et al*., 2008; Lázaro *et al*., 2016). Immediately after collection, insects were fixed and stored using 70% ethanol for later identification in the laboratory (Bates *et al*., 2011; Stein *et al*., 2017). Insect specimens were later mounted, counted and sorted into respective orders, family and genus level using identification keys ABC Taxa (Eardley *et al.*, 2010). Finally, the specimens were identified to morphospecies at the University of Dar es Salaam for Coleoptera, Diptera, Lepidoptera and Hemiptera; and at the Royal Belgian Institute of Natural Sciences for Hymenoptera. Hereafter, all morphospecies will be referred to as species. Voucher specimens are deposited in the entomology section of the Department of Biology at the University of Dodoma.

3.3.3 Estimation of Vegetation Cover, Floral Abundances and Grazing Intensities

The estimation of vegetation cover, flower abundances and grazing intensities was crucial as the sampling sites were in different grazing management categories. The proportion of herbaceous vegetation ground cover was done visually through estimation in percentage by locating five 1 x 1 m square plots within each insect sampling plot (Angassa *et al*., 2010). Thereafter, the identification of all flowering trees and woody shrubs in each plot was accomplished using the field guide to common trees and shrubs of East Africa (Dharani, 2011). Plant species identification was later confirmed at the National Herbarium of Tanzania (NHT), Arusha. During data collection, flowering plants species and their abundances were also determined within different grazing management categories in each 20 x 20 m quadrat through counting numbers of open flower units, i.e., flowers or inflorescence (hereafter referred to as flowers) at the time of pollinator sampling as per Stewart *et al*. (2018). However, floral abundance for trees was not counted due to their height. Grazing intensity in each management category was estimated by counting the number of livestock in each block during each survey round as in Vulliamy *et al*. (2006) with some modifications. More information on actual herd sizes was obtained from interviewing herders.

3.3.4 Soil Sampling

Considering the effects of grazing on soil heterogeneity varies depending on the level of grazing intensity (Wang *et al*., 2016), soil from each quadrat in enclosures and open rangelands were sampled by taking five random cores at a depth of 0-25 cm. The cores were later mixed to obtain a composite soil sample for each block, giving a total of 12 samples which were stored in plastic paper bags. The soil samples were later analyzed in the laboratory of Tanzania Agricultural Research Institute (TARI) at Seliani Arusha. Before analysis, the samples were oven dried at 107^{o}C (Yusuf *et al*., 2015). The dried samples were then crushed and passed through a 2 mm stainless steel sieve (Chen & Cui, 2001;Yusuf *et al*., 2015). The samples were later analyzed for Organic Matter content, Soil Organic Carbon, SOC (Bremmer & Mulvaney, 1982) and total soil nitrogen (TSN) content using Kjedal method (Mofidi *et al*., 2013). Samples were further analyzed for available phosphorous (P) by P-Olsen method (Olsen & Sommers, 1982), potassium (K) (Boltz & Howel, 1978), and pH and Electrical Conductivity was determined potentiometrically in a soil distilled water suspension using a ratio of 1: 5 soil: water (Yusuf *et al*., 2015), Carbonate Calcium Equivalent (CCE) percentage (Sparks, 1996).

3.4 Pollinator Plants and Grazing Management Impact on Visitation and Networks

3.4.1 Insect Flower Visitors Survey Design and Identification

To study bee forage plants and the influence of range management on pollinator visitation and networks, sampling sites were established in private and communal enclosures, wet and dry season grazing areas. In each grazing management category, three line transects were established each measuring 100 m. Thereafter, three 5 m x 5 m (25 m^2) plots were established within each transect placed at a distance of 30 m apart (Westphal *et al*., 2008). Pollinator-plant interactions were recorded for two consecutive days every week in each site from April to June 2019 for honey bee visitations; and March to May 2020 for all pollinators, which covers the main blooming period and all plants visited by bees and other pollinators were recorded. Observations of visiting pollinators were made on co-flowering forbs, herbaceous plants and some grass species; trees were excluded, except for a few cases for honeybees. The selection of plants was based on their availability and abundances during the sampling period. Visiting insects observations were made two times a day, morning between 0900 hrs – 1100 hrs and afternoon 0200 hrs – 0400 hrs (Manincor *et al*., 2020). The surveyors walked randomly in each quadrat recording insects visiting open flowers. The observation time allocated for each species was proportional to the species abundance, however the minimum time allocated for each plot was 15 minutes (Lázaro *et al*., 2019). In addition, the time spent on each of the focal plant was recorded using a stopwatch (Ojija *et al*., 2019). All observations were made under similar weather conditions when there is clear sun without strong winds (Westphal *et al*., 2008). The minimum recorded temperature throughout observations was 21°C suitable for maximum insect activities (Potts *et al*., 2003). All visiting insects were identified immediately in situ, photographed and only a few were captured using sweep nets and preserved in 70% alcohol for later identification in the laboratory (Stein *et al*., 2018). Insect visitors including honey bees, solitary bees, butterflies, beetles, hoverflies, bee flies and other flies were assigned to respective functional groups.

3.4.2 Pollen Sampling and Laboratory Physicochemical Analysis

Plant pollens provide major source of proteins and fatty acids for wild and domesticated bees (Michener, 2007). The study focused on measuring pollen and not nectar because it is the essential resource that bees use for their offspring and colonies (Roulston & Cane, 2002). Accurate quantification of pollen protein for various plants is important for pollinator conservation. To determine whether pollen and fatty acids quantity influence bee foraging behaviour, pollen samples were hand collected from blooming plants from the study sites during data collection. For each plant species, the samples were collected in triplicate to allow replication. The pollen samples were then stored in vials filled with alcohol and later taken to the laboratory at Arusha Technical College (ATC) where they were refrigerated at -50℃. Protein was determined using the Kjeldahl method as described in Vanderplanck *et al*. (2014). In this method, 1g of protein sample was added in a test tube. Digestion tables were further added in the test tube followed by 12 mL of concentrated sulphuric acid. The contents were digested in the digestion unit for about 20 minutes at 100ºC, and later removed and left to cool for approximately 20 minutes. Distilled water measuring 300 mL was then added to the cooled digested contents. The digested sample was attached to the distillation apparatus, and the distillate was collected into a collecting flask containing 25 mL sulfuric acid (0.05 M), 150 mL distilled water, and a few drops of Tashiro indicator. The distilled solution was titrated with sodium hydroxide solution (0.1 mol/L) until the colour of the solution changed from violet to green. The volume of sodium hydroxide used at the point of color change was recorded. Later, titre values were calculated using the formula 1mL sodium hydroxide/sulphuric acid = 1.4 mg nitrogen and results were expressed in milligrams per 100 grams (mg/100 g).

Total fatty acids were determined using titrimetric method (Trout *et al*., 1960). Ten grams of pollen sample were added into a conical flask and later dissolved into 500 mL of the solvent (95% ethanol in diethyl ether). Later, 5 drops of POP indicator were added, and the mixture was titrated with 0.1

M potassium hydroxide in ethanol until the colour changed to pink. The titre value was recorded and total fatty acids were determined using the formula provided below:

$$\text{Fatty Acids (FA)} = \frac{56.1 \times N \times V}{M}$$

Where, N = Molarity of potassium hydroxide in ethanol

V = Volume of potassium hydroxide in ethanol used in titration

M = Mass of the sample measured for analysis

3.5 Statistical Data Processing and Analysis

To understand local Maasai perceptions on insect pollinators, qualitative data were summarized and analyzed using the triangulation method whereby responses were grouped according to their major themes (Chisanga *et al*., 2019). Quantitative information from structured questionnaire were coded and analyzed using the IBM Statistical Package for Social Science (SPSS) software version 20.0 (Sarper *et al*., 2009). Chi-square (χ^2) frequency test was used to explore differences between those who could correctly identify each pollinator and those who could not for the six main pollinator species. Chi-square (χ^2) test was also used to determine the relationship between occupation (pastoralists and agro-pastoralists) versus dependent variables including insect species identification and pollinator benefits on livelihoods. Pollinator identification index was derived using the number of pollinators correctly identified by each respondent. The scores for the index were categorized as Low (less than 50), medium (50 – 69) and high (70 and above) (Tarakini *et al*., 2020). Multinomial logistic regression was used to determine factors influencing pollinator identification scores. Bivariate correlation analysis was performed to determine if participation in beekeeping was influenced by socio-economic factors like gender, education level, age and occupation.

The influence of landscape factors on insect pollinators was determined by computing insect and floral species richness, abundance, and Shannon-Weaner diversity index across grazing management categories using the formula underneath. Thereafter, Pearson correlation was computed between insect abundance and both flower abundance and percentage of herbaceous cover. Before correlation, the average insect abundance, floral abundance, and herbaceous cover for each block were computed to avoid pseudo-replication.

Shannon Diversity Index (H) was also used to determine plant species diversity and richness across the grazing management categories:

$$H = - [\sum P_i \ln P_i]$$

Where:

H = the Shannon diversity index

P_i = proportion of each species in the sample

lnP_i = natural logarithm of this proportion

Since insect data, livestock, floral abundance, and percentage cover were count data, and considering that data collection followed a nested sampling design, Generalized Linear Mixed Models (GLMM), with a Poisson error distribution was used in the analysis using lme4 package (Zuur *et al*., 2009). Block and plot nested with block were specified as random variables. The best fitting model was accepted when the Akaike Information Criterion (AIC) of a full model was lower than that of a null model or when a *p*-value less than 0.05 was obtained while comparing a full and a null model. The GLMM was also used to assess differences in insect abundance, flower abundance, and percentage cover between management categories and seasons, and in determining variables that significantly affect insect abundances (Zuur *et al*., 2009). The same model was also used to test the effect of four grazing management categories and two seasons and their interaction on bee species abundances. Tukey-Kramer's HSD was used to confirm significant differences in the mean number of insect abundances, mean number of flowers, and herbaceous vegetation cover across management categories using multicomp package.

Moreover, grazing intensity was calculated by dividing animal abundances over the sampled area in each management category. Furthermore, quantitative matrix of interactions were constructed, with pollinator species in rows and plant species in columns as described in Oleques *et al*. (2019). Thereafter, pollinator networks were constructed for each management category and networks metrics including connectance, nestedness, robustness, number of links, modularity, network diversity and linkage density were extracted at site level. Connectance (C) refers to the proportion of realized/observed links over the number of all possible links (Manincor *et al*., 2020; Oleques *et al*., 2019). Nestedness measured as weighted NODF refers to a situation where species that interact with specialists are a proper subset of the species interacting with generalists in a network (Bascompte & Jordano, 2007; Tylianakis *et al*., 2010; Dalsgaard *et al*., 2013; Oleques *et al*., 2019), where high values indicate more nestedness (Lázaro *et al*., 2019). Linkage density explains generalization when networks differ in size (Tylianakis *et al*., 2010).

Insect visitors for each plant species were computed to determine their richness, abundance and diversity. Tukey-Kramer's HSD was used to confirm significant differences in the mean number of insect abundances, mean number of flowers, and herbaceous vegetation cover across management categories. Homogeneity of variance and normality of data were checked using

Levene's and Shapiro Wilks test, respectively at $\alpha = 0.05$. Except for socio- ecological data which were analyzed by SPSS, all remaining data were analyzed using R platform version 3.6.2 (R Core Team, 2019) using Vegan, MASS, car, iNext and Bipartite packages. Significant values were accepted at $P \leq 0.05$.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Respondents Demographic Information

Men accounted for 55% (100) and women 45% (81) of the total respondents in our interviews (N = 181). The average (±SD) age of women respondents was 35 ± 10 years (n = 81), which was significantly lower than that of men (43 ± 13 years, n = 100; $t = 4.45$, $df = 179$, $P < 0.001$). Men had a higher education level than women ($R = -0.210$, $P = 0.004$). The largest household size recorded was 90 and mean (±SD) household size of the interviewed respondents was 7 ± 10.41. Fifty per cent (91) of all respondents had never been to school, 43% (78) had primary education, and 7% (12) possessed secondary education. Majority of the respondents (75%, n = 136) were agro-pastoralists, cultivating maize, sesame and beans. However, all respondents declared livestock keeping (cattle *Bos taurus*, sheep *Ovis aries*, goats *Capra hircus*, poultry *Gallus gallus domesticus*, and donkeys *Equus asinus*) as their primary income source (Table 2).

Table 1: Sociodemographic characteristics (number and proportion) of all respondents interviewed (N = 181) in the Simanjiro rangelands in 2019

Variables	Categories	Frequency	Percentage (%)
Age group	20-29	45	24.9
	30-39	57	31.5
	40-49	44	24.3
	50 and above	35	19.3
Gender	Male	100	55.2
	Female	81	44.8
Occupation	Pastoralist	45	24.9
	Agro-pastoralist	136	75.1
Level of education	No formal education	91	50.3
	Primary education	78	43.1
	Secondary education	12	6.6
Time in village	> 10 years	26	14.4
	> 20 years	155	85.6

4.1.2 Maasai Knowledge of Pollinators and their Associated Importance

The study revealed that all 181 respondents were able to identify at least one or more insect pollinators from the six-insect species shown to them. The highest identification score was 100% for those who could correctly identify all pollinators (3.32%) and the lowest score was 16.7% for about 4.97% respondents. Furthermore, the overall average pollinator identification score was 57.2%, which is characterized as medium. Moreover, *A. mellifera* was the only pollinator correctly identified by all respondents (Fig. 3). It was also found out that there was no significant difference in identification skills with respect to occupation, whereby agropastoralists were not less knowledgeable in identification compared with pastoralists for *Lasioglossum sp* (χ^2 = 2.494, *P* = 0.114), *Eurema hecabe* (χ^2 = 0.019, *P* = 0.890), *Syriphidae* (χ^2 = 0.024, *P* = 0.589); *Cheilomenes sp* (χ^2 = 2.943, *P* = 0. 086) and *Eumenidae* (χ^2 = 0.015, *P* = 0.903). On the contrary, observations showed that significantly more men could correctly identify solitary bees, *Lasioglossum sp*, compared with women (*F* = 7.397, *df*= 1, *P* = 0.007) but there was no significant difference for other pollinator species.

