

EFFECT OF *IPOMOEA HILDEBRANDTII* AND *I. KITUIENSIS* ON
LOSS OF NATIVE HERBAGES OF MAASAI STEPPE
RANGELANDS IN SIMANJIRO DISTRICT

BY

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THE REQUIREMENTS FOR THE DEGREE OF MASTER OF
SCIENCE IN BIODIVERSITY CONSERVATION

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AND

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the University of Dodoma dissertation entitled: *Effect of Ipomoea hildebrandtii and I. kituiensis on loss of native herbages of Maasai steppe rangelands in Simanjiro district* in partial fulfilment of the requirements for the degree of Master of Science in Biodiversity Conservation of the University of Dodoma.

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ABSTRACT

Sustainability of many rangelands including Simanjiro Maasai steppe rangelands is limited in part by invasive plant species. A study was conducted among two selected village rangelands (Terrat and Sukuro) of the Simanjiro district aimed to (1) determine the effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage species composition, richness, and basal cover; and (2) determine the effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage biomass productivity. Other objectives were to (3) assess the distribution of *Ipomoea hildebrandtii* and *I. kituiensis* across grassland and woodland habitats, and (4) evaluate the available mitigation measures among the Maasai pastoralists on the effects of *Ipomoea hildebrandtii* and *I. kituiensis* on their rangelands. A total of 10 plots of 70 m² each with 9 quadrats of 1 m² each in the invaded and non-invaded grazing-lands coupled with point sampling technique. Purposeful sampling involved 10 key informants' interviewees; 24 participants for focus group discussions. Simple random sampling involved 30 hamlets representatives for questionnaire surveys. Data on herbage species composition, richness, basal cover, biomass productivity; distribution of invasive *Ipomoea* spp; and mitigation measures for effects of invasive *Ipomoea* spp. were analysed using STATA, Microsoft Excel and SPSS, respectively. Non-invaded grazing-lands had a higher basal cover (54.71%±1.95% for grasses, 45.29%±1.95% for forb) than invaded grazing-lands (29.38%±1.34% for grasses, 24.70%±1.20% for forb), ($P<0.05$). Herbage species composition between invaded and non-invaded grazing-lands doesn't vary ($P>0.05$). Non-invaded grazing-lands had higher biomass productivity (0.289±0.03 t DM/ha) than invaded grazing-lands (0.202±0.02 t DM/ha), ($P<0.05$). Distribution of invasive *Ipomoea* spp. was higher in woodland (70%), wood grassland (80%), and grass woodland habitats (90%).

Mechanical uprooting (100%) was noted as preferable mitigation measures for invasive *Ipomoea* spp. It could be concluded that the presence of *Ipomoea hildebrandtii* and *I. kituiensis* lowers herbage productivity. Thus, it is recommended that Maasai communities should establish a committee for rangelands management including mitigations of invasive plants.

Keywords: Effect of invasive plants, *Ipomoea* spp., native herbage loss, Maasai steppe rangelands, and Simanjiro district.

TABLE OF CONTENTS

DECLARATION AND COPYRIGHT	ii
CERTIFICATION	ii
ACKNOWLEDGEMENTS	iii
DEDICATION	vi
ABSTRACT	vii
TABLE OF CONTENTS	viii
LIST OF TABLES	xiii
LIST OF FIGURES	xiv
LIST OF PLATES	xv
LIST OF APPENDIXES	xvi
LIST OF ABBREVIATIONS AND ACRONYMS	xvii
CHAPTER ONE	1
Introduction	1
1.1 Background of the study	1
1.2 Statement of the research problem	3
1.3 Research objectives	5
1.3.1 General research objective	5
1.3.2 Specific research objectives	5
1.4 Research hypotheses	5
1.5 Significance of the research	6
1.6 Limitations of the study	7
1.7 Scope of the study	7
CHAPTER TWO	8
Literature review	8
2.1 Theoretical review	8
2.1.1 Definition of key terms and concepts	8
2.1.2 Theories underlying the study	11
2.2 Empirical review	14
2.2.1 Overview on invasive plant species	14