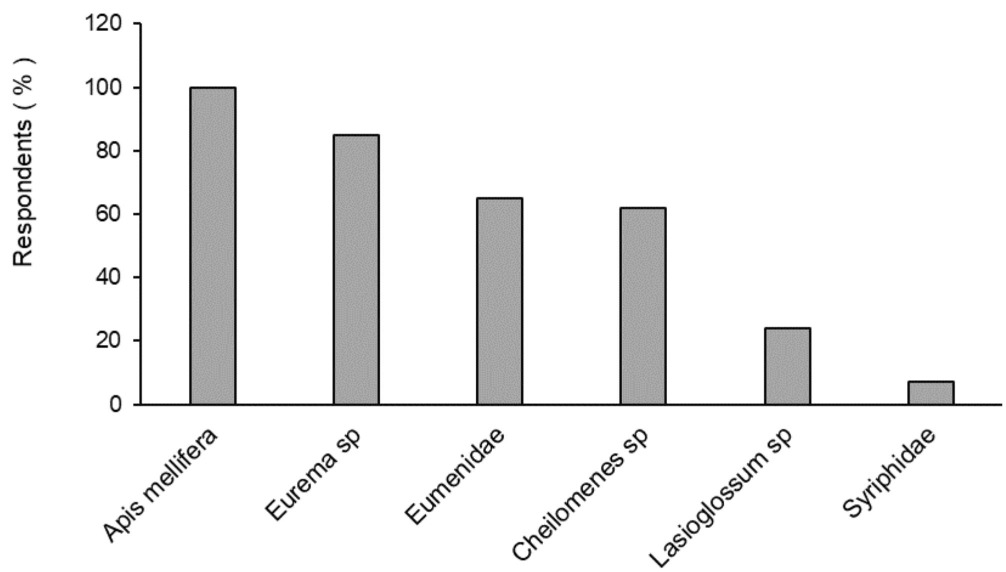


Figure 3: The proportion of respondents that correctly identified various insect species according to the questionnaire survey in three villages of Loiborsiret, Narakawo and Kimotorok during field survey in 2019 (n = 181)

The study findings also showed that age significantly influenced identification skills, with middle aged respondents (30 – 39 years old) being more knowledgeable compared with other age groups in identification of *Eumenidae* (χ^2 = 9.818, *df*=3, *P* = 0.020) and *Eurema hecabe* (χ^2 = 12.432, *df*=3, *P* = 0.006), however, no difference was noted for other pollinators. The correct identification of *Eumenidae* (χ^2 = 6.951, *df*=2, *P* = 0.031) was only significantly influenced by education level, and the majority (72%) of respondents that correctly identified this species had primary education compared with other levels.

The results also revealed that honeybee, *A. mellifera*, was perceived as the most important pollinator compared with other insect groups, as reported by about 93% of males and 78% of females, with significant variation in responses between gender (χ^2 = 14.820, *df*=3, *P* = 0.02). Furthermore, it was revealed that gender is the only significant factor that affected pollinator correct identification scores (χ^2 = 6.319, *df*=2, *P* = 0.042), with males having higher likelihood of correct identification scores than women as revealed by the fitted multinomial logistic regression.

4.1.3 Local Maasai Knowledge on Bee Forage Plants in Rangelands

The study revealed satisfactory local knowledge on bee fodder plant species among Maasai respondents (Appendix 2). *Commiphora africana* was cited by 94 respondents as the leading favourite plant for bees, followed by *Acacia mellifera* (90) and *Albizia anthelmintica* (85) (Fig. 4). Most (66%) of the mentioned pollinator plant species were trees, while the contribution of shrubs (34%) and herbs (0%) in supporting pollinators was less recognized among the interviewed Maasai. Field observations showed several shrubs, herbs, and grasses that served as equally important bee fodder plants. *Aspilia mossambiensis*, *Justica debile* and *Acacia tortilis* (tree) were the leading most visited plant species from field observations in *Alalili* enclosures, wet and dry season grazing sites, with a total of 268, 201 and 150 visitations, respectively. Respondents revealed varied sources of knowledge on insect pollinators. The majority (n = 101, 46%) of respondents claimed that they had gained knowledge on pollinators through friends and relatives, 74 (34%) through personal initiatives such as time spent herding in the bush, and 40 (18%) through extension officers and very few claimed media such as local radio and television 3 (1%).

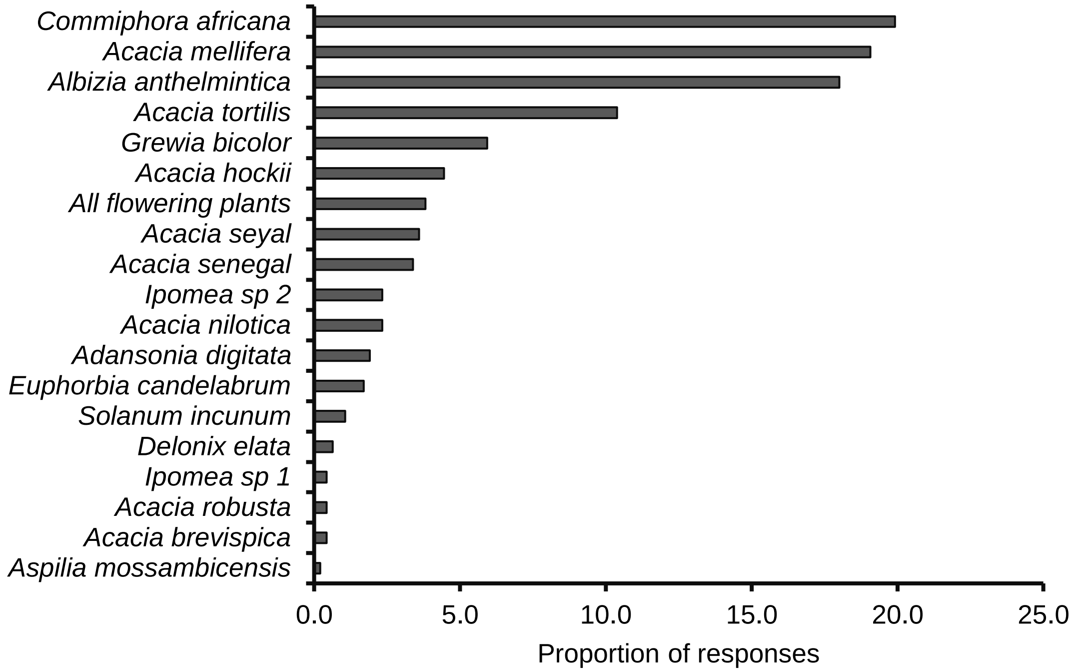


Figure 4: Plants most favoured by bees according to questionnaire surveys with 181 respondents in Loiborsiret, Narakauo and Kimotorok villages in Simanjiro during 2019

4.1.4 Importance of Pollinator for Enclosures and Grazing Lands

Surprisingly, only eight respondents (4%) agreed that pollinators are critical to rangeland health. Furthermore, 34 (19%) did not consider pollinators as having any relevance to rangelands well-being, while the majority (77%) did not know. Open rangelands and alalili, on the other hand, are crucial to pollinators because they provide critical habitat as reported by 69% of respondents. Grazing areas are less important to insect pollinators, as perceived by 16% of the respondents. In general, Maasai believe that pollinators require grazing lands more than the grazing lands need pollinators. The results further revealed significantly more agro-pastoralists compared with pastoralists perceived rangelands to be important for pollinators as they offer essential habitat (χ^2 = 9.89, *df*=3, *P* = 0.020).

4.1.5 Socio-Economic Importance of Pollinators to Maasai Livelihoods

For most respondents (93%), income was reported as the most essential pollinator benefit, which did not differ between agro-pastoralists and pastoralists (χ^2 = 2.032, *df*=2, *P* = 0.362). The majority (90%) of respondents had seen pollinators visiting crops and other plants in the area, an observation that did not differ significantly between pastoralists and agro-pastoralists (χ^2 = 2.794, *df*= 2, *P* = 0.247). The results further revealed that 61% of the interviewed respondents participated in beekeeping for additional source of income while the remaining 39% were non-beekeepers.

Furthermore, it was observed that more Maasai women (89%) were beekeepers compared with men (39%; $\chi^2 = 46.962$, $df = 1$, $P \leq 0.0001$).

Correlation results showed that participation in beekeeping was positively influenced by education level and occupation, but negatively by gender (Table 3). The study findings also showed beekeeping contribute to Maasai financial asset as beekeepers earned an income from honey, which ranged from 36 to 431 USD annually. Beekeepers reported varied locations for beehives placement whereby grazing lands (54%) and wetlands (32%) were the most favourable siting areas. In contrast, cultivation area (8%), woodlands (4%) and boma area (2%) were only reported by few as preferred areas for bee hive siting.

Table 2: **Correlation statistics to describe whether participation in beekeeping was determined by socio-economic characteristics such as gender, age, education or occupation (n = 111) during questionnaire survey in Loiborsiret, Narakauo and Kimotorok during the year 2019**

Factors		**Correlation coefficient**	***p*-value**
Gender	Male Female	-0.509	<0.0001
Age	20-29 30-39 40-49 >50	0.066	0.381
Education level	No formal education Primary education Secondary education	0.421	<0.0001
Occupation	Pastoralist Agro-pastoralist	0.194	0.009

Respondents reported several reasons for declining participation in beekeeping. Majority of non-beekeepers (62%) claimed beekeeping as an activity for the poor, who possess few or no cattle. On the contrary, 24% claimed that it is a woman's job while the remaining 14% reported that they also wished to start beekeeping if they could be supported with modern equipment such as beehives, protecting gears and honey processing machines. Several challenges to beekeeping were reported by the respondents with poor access to market being the leading challenge (Fig. 5). Vandalism, especially illegal honey harvesting from beehives was reported by only 4.8 % of the respondents, who were all females; while 2.1% of the respondents reported they have not experienced any challenge related to beekeeping in the area.

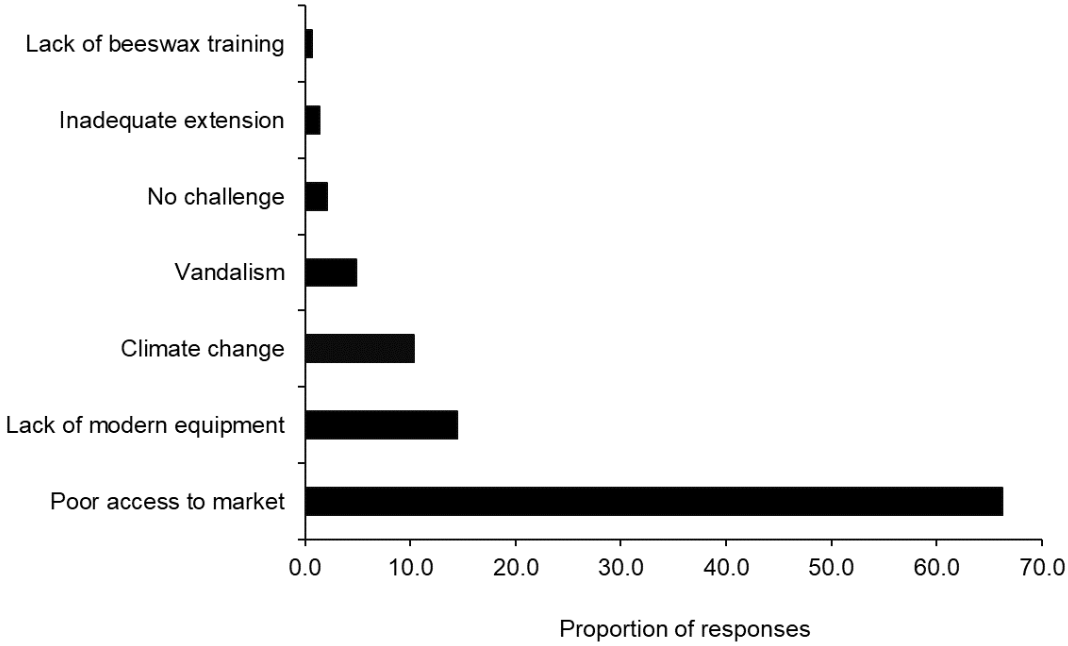


Figure 5: Challenges to beekeeping activities from a survey in Loiborsiret, Narakauo and Kimotorok villages in 2019 as reported by 181 respondents. The bars represent the proportion of how often the challenge was mentioned, and multiple responses were possible

4.1.6 Pollinator Conservation and Trend in the Area

Large proportion of respondents, 130 (72%) reported a declining trend of insect pollinators in the area, while 21% reported an increasing trend and 4% reported a consistent pattern. The remaining 3% did not know anything regarding the trend of pollinators in the area. Reported factors for declining pollinators include climatic factors especially reduced rainfall, and drought. Another major factor reported is increased agricultural activities in the area due to the massive clearance of land (Fig. 6). Swarming (a natural process) and bee absconding (migrating and abandoning a hive due to disturbances) were highlighted by only a few respondents as reasons for the decline. The majority of respondents 165 (91%), claimed to be unaware of any efforts to ensure pollinator conservation in Simanjiro rangelands. In comparison, only a few respondents mentioned possible strategies that could promote pollinator survival in rangelands. Avoiding forest fires, practising environmental conservation, and beehive sitting, were among the strategies proposed by only a few (9 %) respondents.

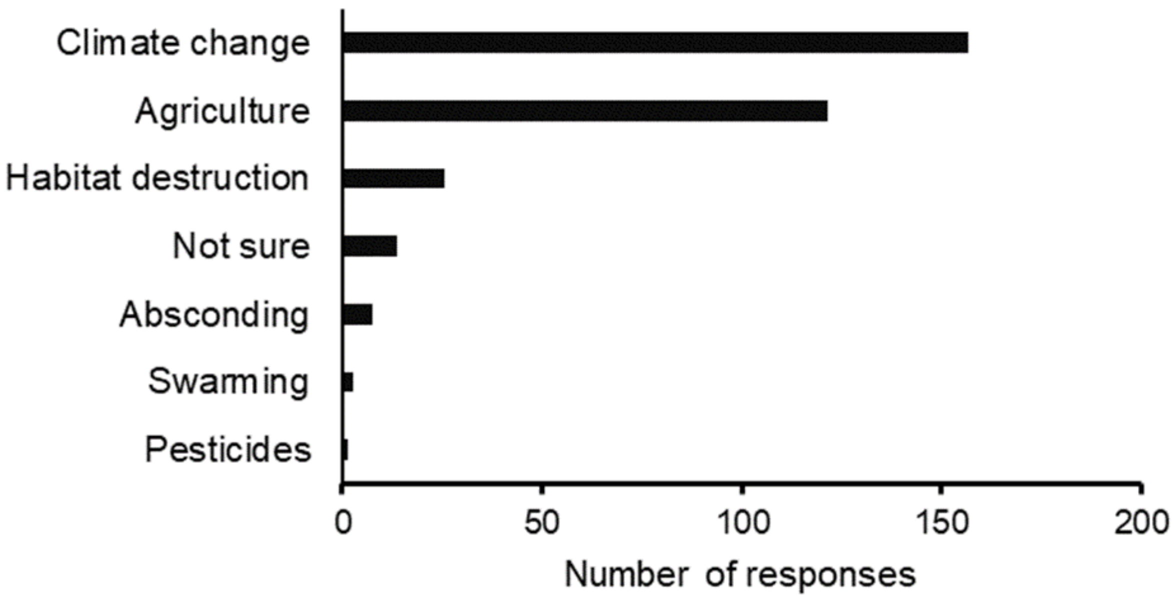


Figure 6: **Factors for a potential decline in pollinators in Simanjiro from the survey in Loiborsiret, Narakauo and Kimotorok villages in 2019 as reported by 181 respondents. The bars represent the frequency a cause was mentioned whereby multiple responses were possible**

4.1.7 Effect of Seasonality, Vegetation Cover and Flower Abundance on Insect Pollinators

The results indicated variation in insect abundance with seasons whereby the mean number of insect abundance across all management regimes was significantly higher (χ^2 = 136.77, P < 0.0001) during the wet (148 ± 71) as compared with the dry season (17 ± 7) (Fig. 7) across all sites. The results further revealed variations between insect groups in both seasons. Beetles (35%) and bees (27%) were noted as the most abundant trapped insects while true bugs were the least abundant in all study sites during the wet season. On the contrary, wasps formed the most abundant group during the dry season across all sites. The results further revealed variations of group composition with seasonality in study sites. For instance, there was a significant difference in number of insects between beetles and true bugs (χ^2 = 18.60 P = 0.0049) during rainy season in the communal enclosure site however no significant variation was noted during the dry season. Beetles were higher than other insect groups during wet season collection in Ranger post, a dry season site, however, the difference in insect abundance within the site was significant between flies and ants (P = 0.020), beetles and flies (P <0.001); and between beetles and bugs (P = 0.029). Study findings also revealed that bee abundances were strongly influenced by season (χ^2 = 194.37, P < 0.0001), with more bees recorded in the wet season across all management categories.

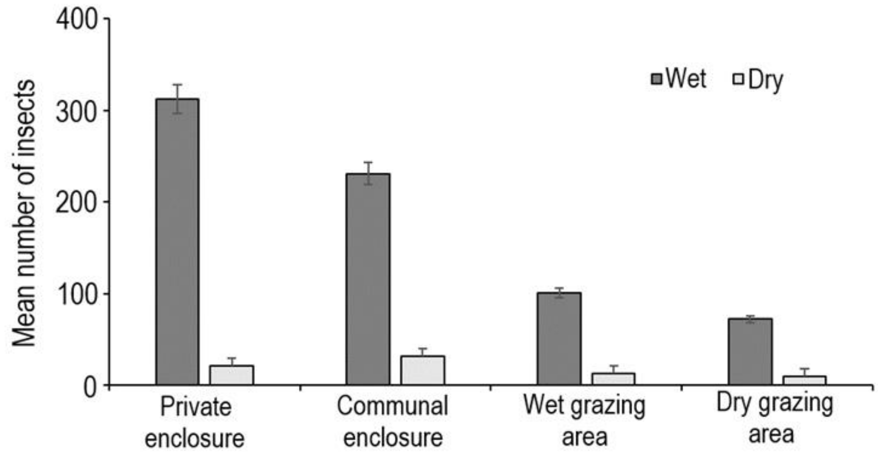


Figure 7: Mean (±SE) number of insect pollinators for wet and dry season according to the field survey across four different grazing categories, i.e., private enclosure, communal enclosure, wet and dry season grazing areas in Loiborsiret, Tanzania, from pollinator trapping using sweep nets and pan traps from May to October 2019

Furthermore, flower abundance was observed to influence insect in the study sites. Overall, a total of 7364 floral units were recorded during wet season data collection because there were no flowers during the dry season. Private enclosure site was observed to have the highest floral abundance of 2480 (34%) and the lowest was found in the dry grazing site with 1880 (19.7%). The output of a generalized linear mixed model further revealed a significant variation in floral abundance across sampling sites ($\chi^2 = 23.88$, $P < 0.0001$). The private enclosure site, which had the highest floral abundance contained 1.7 times more flowers compared with dry season grazing site ($Z = 4.84$, $P < 0.001$) (Table 4) which had the lowest floral abundance as revealed by a post hoc Tukey Kramer's test.

Table 3: Flower species richness, abundance and diversity across grazing management categories collected during wet and dry season from May to October 2019 in Loiborsiret, Simanjiro

Parameter	Sites				*F*	*P*
	Private enclosure	Communal enclosure	Wet season grazing	Dry season grazing		
Mean inflorescence abundance	827^{b}	627^{ab}	517^{ab}	484^{a}	362.5	0.001
Flower species richness	11^{ab}	13^{b}	10^{ab}	8^{a}	9.5	0.005
Flower diversity	1.99^{ab}	2.13^{b}	1.84^{a}	1.88^{ab}	4.2	0.047

Means that do share the same letter are significant different according to Tukey Kramer's HSD post hoc test at $P < 0.05$.

The study further revealed that flowering plant species richness and diversity was highest in the communal enclosure compared with other sites Table 4. The *A. mossambiensis*, *G. cordifolia*, and *J. debile* were noticed as species with the most abundant flowers. In addition, a significant positive correlation was noted between the mean number of insects and the mean number of inflorescences across management categories (r = 0.68, P = 0.015) (Fig. 8a).

The results further showed that percentage vegetation cover also influence insect pollinators whereby a significant correlation was found between average percentage vegetation cover and the mean number of insects (*Pearson's* r = 0.37, P = 0.002) (Fig. 8b). However, there was no significant correlation between insect diversity and floral diversity (r = 0.33, P = 0.667). All sampled sites differed significantly from each other in percentage cover during both wet (χ^2 = 22.75, $P < 0.0001$) and dry season (χ^2 = 82.31, $P < 0.0001$) as revealed by GLMM, whereby private enclosure and wet season grazing sites contained higher vegetation cover compared with communal enclosures and dry season grazing sites.

The output of a GLMM showed that number of flowers (χ^2 = 3.5, P = 0.05), percentage herbaceous cover (χ^2 = 5.99, P = 0.015) and season (χ^2 = 126.57, $P < 0.0001$) were the significant factors that could be attracting insect visitation in the management categories. Therefore, both seasonality and landscape factors including floral abundance and vegetation cover influenced insect pollinators in the study sites.

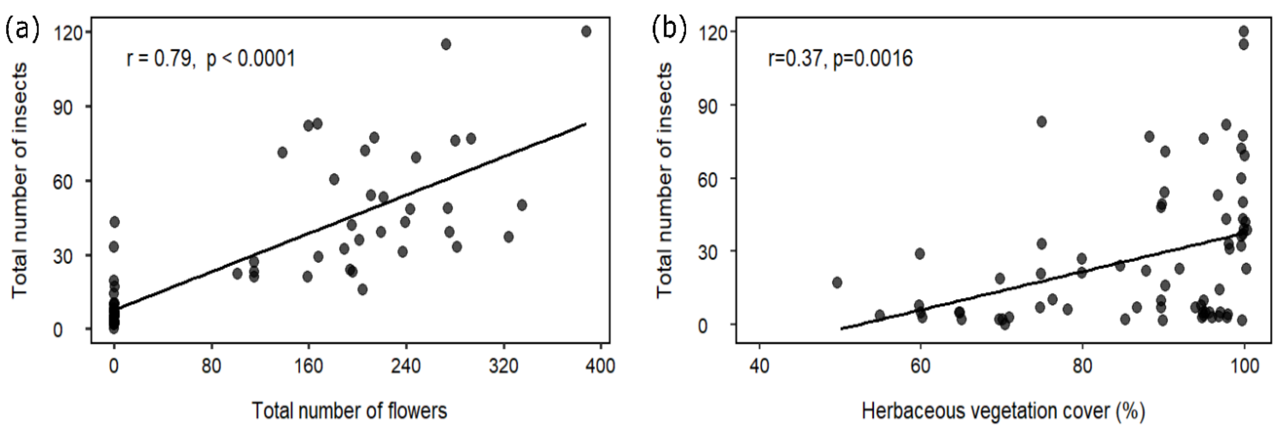


Figure 8: **Correlation analysis involving number of flowers and vegetation cover versus number of insects (a) Correlation between the total number of insect pollinators and floral abundance (b) Correlation between percentage vegetation cover and mean total number of insects across all four grazing management categories of private enclosure, communal enclosure, wet season grazing and dry season grazing in Loiborsiret Simanjiro from data collection during wet and dry season in 2019**

4.1.8 Honeybees Visitation and Foraging on Flowering Plants

The study findings revealed diverse visitation preferences of honeybee among plant species. The *A. mossambiensis* received the largest proportional of bee visitors (27.92%) followed by *J. debile* (20.94%; Fig. 9). The findings further showed that among the surveyed plants, *O. gratissum* was the least visited herbaceous plant by honeybees. On the contrary, *A. brevispica* received least visitors from the overall survey of honey bee visitors.

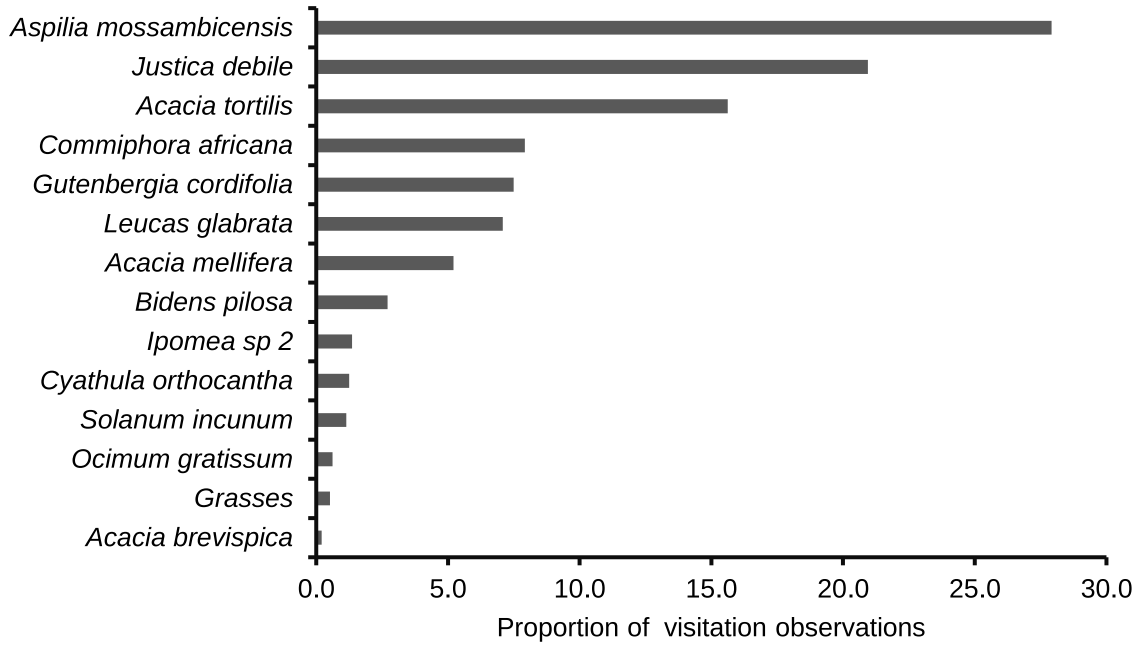


Figure 9: Bee forage plants recorded from visitation observations in private and communal enclosures, wet and dry season grazing areas in Simanjiro during April to June 2019

4.1.9 Protein and Fatty Acids Content of Selected Herbaceous Bee Forage Plants

Findings from this study showed that mean protein concentration in sampled pollens varied significantly between plant species (χ^2 = 25.9, *P* = 0.001). Overall pollens of *Solanum incunum* contained the highest concentration of total proteins (299.3 ± 0.68) and *Ocimum gratissum* had the least content (Table 4). On the contrary, average fatty acids concentration ranged between 1.7 mole/kg to 3.3 mole/kg, *Justicia debile* contained highest fatty acids concentration (3.3 ± 0.17) (Table 4) followed by *Guternbergia cordifolia* (2.8 ± 0.19) as compared with other sampled plants. Further comparison revealed a significant variation in fatty acids contents between the sampled plants (χ^2 =25.9, *P* = 0.001). The results further revealed no correlation between honey bee visitation and protein concentration in pollens (*r* = -0.471, *P* = 0.239) nor with fatty acids concentration (*r* = 0.253, *P* = 0.546).