2.2.2 Potential of Maasai steppe rangelands on enhanced livestock and wildlife management.....	15
2.2.3 Wildlife population and migratory pattern in Simanjiro rangeland plains	16
2.2.4 Land use management of Simanjiro district	17
2.2.5 Integrated livestock-wildlife management approaches	18
2.2.6 Simanjiro Conservation Easement scheme	19
2.2.7 Factors affecting sustainable integrated livestock-wildlife approaches.....	22
2.2.8 Dispersal mechanisms of invasive plant species.....	24
2.2.9 Factors influencing dispersal of invasive plants species.....	24
2.2.10 Habitat distribution of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i>	25
2.2.11 Effect of invasive plant species on herbage species composition, species richness and basal cover	28
2.2.12 Effect of invasive plant species on herbage biomass productivity	31
2.2.13 Mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> in Maasai steppe rangelands	32
2.2.14 Effect of invasive plant species on soil fertility	34
2.3 Research gap.....	34
2.4 Conceptual framework	35
2.4.1 Independent variables.....	35
2.4.2 Intermediate variables	36
2.4.3 Dependent variables	37
CHAPTER THREE	39
Research methodology	39
3.1 Description of the study area.....	39
3.1.1 Study area.....	39
3.1.2 Location.....	39
3.1.3 Edaphic characteristics.....	40
3.1.4 Climate	42
3.1.5 Vegetation	42
3.1.6 Demographic characteristics	42
3.1.7 Main socio-economic activities.....	43
3.2 Research design and study settings	43

3.2.1 Experimental design.....	43
3.2.2 Non-experimental design	44
3.3 Population, sample and sampling procedure.....	44
3.3.1 Study population	44
3.3.2 Sampling techniques	44
3.3.3 Sampling design.....	47
3.3.4 Sampling frame	49
3.3.5 Sampling unit	51
3.3.6 Sampling intensity and size.....	51
3.4 Data collection techniques.....	52
3.4.1 Types of data	52
3.4.2 Data collection methods.....	52
3.4.3 Data collection tools.....	52
3.4.4 Field assessment.....	53
3.5 Data analysis techniques	57
3.5.1 Herbage species composition, species richness and basal cover	57
3.5.2 Herbage biomass productivity	58
3.5.3 Habitat distribution pattern of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i>	59
3.5.4 Mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i>	59
3.6 Validity and reliability of the study.....	59
3.6.1 Validity.....	59
3.6.2 Reliability.....	60
CHAPTER FOUR.....	62
Results	62
4.1 Effect of invasive <i>Ipomoea</i> species on herbage species composition, species richness and basal cover	62
4.1.1 Effect of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> on herbage species composition.....	62
4.1.2 Effect of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> on herbage species richness	66
4.1.3 Effect of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> on herbage basal cover.....	66
4.2 Effect of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> on herbage biomass productivity.	69

4.3	Habitat distribution of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i>	71
4.4	Available mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> in Maasai steppe rangelands	73
4.4.1	Dispersal mechanism and spread of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> invasion in the rangelands	73
4.4.2	Mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> in the rangelands	73
4.4.3	Effectiveness of mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I.</i> <i>kituiensis</i> in the rangelands	76
4.4.4	Proposed alternative mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I.</i> <i>kituiensis</i> in the rangelands	76
CHAPTER FIVE.....		78
	Discussions.....	78
5.1	Effect of invasive <i>Ipomoea</i> species on herbage species composition, species richness and basal cover	78
5.1.1	Effect of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> on herbage species composition.....	78
5.1.2	Effect of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> on herbage species richness	81
5.1.3	Effect of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> on herbage basal cover.....	82
5.2	Effect of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> on herbage biomass productivity.....	84
5.3	Habitat distribution of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i>	86
5.4	Available mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> in Maasai steppe rangelands	87
5.4.1	Dispersal mechanism and spread of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> invasion in the rangelands	88
5.4.2	Mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> in the rangelands	89
5.4.3	Effectiveness of mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I.</i> <i>kituiensis</i> in the rangelands	90
5.4.4	Proposed alternative mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I.</i> <i>kituiensis</i> in the rangelands	90