Table 4: **Mean (±SE) protein and fatty acids concentration in pollen of selected bee forage plants collected in the four grazing categories of private enclosure, communal enclosure, wet season grazing and dry season grazing in Loiborsiret Simanjiro from data collection in Simanjiro between March and May 2020**

Plant species	Family	Proteins concentration	Fatty acids concentration
Solanun incunum	*Solanaceae*	47.9 ± 0.68	2.2 ± 0.09
Cyathanula orthocantha	*Amaranthaceae*	41.5 ± 1.44	2.8 ± 0.10
Leucas glabrata	*Lamiaceae*	34.6 ± 1.61	1.7 ± 0.08
Guternbergia cordifolia	*Asteraceae*	33.8 ± 0.91	2.8 ± 0.19
Bidens pilosa	*Asteraceae*	33.3 ± 0.83	2.8 ± 0.17
Justicia debile	*Acanthaceae*	33.2 ± 2.10	3.3 ± 0.17
Aspilia mosambiensis	*Asteraceae*	30.3 ± 0.95	2.3 ± 0.15
Ocimum gratissum	*Lamiaceae*	30.0 ± 1.16	1.7 ± 0.09

4.1.10 Pollinator Networks Structure and Grazing Management

A total of 1896 floral visitors of all pollinator groups were recorded during the entire data collection period across all management categories (Plate 3). The results revealed significant variation in visitors number between management categories (F=2.8, P = 0.068) whereby the amean number of visitors was significantly higher in the private enclosures compared with other sites. Tukey Kramer post hoc test revealed a significant variation in flower visitors between private enclosure and dry season grazing area (P= 0.018).

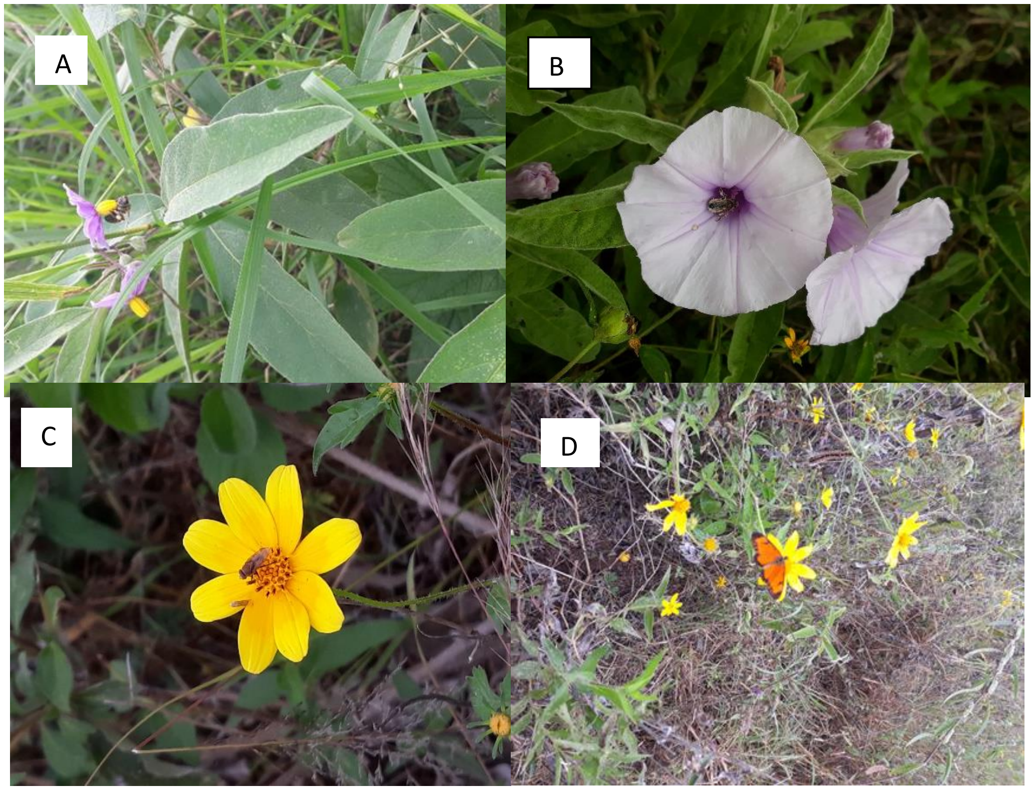


Plate 3: Plant-pollinator interactions recorded during field observations between March and May 2020 in Simanjiro rangelands: (A) *Apis mellifera* visiting *Solanum incunum*, (B) Solitary bee, *Halictidae* visiting *Ipomoea spp* (C) *Diptera* visiting *Aspilia mossambiensis* plant (D) Butterfly, *Eumenidae* visiting *Aspilia mossambiensis* plant

The results further showed varied pollinator group composition (Table 6). Hymenoptera, especially bees, contained most of the flower visitors (45%) with honey bees, *A. mellifera* dominating as the most prevalent (28.38 %) followed by Lepidoptera (22.99%) and yellow butterfly *E. hecabe* (11.92%) (Table 6). Beetles (16.88%) were the third largest visitors despite their abundance in Simanjiro rangelands from insect trapping results in the second objective.

Table 5: Composition of different groups of flower visitors from observation in four management categories of private and communal enclosures, wet and dry season grazing sites in Simanjiro between March and May 2020

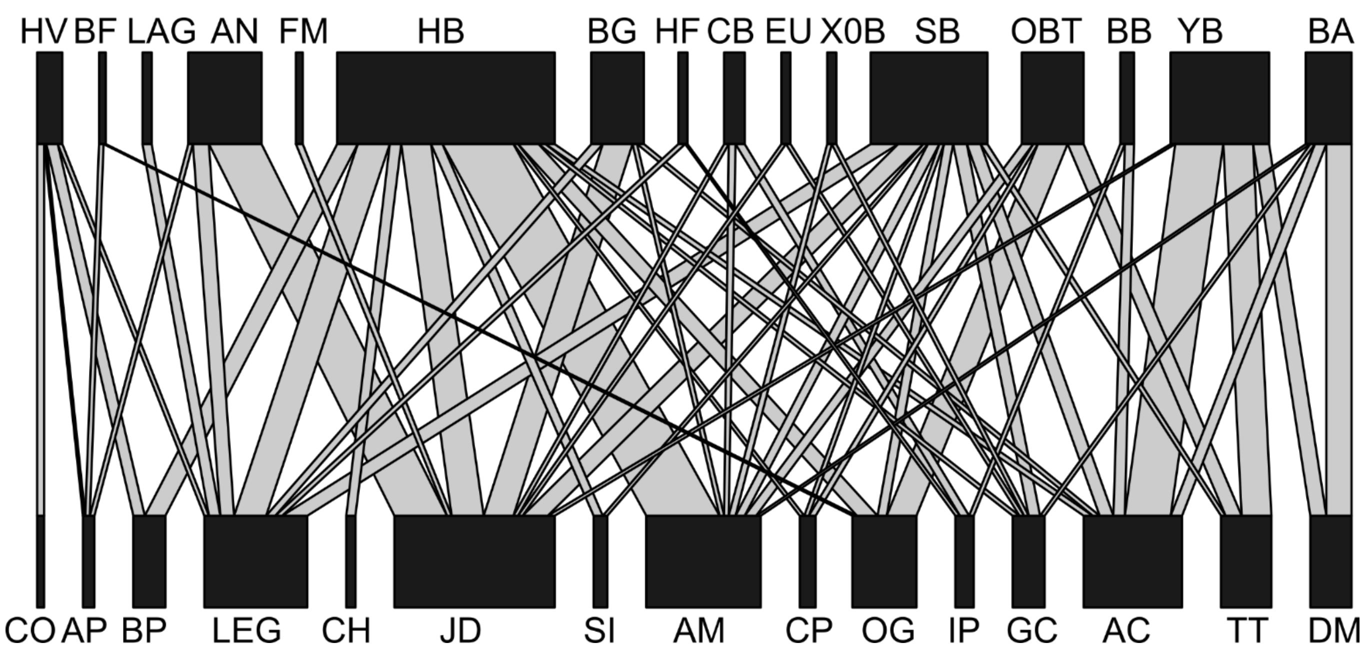
Order	Common name	Number (n)	Overall visitors' proportion (%)
Hymenoptera	Honey bees	538	28.38
	Solitary bees	270	14.24
	Ants	124	6.54
	Lasioglossum bees	26	1.37
	Wasp	22	1.16
	Xylocopa bees	20	1.05
Lepidoptera	Yellow butterflies	226	11.92
	B. aurota	92	4.85
	Orange butterflies	80	4.22
	White butterflies	30	1.58
	Flower moth	8	0.42
Coleoptera	Chaffer beetle	116	6.12
	Blister beetles	90	4.75
	Lady beetle	54	2.85
	Other beetles	44	2.32
	Flower beetle	16	0.84
Diptera	Other Flies	24	1.27
	Bee flies	16	0.84
	Hoverflies	16	0.84
	Blow fly	4	0.21
Hemiptera	Bugs	80	4.22

4.1.11 Network Metrics and Grazing Management

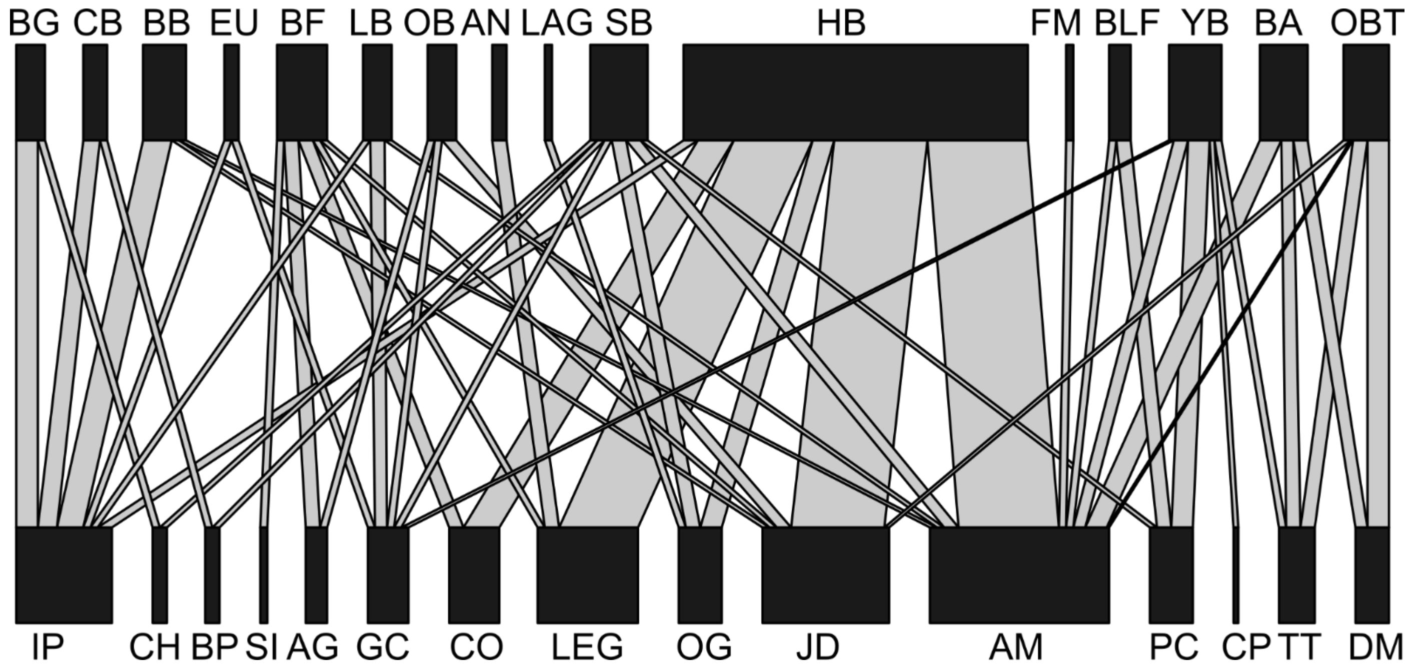
There was variation in some properties of plant-pollinator networks across grazing management categories. A quantitative pollinator-plant networks for the four grazing areas management is shown in (Fig. 10). Private enclosure contained largest networks with more interactions and significantly higher linkage per species (t = 15.4, P < 0.001) as well as higher linkage density (4.48) compared with other grazing categories (t = 12.3, P = 0.001). There was also a significant difference in nestedness (N) between pollinator networks across the four grazing management categories (t = 10.8, P = 0.002) whereby networks indices in communal enclosures and wet season grazing had higher nestedness values as compared with private enclosure and dry season grazing (Table 7). On the contrary, robustness varied slightly between private enclosure, communal enclosure and wet season grazing. However, networks in dry season grazing were least robust (0.6769) compared with other management categories (Table 7). Furthermore, networks between the management categories did not differ significantly in the level of connectance and species diversity.

Table 6: Network properties across four grazing management categories of private and communal enclosure, wet and dry season grazing land in the Simanjiro rangelands from pollinator visitation in March to May 2020

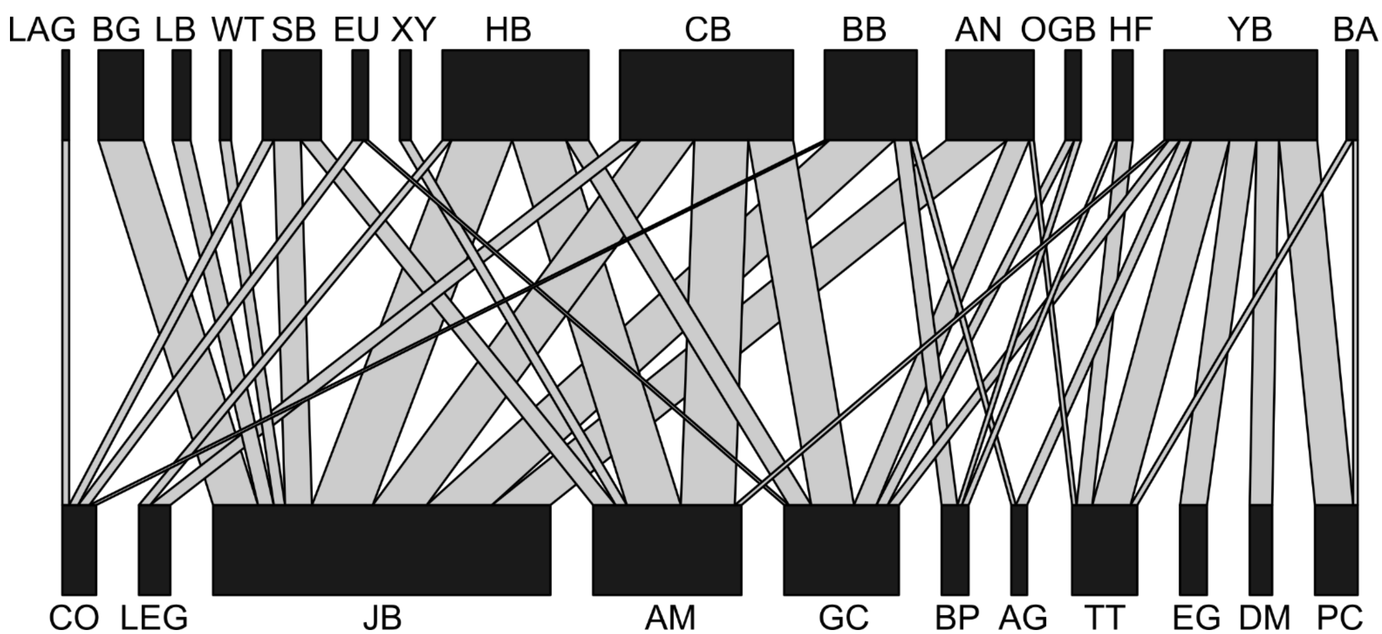
	Grazing Category			
Network- Level Metrics	**Private enclosure**	**Communal enclosure**	**Wet season grazing**	**Dry season grazing**
Nestedness	22.65	29.77	29.16	20.26
Shannon diversity	3.68	3.45	3.18	3.13
Connectance	0.24	0.20	0.26	0.22
Robustness	0.76	0.74	0.78	0.68
Specialization degree H2'	-0.01	0.08	-0.09	-0.17
Generality	4.76	3.95	3.08	2.73
Linkage per species	1.84	1.58	1.44	1.38
Linkage density	4.48	3.62	3.01	3.81



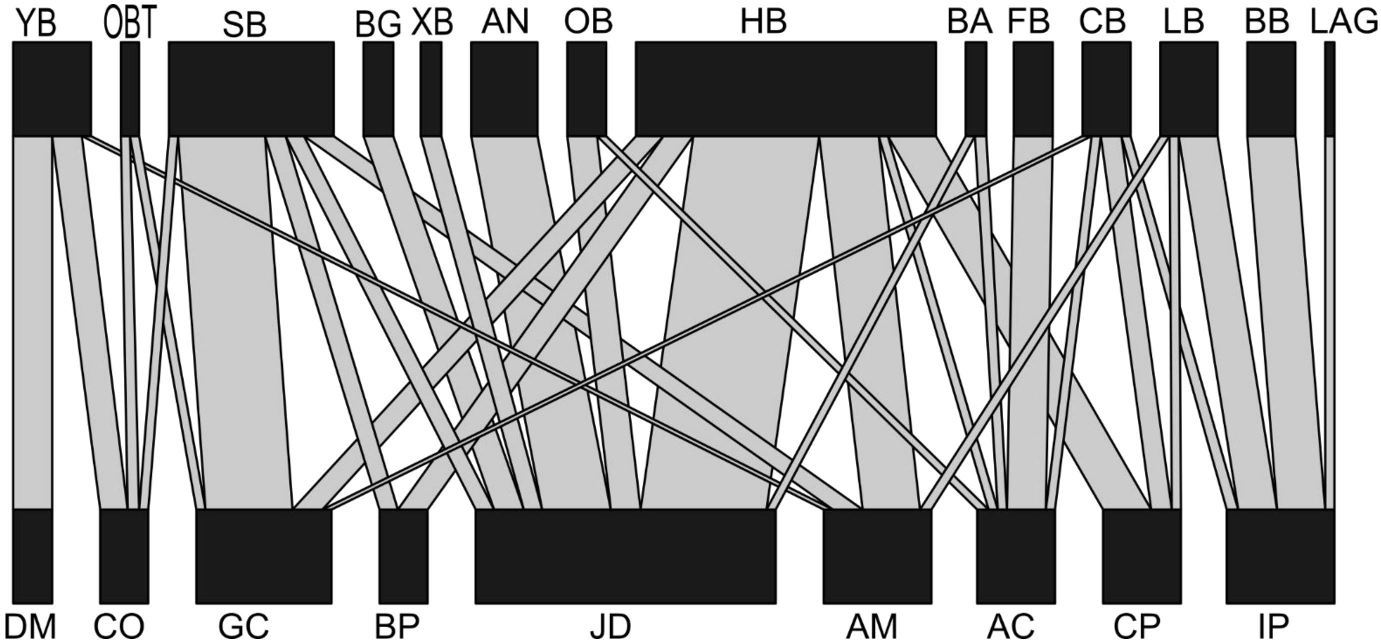
(a) Private enclosure



(b) Communal enclosure



(c) Dry season grazing



(d) Wet season grazing

Figure 10: A network showing plant-pollinator interaction in grazing areas management in Loiborsiret (a) Private enclosure (b) Communal enclosure (c) Dry season grazing (d) Wet season grazing

The upper level black boxes indicate insect species while the lower level black boxes indicate plant species. The width of the black box indicates the number of visits while the interactions are indicated by the grey lines. The abbreviations of insects are BA: B. aurota, BB: Blister beetle, BG: Bug, HB : Honey bee, SB: Solitary bee, YB: Yellow butterfly, CB: Chaffer beetle, OBT: Orange butterfly, OB: Other beetles, BF: Bee fly, AN: Ants, HV: Hoverfly, EU: Wasps, HF : Housefly, FM: Flower moth, LAG: Lasioglossum bee. On the other hand, plants species are abbreviated as AC: *Ageretum conyzoides*, AM: *Aspilia mossambicensis*, AP: *Aspilia pluriseta*, BP: *Bidens Pilosa*, CH: *Chasccanum hildebranditii*, CP: *Commicarpus plumbagines*, CO: *Cyathula orthocantha*, DM: *Digitaria macroblephara*, GC: *Guternbergia cordifolia*, IP: *Ipomoea sp*, JD: *Justicia debile*, LEG: *Leucas glabrata*, OG: *Ocimum grattisum*, PC: *Panicum coloratum*, SI: *Solanum incunum*, TT: *Themeda trianda*.

4.1.12 Grazing Intensity and Range Management in Semi-Arid Rangelands

The mean number of grazing animals was significantly highest ($\chi^2 = 200.29$, $P < 0.0001$) in dry season grazing (166.67 ± 50) and lowest in private enclosure areas (7.78 ± 3.6) Table 8. Likewise, the percentage grazing intensity was also highest in the dry season grazing site with 41.67%, followed by the communal enclosure (33.33%), the wet season grazing area (25.56%) and the private enclosure (1.94%).

Table 7: Mean livestock abundances (±SE) and grazing intensity in four management categories of private and communal enclosures, wet and dry season grazing site

Site	Mean livestock abundance	Mean Grazing intensity	Percentage grazing intensity (%)
Private enclosure	7.78 ± 3.67	0.02	1.94
Communal enclosure	133.33 ± 78.10	0.33	33.33
Wet season grazing	102.22 ± 42.16	0.26	25.56
Dry season grazing	166.67 ± 50.00	0.42	41.67

4.1.13 Pollinator Abundance, Species Richness and Diversity Across Management Categories

During the entire data collection period, a total of 1977 insects from seven groups representing 44 families were trapped using both pan trapping and sweep nets across the four grazing management categories (Appendix 3). These included 522 (26%) bees (*Hymenoptera*), 646 (33%) beetles (*Coleoptera*), 298 (15%) wasps (*Hymenoptera*), 54 (3%) butterflies (*Lepidoptera*), 270 (14%) ants (*Hymenoptera*), 166 (8%) flies (*Diptera*) and 21 (1%) true bugs (*Hemiptera*).

Insect pollinator abundance, richness, diversity, and species composition were all affected by grazing management, according to the study findings (Appendix 4). Pollinator abundance varied between management categories, whereby dry season grazing significantly differed for the other three management categories ($\chi^2 = 26.70$, $P < 0.0001$), with abundance being lowest in the dry season grazing site, which contained 273 (14%) individuals, and highest in the private enclosure site, with 703 (36%) individuals (Fig. 11). As revealed by aTukey Kramer's post hoc analysis, dry season grazing was significantly lower than all other management categories as shown in Fig. 11.

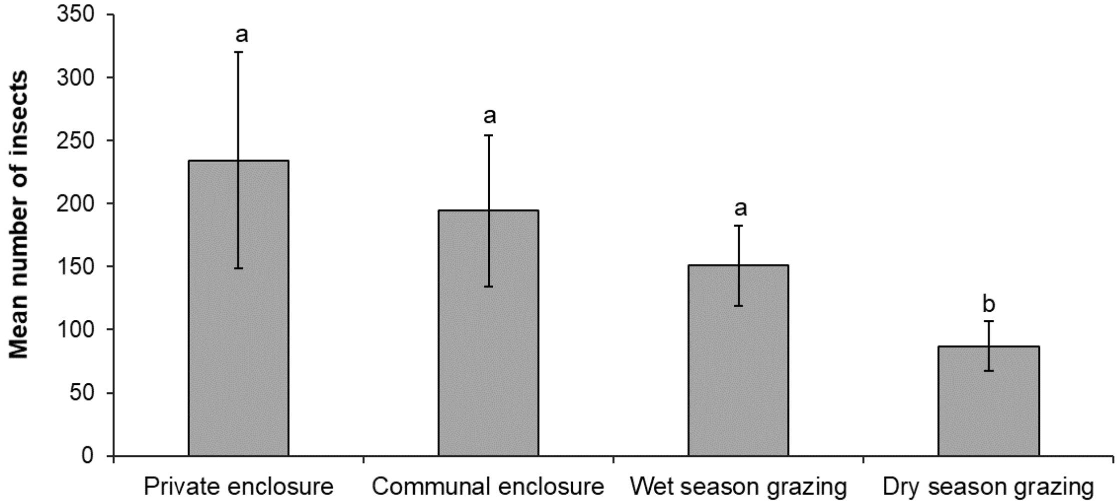


Figure 11: Average (±SE) insect pollinators abundance across four different grazing categories, in Loiborsiret, Tanzania, from pollinator trapping using sweep nets and pan traps in May to October 2019.

Note that bars that do not share the same letter are significantly different based on Tukey Kramer's HSD post hoc test at $P < 0.05$

The study further recorded 239 insect species, grouped into 44 families from the four grazing management categories (Table 9). Furthermore, the data demonstrated a varying pattern of species richness between different insect groups, with bees accounting for the highest species (23%) from the overall sample, followed by flies (8.8%) and wasps (8.4%). Ants had the least amount of species richness as shown in Table 9. This study, on the other hand, found no significant variation in bee abundance between grazing management categories ($\chi^2 = 3.00$, $P = 0.392$).

Table 8: Pollinator species richness across the four grazing management categories in Loiborsiret Simanjiro collected by sweep nets and pan traps between May to October 2019, (N= 81)

Site	Species richness							
	Bees	**Flies**	**Wasps**	**Beetles**	**Bugs**	**Butterflies**	**Ants**	**Total**
Private enclosure	31	9	11	12	7	4	2	76
Communal enclosure	28	5	9	10	3	5	1	61
Dry Season Grazing	17	8	10	9	0	3	2	49
Wet Season Grazing	20	9	10	8	2	3	1	53
								239

4.1.14 Bees Abundance, Richness and Diversity Across Grazing Management Categories

A total of 522 bee specimens were captured from the four grazing management categories as revealed by the findings. The trapped bees represented 56 species and three families of *Apidae*, *Megachilidae,* and *Halictidae* (Appendix 5). Bees from *Colletidae* and *Andrenidae* families were not trapped during the entire data collection. The honey bee *A. mellifera* was the most prevalent species, accounting for 107 (21%) of the total bee individuals collected, followed by *Lasioglossum* of subgenus *Ipomalictus* sp "TZ 8" (Halictidae) with 105 (20%) individuals.

The study further revealed variation of bee abundances as well as number of taxa with grazing management. Overall, enclosures contained twice as many bees as compared with the wet and dry season grazing sites (χ^2 = 55.15, P < 0.0001) (Fig. 12). Further analysis revealed a significant interaction between season and management categories in influencing the number of bees (χ^2 = 19.84, P = 0.0002), with wet season numbers being higher compared with dry season.

With grazing management, the species and family composition of bees changed slightly but not significantly. The honey bee *Apis mellifera* was not collected from the wet season grazing area while only a few individuals of the ground-nesting solitary bee, *Lasioglossum (Ipomalictus)* specie "TZ 8", were collected in dry season grazing area. The private enclosure contained the highest bee species diversity (H' = 2.72) but differed only slightly and not significantly (χ^2 = 3.00, P = 0.392) from the other grazing categories, i.e., communal enclosure (H' = 2.35), wet season grazing (H' = 2.34) and dry season grazing (H' = 2.50). Bee species diversity was not related to floral diversity in the study sites (*Pearson's r* = - 0. 079, P = 0.921).

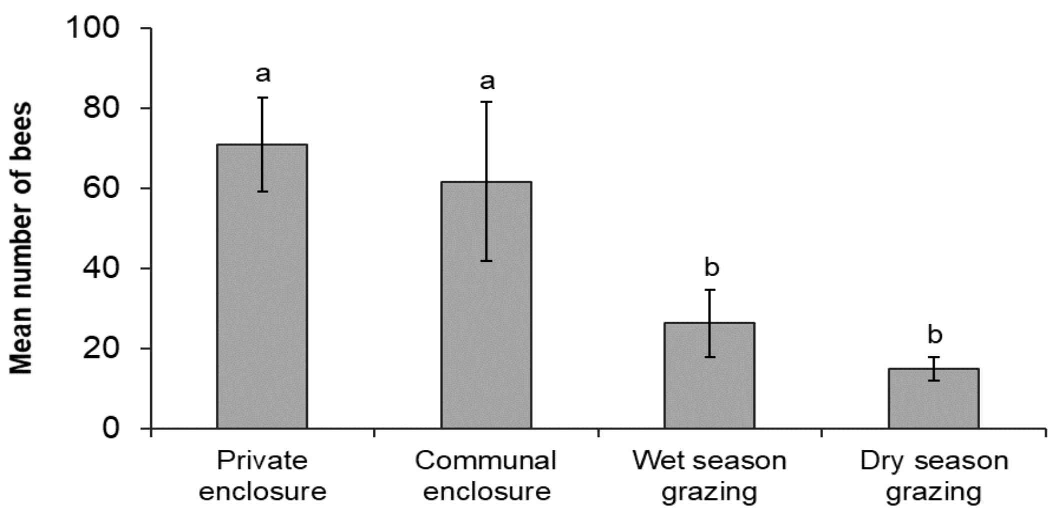


Figure 12: Mean total bee abundances from four grazing categories of private enclosure, communal enclosure, wet and dry season grazing sites, collected during the wet and dry season from May to October 2019 at grazing sites under different management in Loiborsiret, Simanjiro.

Note that bars that do not share the same letter are significant different according to Tukey Kramer's HSD post hoc test at P < 0.05

4.1.15 Differences of Soil Chemical Properties Across Grazing Management

Most of the soil chemical properties did not differ across management categories (Table 10). A significant difference between management categories was noted for percentage of organic carbon (*F*= 6.563, *df*= 3, *P* = 0.053) and organic matter (*F*= 6.545, *df*=3, *P* = 0.053), whereby enclosures contained significantly higher amount than wet and dry season grazing areas. Manganese (Mn) also varied significant across sites (*F*= 8. 917, *df* = 3, *P* = 0.027). However, no significant correlation was noted between insect abundances and organic carbon (r = 0.058, *P* = 0.858), organic matter (r = 0.058, *P* = 0.858) and Manganese (r = 0.190, *P* = 0.555).

Table 9: **F - test Statistics of the means (± SE) soil properties in grazing management categories of private and communal enclosures, wet and dry season grazing areas in Loiborsiret Simanjiro. PE = Private enclosure, CE= Communal enclosure, WSG = Wet season grazing, DSG = Dry season grazing**

Soil properties	**PE**	**CE**	**WSG**	**DSG**	**F**	**df**	**P value**
OC (%)	2.04± 0.43	1.19 ± 0.04	1.46± 0.45	1.57 ± 0.16	6.563	3	**0.053**
Organic Matter (%)	3.51±0.75	2.05 ± 0.06	2.51± 0.781	2.70 ± 0.28	6.545	3	**0.053**
Ph	6.20 ± 0.3	5.9 ± 0.1	6 ± 0.2	5.9 ± 0.3	1.350	3	0.385
EC (dS/m)	1.10 ± 0.04	1.03 ± 0.34	1.53 ± 0.27	1.39 ± 0.38	2.213	3	0.247
Total Nitrogen (%)	0.07 ± 0.01	0.06 ± 0.01	0.056 ± 0.01	0.06 ± 0.00	2.155	3	0.248
P (mg kg^{-1})	3 ± 1	5 ± 1	7 ± 2	3 ± 1	2.464	3	0.193
Ca (Cmol/kg)	0.73 ± 0.18	0.33 ± 0.18	0.85 ± 0.27	0.63 ± 0.28	2.915	3	0.154
K (Cmol/kg)	0.02 ± 0.01	0.03 ± 0.00	0.02 ± 0.01	0.02 ± 0.01	1.600	3	0.316
Mg (Cmol/kg)	0.11 ± 0.06	0.06 ± 0.02	0.08 ± 0.03	0.06 ± 0.01	1.001	3	0.476
Na (Cmol/kg)	0.20 ± 0.28	0.28 ± 0.22	0.17 ± 0.28	0.64 ± 0.48	0.581	3	0.656
S (mg kg^{1})	37.12 ± 13.13	45. 69 ± 12.39	36.31± 8.29	46. 46 ± 22.88	0.397	3	0.762
Mn (mg kg^{1})	5.59±0.42	3.98 ± 0.29	3.91 ± 0.36	5.10 ± 1.75	8.917	3	**0.027**
Al (mg kg^{1})	51.33 ± 5.34	38.46 ± 3.43	46.84 ± 12.88	52.064 ± 6.08	4.782	3	0.078
Zn (mg kg^{1})	0.48 ± 0.12	0.51 ± 0.11	0.63 ± 0.08	0.49 ± 0.04	1.686	3	0.308
Fe (mg kg^{1})	45.03 ± 5.94	31.52 ± 9.90	44.04 ± 13.57	46.39 ± 16.23	1.116	3	0.439

Bold *p* values are significant at $p < 0.05$

4.2 Discussion

4.2.1 Local Pastoral Knowledge and Recognition of Common Pollinator Groups

Findings that all interviewed respondents accurately identified honey bees (*A. mellifera*) compared with other insect groups are similar to those of (Kasina *et al.*, 2009), who conducted a survey in Kakamega district, Kenya. More than half of the respondents in Ethiopia's Amhara region were also unaware of insect pollinators other than honeybees, *A. mellifera* (Misganaw, 2017), as was the situation in West Bengal, India (Bhattacharyya *et al*., 2017) and Zimbabwe's Zvimba district (Tarakini *et al*., 2020). Generally, small bees are less likely to be identified, even by experienced persons (Smith *et al*., 2017), as evidenced by the fact that few Maasai in this study identified solitary bees, *Lasioglossum* of the subgenus *Ipomalictus*. Our findings suggest that the conservation of other pollinator groups in the area, aside from honey bees, is in jeopardy. For example, although dipterans are the second dominant pollinator group after hymenoptera and are abundant in the area, our respondents did not recognize the dipteran hoverfly, *Syriphidae*.

However, the knowledge expressed by this study respondents on pollinator species was better than that of other farming communities e.g. Elisante *et al*. (2019), where some respondents were not able to recognize even a honey bee, *Apis mellifera*. The knowledge in the study villages is likely linked to sensitization by Tanzania People and Wildlife (TPW), an NGO working in the area promoting beekeeping. Pollinator knowledge varies based on geographical location and efforts by authorities and other stakeholders to raise pollinator awareness in the community (Smith *et al*., 2017). Parents and grandparents formed an essential source of knowledge among the interviewed respondents in our study, which concur with Angassa and Oba (2008) where parents formed an important knowledge source among pastoral communities in Ethiopia.

4.2.2 Maasai Knowledge on Favourable Bee Forage Plants

Respondents for this study mentioned *C. africana, A. mellifera* and *A. anthelmintica* as plant species mostly favoured by bees. These species were available both within alalili enclosures and open grazing areas. These results are similar to those reported from Amhara region, Ethiopia, and Mubi region, Nigeria, where the majority of respondents listed plants visited by honeybees during the flowering season (Misganaw, 2017; Abdullahi *et al*., 2011). Pastoral communities usually have an in depth understanding of the grazing areas environment gathered by continuous herding and further augmented by historical land use knowledge (Angassa & Oba, 2008). Maasai are therefore quite knowledgeable on plant species as they use them for medicinal purposes for human beings and livestock (Nankaya *et al*., 2020). Woodhouse and McCabe (2018), reported that the Simanjiro plains are the richest rangelands in terms of biodiversity of both flora and fauna compared to other tropical rangelands, which is in agreement with our findings where most bee plants recorded in grazing and forest reserve by Abdullahi *et al*. (2011) are also found in Simanjiro. Hence, the high diversity of bee fodder plants in Simanjiro rangelands highlights the potential of beekeeping as a source of income generation in addition to livestock keeping. As reported by Greenleaf *et al*. (2007), forage resources for honey bees are an essential consideration for beekeepers and overuse or destruction of resources should be avoided (Havstad *et al*., 2007).

4.2.3 Perception on Pollinator Ecosystem Services in Rangeland

Most of the respondents in the study area were unaware of the important role played by pollinators in the health of rangelands including *alalili*. This resulted into little attention of Maasai pastoralists on pollinator species found in the Simanjiro rangelands. Pollinators are keystone species in most terrestrial ecosystems, including rangelands (Kearns & Inouye, 1998). For instance, solitary bees (*Halictidae*) have been reported to collect pollen from temperate grass species, which promotes a better seed set compared with only wind pollinated grasses (Harmon *et al*., 2011). The inability of Maasai to link rangeland health to pollinator presence is similar to findings reported by Misganaw (2017), who found that more than half of the respondents were not familiar with the role played by bees and other insects when they visit crops, indicating a lack of awareness of pollination. Additionally, pollinators have been reported to benefit crops grown by our respondents in the Simanjiro district such as sesame (Stein *et al*., 2018) and beans (Elisante *et al*., 2020). In a study conducted in Burkina Faso, West Africa, (Stein *et al*., 2017) reported a 62 % increase in output of pollinated sesame when compared with sesame plants that were not pollinated. These findings imply the need for disseminating pollination knowledge among pastoral communities so that they can acquire multiple benefits from pollination for livestock forage and increased crop production.

4.2.4 Pollinator Role in Livelihood Diversification

In times of climate change, livelihood diversification entails participation in more than one source of income to mitigate risks (Baird & Hartter, 2017; Mccabe *et al*., 2010). Many Maasai have diversified their income through integrating off-farm payment, agriculture and other small-scale economic activities into their traditional pastoralist livelihoods (Mccabe *et al*., 2010; Woodhouse & McCabe, 2018), which also agrees with our findings. Similar diversification of livelihoods by rural communities through beekeeping has also been reported by Jeil *et al*. (2020). According to Ali and Jabeen (2015), managing bees in rural communities can significantly improve livelihood security by boosting income access, a financial livelihood asset. Beekeeping further plays a vital role in improving biodiversity conservation, socio-economic development, food security and poverty reduction in many parts of the world and is an environmentally friendly economic activity for income addition (Austin *et al*., 2020; Abdullahi *et al*., 2011).

4.2.5 Gender Roles, Participation in Beekeeping and Associated Challenges

The involvement of more women as compared with men in beekeeping is mainly due to the support by TPW, albeit men were involved in some activities such as hive sitting, monitoring, honey harvesting, processing and finally marketing. These results resembled those of Qaiser *et al*. (2013)

in Pakistan where women engaged in beekeeping activity because they received training from development agencies that enhanced their skills in apicultural management. The findings from Simanjiro is however in contradiction to that of Jeil *et al*. (2020) from Ghana where males dominated all activities in beekeeping value chain except honey marketing. In the study area, majority of Maasai males saw beekeeping as a source of revenue for poor households with little or no animals, a finding that has also been documented by Lyver *et al*. (2014). This perspective of beekeeping is primarily limited to Maasai pastoralists, as beekeeping is a male dominated activity in most other rural areas (Austin *et al*., 2020; Chemurot, 2011; Nyunza *et al*., 2018). These findings highlight the need for more awareness creation on the benefits of beekeeping among Maasai men inorder to promote their participation as beekeeping can be practised alongside livestock keeping.

Regarding the challenges associated with beekeeping, this study revealed access to market and modern equipment as major challenges. According to Mushimba *et al*. (2001), successful beekeeping requires suitable climate, skills, technology including modern equipment and reliable market opportunities for bee products especially honey and beeswax.

4.2.6 Pollinators Decline and Conservation Strategies in Maasai Plains

The loss of both managed and wild pollinators is a primary concern in conservation around the world (Black *et al*., 2011; Potts *et al*., 2010). Many of our respondents were aware of pollinator decline and the underlying causes, which have also been addressed by other studies in agricultural and natural ecosystems (Potts *et al*., 2010; Marques *et al*., 2017; Misganaw, 2017; Tarakini *et al*., 2020). Simanjiro plains are currently faced with unprecedented land clearance where large portions of rangelands are cleared for small and large-scale cultivation (Msoffe *et al*., 2011). However most of the respondents in this study were not aware that this impacts pollinators, nor of pollinator conservation strategies to reverse the trend. This finding is comparable to that of Winfree (2010), who discovered that habitat fragmentation has a negative impact on bee abundance and species richness. As the majority of Maasai are currently agro-pastoralists, utilizing pollinator advantages such as pest control from *Coccinellidae* beetles (Mkenda *et al*., 2020) and pollination to increase crop yields will contribute to pollinator conservation as reported by Elisante *et al*. (2020) and Klein *et al*. (2007). With natural disasters such as climate change and drought excluded, there is a need to raise awareness on human disturbances that contribute to pollinator losses, particularly in pastoralist communities. This is because Maasai could not immediately establish the link between pollinators and rangeland wellbeing as demonstrated by the study results. According to Elwell (2012), moderate levels of cattle grazing had little effect on the quantity, richness, or variety of overall pollinator assemblages or functional groups. In general, if livestock grazing is done moderately, it can encourage herbaceous plant dominance, which could support a variety of insect pollinators in a sustainable manner.

4.2.7 Pollinator Abundance and Richness Across Management Categories

The study results showed that private enclosures had the highest pollinator abundance, confirming the hypothesis and indicating that traditional grazing management has an impact on pollinator abundance. These findings concur with those of Sjödin *et al*. (2008) who studied pollinator groups such as beetles, butterflies, flies and bees in Sweden. The findings of this study are critical for tropical Africa, since rangelands comprise much of the continent and little is known about the associated pollinator communities. In southeastern Arizona, Sichuan Tibet and Germany, pollinator responses to grazing management have been documented, both positive (Carvell *et al*., 2007; Vulliamy *et al*., 2006) and negative (Kruess & Tscharntke, 2002; Debano, 2006; Hatfield & LeBuhn, 2007; Xie *et al*., 2008). The findings from this study further suggest that inorder to promote pollinator abundance throughout the dry season in semi-arid rangelands, enclosures should be grazed moderately. This is especially true in eastern African rangelands, which are frequently overgrazed (Abdulatife, 2016). According to Angassa *et al*. (2010), removing cattle grazing for five years enhances herbaceous biomass, which may contribute to improved pollinator abundance and diversity in enclosures, even during the dry season. This is in contrast with the present study, in which enclosures were continuously grazed during successive dry seasons.

4.2.8 Grazing Management, Environmental Factors and Pollinators

This study results concerning seasonality are in contrast to Stein *et al*. (2018) in Burkina Faso, where more pollinators were found during the dry season compared with the wet season. In this study, livestock grazing might have contributed to low pollinator abundances during the dry season due to high grazing pressure, a fact that had not been mentioned by Stein *et al*. (2018). The findings also revealed that private enclosures had higher floral abundance and diversity, which could be attributed to the traditionally low grazing pressure in these enclosures due to the traditional limitation of livestock numbers and the prevention of tresspassing wild or domestic animals from other owners. Grazing intensity, according to Kimoto *et al*. (2012), may have a direct impact on vegetation structure, composition, soil compaction, and nutrient cycling. A study by Lázaro *et al*. (2016) also reported grazing to negatively affect plant species richness and diversity in Lesvos Island, Greece. A strong correlation between pollinator abundance and floral abundance exist since they use floral resources for food and nesting as revealed by Potts *et al*. (2003), Biesmeijer *et al*. (2006), Vulliamy *et al*. (2006), Kearns and Oliveras, (2009), Vulliamy *et al*. (2006) and Roel *et al*. (2016). The abundance and diversity of pollinator populations were further influenced by habitat and landscape factors such as floral abundance, plant diversity, patch size and amount of wood vegetation (Bates *et al*., 2011; Kearns & Oliveras, 2009). Our positive correlation between herbaceous vegetation cover and insect communities was similar to that of Debano (2006) who reported higher insect abundance in sites with high vegetation cover. Inorder to improve pollinator populations, range managers should consider maintaining both floral abundances and plant cover, rather than focusing solely on vegetation cover. Pollinator responses to floral abundances, on the other hand, can vary depending on pollinator groups, as only bee abundance increased significantly in response to floral abundances, while other pollinator groups did not (Sjödin *et al*., 2008).

4.2.9 Flower Visitation, Pollinator Networks and Grazing Management

The high level of generalization in private, communal enclosures and wet season grazing increases the robustness of pollinator networks as it also promotes connectance of networks (Oleques *et al*., 2019) and stability of networks in these sites (Dormann *et al*., 2009). Plant pollinator communities with high generalization may further be less vulnerable to disruption due to increase in network resilience and interaction redundancy (Aizen *et al*., 2002). In general, if a plant or pollinator species possess many interaction partners, the less likely that the loss of an interaction partner will result in secondary population extinctions (Elle *et al*., 2012). In addition, specialized plants and pollinators have long been thought to be more vulnerable to disturbances, such as habitat alteration or fragmentation, than more generalized species (Memmott *et al*., 2004). The higher number of links per species in enclosures reported by this study is similar to that of Lázaro *et al.* (2019) who reported a higher number of links and generalization in sites with moderate grazing in a study conducted in the Mediterranean phrygana shrubs. However, Lázaro *et al.* (2019) results relating to higher species diversity in moderate grazed areas is contrary to this study whereby all grazing categories contained higher species diversity. The results regarding high diversity of floral visitors in networks in moderate and high grazing are similar to that of Vulliamy *et al*. (2006) in northern Scotland. In general, the effects of grazing on flower visitors vary across ecosystem and therefore generalization is always inappropriate (Oleques *et al*., 2019). The results showing little variation in connectance across grazing management is in contradiction to that reported by Oleques *et al*. (2019) whereby connectance varied significantly with grazing intensities. The NODF values reported in this study coincides with the range observed from other studies in literature which is from 20 – 60 (Elwell, 2012), regardless of lower value in dry season grazing area. The domination of *A. mossambiensis* (*Asteraceae*) and *J. debile* (*Acanthaceae*) in floral visitation both for honey bees and other pollinators is attributed to their abundance in the ecosystem. Furthermore, *Aspilia* is a member of *Asteracea*e, an observation which agrees with findings from other studies in South

America whereby members of the family *Asteraceae* frequently receive large number of visitors because they usually offer good resources to pollinators (Oleques *et al*., 2019).

4.2.10 Physicochemical Properties of The Pollen for Bee Forage Plants

As revealed by study findings, pollen protein and fatty acids concentration varied significantly between species. These findings are similar to those of other researchers including Russo *et al*. (2019), Rowe *et al*. (2020) and Vaudo *et al*. (2020). In general, pollen serve as primary protein and lipids source for developing offspring in most bee species (Michener 2000; Vaudo *et al*., 2020). The pollen concentration range for the studied plants in Simanjiro (30.0% to 47.9%) is within the reported range (i.e. 2.5% to 61%) from various plant species elsewhere (Radev, 2018; Roulston & Cane, 2002; Roulston *et al*., 2000). Furthermore, the recorded protein percentage for *Solanum* is in line with that of Buchmann and Cane (1989) and Roulston *et al*. (2000) which ranged between 40 – 56 %.

The reported lack of correlation between the percentage of pollen concentration and honey bee visitation corresponds with that of Roulston *et al*. (2000) whereby zoophilous plant species were not statistically richer in pollen protein than anemophilous species, and therefore had no influence on visitation. Furthermore, the need for growing pollen tubes is also reported to play an important role in determining pollen protein content than aspect of rewarding pollinators (Roulston *et al*., 2000). These results are however in contradiction with that of Russo *et al*. (2019) who reported a significant correlation between bee visitation and protein content in thistle (*C. acanthoides*), however no correlation was observed with lipid contents similar to this study findings. The Findings regarding low honey bee visitation to *S. incunum* regardless of higher protein content further supports the finding regarding the slack of correlation between protein concentration and visitation. Generally, *Solanaceae* family uniformly contained protein rich pollens despite of flower variation within the family. On the contrary, members of the plant family *Asteraceae* such as *Aspilia* spp are generally thought to have poor quality pollen (Praz *et al*., 2008) and yet they received higher visitors probably due to their higher floral abundances. The low pollinator visitation to *Solanum* might be attributed to flower morphology and abundance. Somme *et al*. (2015) reported that although nutrition influences visitation rates for bees, considerations should also be made for floral density. According to Buchmann and Cane (1989), *Solanum* attracts fewer pollinators even though their pollen is abundant and nutritious, because it is hidden from the usual direct visual and contact chemosensory inspection that is used by bees and other pollen-collecting insects that harvest pollen by scrabbling. This study however did not measure other pollen qualities such as carbohydrates.

4.2.11 Effect of Grazing Management on Abundance, Richness and Diversity of Bees

The findings showing that bee abundance and taxa were twice as high in traditional enclosures compared with community wet and dry season grazing lands are comparable to those of Kearns and Olivera (2009) and Mayer (2007), who found that bee abundance varied depending on grazing regime, particularly for ground nesting bees, in Colorado grasslands and Namaqualand, South Africa respectively. These findings, however, contradict those of Shapira *et al*. (2020b), Kimoto *et al*. (2012), and Sjödin *et al*. (2008), who found no significant impact of grazing on wild and native bee abundance or species richness in Mediterranean rangelands, Israel; Zumwalt Prairie, USA; and temperate rangelands ecosystems in Sweden. Geographical factors including differences in habitat type, land uses, and management strategies such as the use of fire as a management component might have contributed to differences in results between the studies. The variation of species composition across our study sites might be due to the destruction of nesting sites through livestock trampling (Sjödin *et al*., 2008) as the largest proportion of our collected bees were ground-nesting solitary bees such as *Lasioglossum* of subgenus *Ipomalictus, Ctenomia, Transvalense* etc., compared with the flying and beehive-building social bees, *A. mellifera*.

The study findings are however in contradiction to that of Kimoto *et al*. (2012), who reported no significant difference on abundance of *Lasioglossum* genera with grazing intensity. Findings from this study indicate traditional enclosures are crucial for maintaining bee populations bee both wild and managed as they contained higher abundances and species richness, therefore have the potential for supporting pastoral livelihoods through pollination and beekeeping. This study however did not take into consideration the abundance of tree flowering which may have affected floral abundances throughout our study sites.

4.2.12 Soil Properties and Rangeland Management

The findings that private enclosure contained highest OC % as well as organic matter is in line with that of Mofidi *et al.* (2013), Yong-Zhong *et al.* (2005) and Lai and and Kumar (2020) who reported that areas excluded from excessive grazing contained higher organic matter. Organic matter is frequently higher in soils with good plant cover and aerial biomass, attributes that also applied to private enclosures in the study area. Generally, excessive grazing depletes rangeland ecosystems by removing biomass that consequently lower soil organic matter and nutrient content (Lai & Kumar, 2020; Steffens *et al.*, 2008). Because soil is the only source of nutrients for plant growth, this has a long-term negative impact on rangeland production and quality of forage (Moghaddam, 2007). Similarity in nitrogen level contents between enclosures and open rangelands is in contradiction to results reported by Mofidi *et al.* (2013) where enclosures contained higher nitrogen levels as soil nitrogen concentration is heavily influenced by vegetation cover. However, this is in contradiction to our findings probably due to ongoing management whereby enclosures in Maasai rangelands are continuous grazed over successive dry seasons with no fallow period. The pH results are also in contradiction with that of Yong-Zhong *et al.* (2005) who reported significantly higher pH with increasing grazing intensity because of the animal urination and excreta addition contrary to our study where pH did not vary significantly between grazing management categories. In this study, electrical conductivity (EC) results were similar to those of Yong-Zhong *et al.* (2005) who also reported no significant difference with grazing intensity. Overgrazing of rangeland has been shown in numerous studies to degrade the physical, chemical and biological properties of the soil, resulting in dramatic changes in vegetation and nutrient cycling (Chen & Cui, 2001; Lai & Kumar, 2020), as well as a permanent decline in land productivity and ecosystem degradation (Su *et al.*, 2004).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The results from this study show that apart from honey bees, the majority of Maasai pastoralists had limited understanding about other insect pollinators. The study concludes that, while there has been good progress in promoting beekeeping in the area, more has to be done to encourage information and knowledge exchange between experts and Maasai pastoralists about the benefits of other insect groups, particular aspect of ecosystem service of pollination. This might promote both gender participation in beekeeping and reduce current challenges to beekeeping in the area especially vandalism. As enclosures, especially private ones contained higher pollinator, floral abundances and stable pollination networks they might have the potential of promoting insect pollinator conservation in semi-arid rangelands. In addition, higher organic matter and Organic Carbon percentage might also promote vegetation growth and recovery in enclosures consequently promote pollinator communities. Communal and private enclosures also contained higher plant diversity and richness, some of which serve as bee forage. Therefore, beekeeping as an alternative livelihood might be practised alongside livestock keeping in enclosure areas. While the primary goal of implementing enclosures was to ensure vegetation recovery and nutrient conservation during the dry season, communities should be aware of the additional benefits of enclosures, such as pollinator conservation.

The study further concludes that most of the plant species available in Simanjiro rangelands have the potential of supporting beekeeping regardless of their nutrient contents especially fatty acids and protein. The plants preferred by bees such as *A. mossambiensis* and *J. debile* did not contain higher protein compared with less visited plants. Communities should be well informed on the protection of these preferred bee plants which have also proven to be resistant to grazing due to their abundance in study sites and insect visitation as revealed by pollinator networks.

5.2 Recommendations

Based on the study findings, the study recommends that pastoral communities should be well informed about broader pollinator benefits for all groups instead of honeybees only, in order to promote the conservation of all pollinator groups which might further improve ecosystem services. Radio programs may be useful tools for disseminating pollinator information, particularly in rural areas of developing countries such as Simanjiro district, where extension services are scarce.

The participation of Maasai pastoralists in pollinator conservation and monitoring in rangelands is critical for knowing present status and trends, as well as how grazing management and climate change affect pollinators in the area. This is especially crucial in times when most Maasai have incorporated agriculture in their cultural pastoralism livelihood. In addition, the study recommends the adoption of private enclosures by Maasai pastoralist as they have proven to help in conservation of both vegetation and insect pollinators. However, enclosure management should adopt fallow periods to promote quick recovery and improvement of both vegetation and soil properties unlike the current situation, where most of the soil properties were similar. In addition, local communities should be well informed and trained before the establishment of enclosures. The management of open rangelands (wet and dry season areas) should also take into consideration the pressure exerted on these open rangelands. Currently, the wet season grazing area faced lower grazing pressure and recovered better in terms of vegetation cover compared with dry season grazing lands, and therefore we recommend that dry season rangeland areas should be larger in size and number compared with wet season areas as during the wet season, forage is available in most of the pasture and village lands. Furthermore, the study recommends the conservation of all bee forage plants both in enclosures and open rangelands for the sustainability of pollinator populations and beekeeping livelihoods. In addition, the conservation of pollinator forage plants may be promoted through seed collection and multiplication which is vital for the recovery and maintenance of rangeland vegetation especially in dry season grazing areas. This study also recommends further studies to cover multiple grazing areas over a long period of time to study pollinators and their preferred plants using molecular techniques such as DNA barcoding.

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APPENDICES

Appendix 1: Questions asked during interviews

General Information

Name of Enumerator: …………………………………. Date………… ….... Questionnaire Number……………..

Ward: ………………. Village…………………. Coordinates: …………..Mobile no: …………………..

SECTION A: Respondent's Personal Information

1. Name: ____________________ Sex ( ) Male ( ) Female Age: ___________ (years)
2. Household size _____________________
3. Marital status ( ) Single ( ) Married ( ) Divorced ( ) Widowed ( ) Separated
4. Education level ( ) No formal education ( ) Primary education ( ) Secondary education ( ) Post – secondary education ( ) others (specify) _______________
5. Position in the household ( ) Head ( ) Spouse ( ) Child ( ) Representative ( ) other __
6. Occupation ( ) Pastoralist ( ) Farmer ( ) Agro - pastoralist ( ) Trader ( ) Employee ( ) other ________________
7. Time spent in the village ( ) < 5 yrs ( ) 5 – 10 ( ) 11 – 15 ( ) 16 – 20 ( ) > 20

SECTION B: Household Information

8. Does your household own livestock? ( ) Yes ( ) No

9. If yes, what livestock types do you have? (Please tick)

1. Cattle	2. Sheep	3. Goats	4. Poultry	5. Donkeys	6. Others (Specify)

10. What are the main sources of household income? (Please tick which are applicable)

	Source	(Tick)
i.	Formal employment	
ii.	Sale of animal produce	
iii.	Sale of livestock	
iv.	Sale of agricultural produce	
v.	Trade	
vi.	Selling of bee products	
vii.	Other (specify)	

SECTION C: Local Community Knowledge on Insect Pollinators and their role in livelihoods

A. Pollinators General Questions

11. (a) Do you recognize the following insects? ( ) Yes ( ) No

(Provide pictures and specimens)

(b) Tick insects correctly recognized by respondents

Honeybee	Solitary bee	Butterflies	Hoverflies	Beetles	Wasps

12. How did you know about insects shown in the picture? ( ) Media (radio, television and newspaper) ( ) Extension Officers ( ) Friends and relatives ( ) others _______________

13. Among the insects in the picture which ones are available in your area?

( ) Honeybees ( ) Solitary bees ( ) Butterfly ( ) Beetles ( ) Hoverflies ( ) All

14. Among insect pollinators which do you think are most important?

( ) Bees ( ) Wasps ( ) Butterflies ( ) Beetles ( ) Hoverflies ( ) I don't know

15. What benefits of pollinators are you are aware of? ( ) Food production ( ) Environmental ( ) Income ( ) Health ( ) others ________________

16. (a) Are you aware of any ecosystem service offered by insect pollinators?

( ) Yes ( ) No ( ) I don't know

(b) If yes, mention the service (s) ____

____

17. Do you think pollinators are important for rangelands wellbeing?

( ) Yes ( ) No ( ) I don't know

If yes how

____

18. What are the importance of Alalili enclosures to pollinators?

( ) Food resources ( ) Improve abundance and diversity ( ) Habitats ( ) others

____

19. Mention plants which are mostly preferred by pollinators in your area?

____

20. Have you observed insect pollinators visiting your crops/plants?

( ) Yes ( ) No ( ) Not sure

21. If yes, what type of pollinators mostly visit your crops/plants?

( ) Bees ( ) wasps ( ) Butterflies ( ) Beetles ( ) Flies ( ) I don't know ( ) Not sure

22. What is the trend of pollinator population in this area?

( ) Increasing ( ) Decreasing ( ) Constant ( ) I don't know

23. If the trend is increasing, what might be the reason?

( ) Conservation education ( ) Food availability ( ) Habitat protection ( ) other (s)

____

24. If the trend is decreasing what are the reasons?

( ) Climate change ( ) Agriculture ( ) Pesticides ( ) Habitat destruction ( ) Invasive species

( ) others ________________________

25. Do you think if pollinator populations were in decline, will this have any effect in your livelihood?

( ) Yes ( ) No ( ) I don't know

26. If yes, what are the effects? ____

( ) Loss of income ( ) Reduced quality of grazing lands ( ) Reduced crop yield ( ) Cultural effects ( ) others ______________

27. (a) Is there any institution promoting pollinator conservation in the area?

( ) Yes ( ) No

(b) If yes, mention the organization (s)

____

28. (a) Do you know any strategy to conserve pollinators in your areas? ( ) Yes ( ) No

(b) If yes, please mention them ____

____

____

B. Bees and Beekeeping questions

29. (a) Have you heard about bee keeping? ( ) Yes ( ) No

(b) If yes, from whom? ( ) Media ( ) Experts ( ) Friends and relatives ( ) others _____

30. How many types of bees do you know? ( ) Honey bee ( ) Solitary bee ( ) Stingless bee ( ) others _______

31. Mention plants that are preferred by bees, rank inorder of importance

32. Mention products that can be obtained from bees (i) _________________ (ii) ______________

(iii) _______________________ (iv) ____________________ (v) _______________________

33. How often do you see a bee per day? ( ) Very often ( ) Few times ( ) rarely ( ) others

34. Which time of the day bees are more active? ( ) Morning ( ) Afternoon ( ) Evening ( ) I don't know

35. What is the general trend of bee population in the area? ( ) Declining ( ) Increasing ( ) Constant ( ) Not sure

36. If the population is declining what is the reason (s): ( ) Climate change ( ) Grazing ( ) Habitat fragmentation ( ) Illegal cutting of trees ( ) Pesticides ( ) others _______________________

37. (a) Do you practice beekeeping? ( ) Yes ( ) No

(b) If yes, for how many years? ( ) >5 ( ) 5 - 10 ( ) 11 – 15 ( ) 16 – 20 ( ) > 20

(c) If no, why ____

38. (a) Who are main beekeepers in this area? ( ) Males ( ) Females ( ) Both ( ) Others_____________

(b) Why? ____

39. Where do you site your beehives? ( ) Woodlands ( ) Grazing lands ( ) Cultivation areas

( ) Wetlands ( ) others ____________________

40. Which type of beehive do you use ( ) Top bar hives ( ) Commercial hives ( ) Bark hives

( ) Log hives ( ) others _________________________

41. Which tree species do you prefer to site your beehives?

____

42. Which other criteria do you consider before siting beehives? ( ) Closeness to water ( ) Proximity to the village ( ) Close to national park ( ) Security ( ) Accessibility ( ) others _________

43. How much honey do you harvest per season?

( ) > 5 litres ( ) 5 - 20 litres ( ) 21 – 50 litres ( ) < 50 litres

44. What are the major uses of honey in this area? ( ) Food ( ) medicine ( ) cultural ( ) others __________

____

45. What is the price of honey per litre / kg? ( ) 3000 TSH ( ) 5000 TSH ( ) 10000 TSH ( ) > 10,000

46. What do you do with combs after honey extraction?

( ) Thrown away ( ) Making of beeswax ( ) Feeding livestock ( ) others ________________

47. Estimate your income from selling of bee products ____

48. What are challenges to beekeeping in this area?

( ) Lack of modern equipment ( ) Poor access to market ( ) Climate change ( ) Inadequate extension services ( ) others ___________________

Appendix 2: Common flowering plants favoured by pollinators from field surveys and literature survey in Simanjiro rangelands in May 2019

S/N	Scientific name	Local Name	Family	Source of information
1	*Acacia brevispica*	Olgigiri	Fabaceae	x, *
2	*Acacia mellifera*	Eiti	Fabaceae	x, *, a
3	*Acacia nilotica*	Olkiroriti	Fabaceae	*
4	*Acacia robusta*	Oljorahi	Fabaceae	*
5	*Acacia senegal*	Endepesi	Fabaceae	*, a
6	*Acacia seyal*	Oltepesi	Fabaceae	*, a
7	*Acacia tortilis*	Olgorete	Fabaceae	x, *, a, b
8	*Adansonia digitata*	Mbuyu	Malvaceae	*, a
9	*Albizia anthelmintica*	Olmokotani	Leguminosae	*
10	*Aspilia mossambicensis*	Olyabase	Asteraceae	x, *
11	*Bidens pilosa*	-	Asteraceae	x, b
12	*Commiphora africana*	Osilalei	Burseraceae	x, *, b
13	*Cyathula orthocantha*	Olorungoti	Amaranthaceae	x
14	*Delonix elata*	Enderekesi	Fabaceae	*
15	*Euphorbia candelabrum*	Orpopongi	Euphorbiaceae	*
16	*Grewia bicolor*	Esiteti	Malvaceae	*
17	*Gutenbergia cordifolia*	Mrengere zambarau	Asteraceae	x
18	*Ipomoea sp 1*	Ndelemeti	Convolvulaceae	x, *, a
19	*Ipomoea sp 2*	Olekitenyi	Convolvulaceae	*, a
20	*Justicia debile*	Olbibi	Acanthaceae	x
21	*Leucas glabrata*	-	Lamiaceae	x
22	*Leonotis nepetifolia*	Embibiai	Lamiaceae	x
23	*Ocimum gratissum*	Olemurran	Lamiaceae	x, b
24	*Solanum incunum*	Endulelei	Solanaceae	x, *, b

x = Field observation, * = interviews (n = 181), a = Abdullahi *et al*. 2011, b = Elisante *et al*. 2019

Appendix 3: Pollinator families and species abundance collected using sweep nets and pan traps from the four grazing management categories of private enclosure, communal enclosure, wet season grazing and dry season grazing in Loiborsiret Simanjiro from May to October 2019

Taxa/ Group	Family	Number	Proportion (%)
Bees	*Apidae*	259	13.10
	Halictidae	207	10.47
	Megachilidae	56	2.83
Beetles	*Bethylidae*	6	0.30
	Carabidae	7	0.35
	Chrysididae	10	0.51
	Coccinelidae	127	6.42
	Meloidae	279	14.11
	Melyridae	76	3.84
	Tenebrionidae	149	7.54
	Tabanidae	3	0.15
	Tachinidae	1	0.05
	Chrysomelidae	18	0.91
Wasps	*Vespidae*	60	3.03
	Pompilidae	48	2.43
	Sphecidae	87	4.40
	Scoliidae	6	0.30
	Chrysididae	10	0.51
	Bethylidae	6	0.30
	Eumenidae	49	2.48
	Mutillidae	5	0.25
	Crabronidae	1	0.05
	Ichnemonidae	1	0.05
Butterflies	*Pieridae*	32	1.62
	Lymantridae	17	0.86
	Erebidae	3	0.15
Bugs	*Aphididae*	3	0.15
	Cicadidae	1	0.05
	Delphacidae	2	0.10
	Diopsidae	1	0.05
	Notonectidae	6	0.30
	Tephritidae	12	0.61
	Gerridae	1	0.05
Flies	*Anthomyiidae*	17	0.86
	Chalcididae	1	0.05
	Muscidae	33	1.67
	Philoliche	23	1.16
	Syriphidae	1	0.05
	Dolichopodidae	1	0.05
	Calliphoridae	14	0.71
	Bombylidae	4	0.20
	Asilidae	49	2.48
	Stratiomyiidae	3	0.15
Ants	*Formicidae*	294	14.87

Appendix 4: Insect species diversity computed using Shannon-weaner diversity index in the four grazing management categories of private enclosure, communal enclosure, wet and dry season grazing management collected using sweep nets and pan traps from May to October 2019 in Loiborsiret, Simanjiro

Site	Pollinator groups						
	Bees	**Flies**	**Wasps**	**Bugs**	**Butterflies**	**Beetles**	**Ant**
Communal enclosure	2.42	0.79	1.61	0.64	1.10	1.8	0.00
Private enclosure	2.71	1.55	1.89	1.71	1.17	1.6	0.10
Dry season grazing	2.56	1.08	1.56	0.00	0.00	1.31	0.00
Wet season grazing	2.28	1.85	1.71	0.64	1.10	1.09	0.00
Overall diversity	**3.04**	**2.39**	**1.97**	**1.94**	**1.92**	**1.86**	**0.047**

Appendix 5: Bee family abundance collected using sweep nets and pan traps from the four grazing management categories of private enclosure, communal enclosure, wet season grazing and dry season grazing in Loiborsiret Simanjiro from May to October 2019 covering wet and dry season

Grazing category	Family	Total individuals	Proportion
Private enclosure	*Apidae*	107	20.5
Communal enclosure	*Apidae*	88	16.9
Wet season grazing	*Apidae*	37	7.1
Dry season grazing	*Apidae*	26	5.0
Private enclosure	*Halictidae*	75	14.4
Communal enclosure	*Halictidae*	82	15.7
Wet season grazing	*Halictidae*	36	6.9
Dry season grazing	*Halictidae*	15	2.9
Private enclosure	*Megachilidae*	31	5.9
Communal enclosure	*Megachilidae*	15	2.9
Wet season grazing	*Megachilidae*	6	1.1
Dry season grazing	*Megachilidae*	4	0.8
TOTAL		**522**	**100.0**

RESEARCH OUTPUTS

(i) Publications

Mpondo, F. T., Ndakidemi, P. A., & Treydte, A. C. (2021). Balancing Bees and Livestock: Pastoralist Knowledge, Perceptions and Implications for Pollinator Conservation in Rangelands, Northern Tanzania. *Tropical Conservation Science*, 14, 19400829211028127.

Mpondo, F. T., Ndakidemi, P. A., Pauly, A., & Treydte, A. C. (2021). Traditional rangeland management can conserve insect pollinators in a semi-arid rangeland, northern Tanzania. *Acta Oecologica*, 113, 103790.

(ii) Poster Presentantion