CHAPTER SIX	92
Conclusion and Recommendations	92
6.1 Conclusion	92
6.2 Recommendations.....	94
6.2.1 Recommendations for action.....	94
6.2.2 Recommendation for further research.....	95
REFERENCES	96
APPENDIXES	101

LIST OF TABLES

Table 1:	Effect of alien <i>Ipomoea</i> species in Eastern Africa region.....	27
Table 2:	Maasai communities' participants for the socio-economic survey.....	50
Table 3:	Grass species composition (%) between invaded and non-invaded grazing lands.....	63
Table 4:	Forb species composition (%) between invaded and non-invaded grazing lands.....	65
Table 5:	Herbage type with respect to the number of species between invaded and non-invaded grazing lands.....	68
Table 6:	Herbage basal cover between invaded and non-invaded grazing lands.....	68
Table 7:	Range – biomass productivity with respect to the village and grazing lands.....	70
Table 8:	Herbage biomass productivity between invaded and non-invaded grazing lands.....	70
Table 9:	Habitat distribution of <i>Ipomoea hildebrandtii</i> , and <i>I. kituiensis</i>	72
Table 10:	Dispersal mechanism and spread of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> invasion in the rangelands.....	75
Table 11:	Mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> in the rangelands.....	75
Table 12:	Effectiveness of mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> in the rangelands.....	77
Table 13:	Proposed alternative mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> in the rangelands.....	77

LIST OF FIGURES

Figure 1: Location of Simanjiro Conservation Easement Area (SCEA) and the associated integrated livestock and wildlife management.....	21
Figure 2: Conceptual Framework.....	38
Figure 3: Map of Simanjiro plains showing the two selected villages of the Simanjiro district.....	41
Figure 4: An experimental plot layout on data collection for herbage species composition, species richness, basal cover, and biomass productivity. ...	49

LIST OF PLATES

- Plate 1: Showing (a) setting of GPS; (b) demarcation of the plot; (c) recording of herbage species composition, species richness and basal cover and biomass productivity; (d) identifications of herbage species in the herbarium room. 54
- Plate 2: Showing (a) measurement of herbage height; (b) and (c) recording of herbage species composition, species richness and basal cover and biomass productivity; (d) measurement of sample fresh weight; (e) drying of sample in the oven; (f) measurement of sample dry weight. 56
- Plate 3: Showing (a) focus group discussions at Sukuro village; (b) focus group discussions at Terrat village. 57
- Plate 4: Showing spread of *Ipomoea kituiensis* across a tree. 67
- Plate 5: Showing (a) observations of herbage basal cover and biomass productivity in non-invaded grazing lands; (b) spread of *Ipomoea hildebrandtii* and *I. kituiensis*. 67
- Plate 6: Showing (a) spread of *Ipomoea hildebrandtii* and *I. kituiensis*; (b) spread of unpalatable perennial herb species. 71

LIST OF APPENDICES

Appendix 1	Sampling sheet.....	101
Appendix 2	Herbage species composition, species richness, and basal cover sampling	103
Appendix 3	Herbage biomass productivity sampling	104
Appendix 4	Sampling for habitat distribution of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> across grassland and woodland habitats	105
Appendix 5	Focus group discussion.....	106
Appendix 6	Key informants interviews	109
Appendix 7	Questionnaire survey	112

LIST OF ABBREVIATIONS AND ACRONYMS

FGDs	Focus Group Discussions.
GIS	Geographical Information System.
GPS	Global Positioning System.
IED	Informal Experimental Design.
IUCN	International Union for Conservation of Nature.
KIIs	Key Informant Interviews.
km ²	Kilometre squared.
LGAs	Local Government Authorities.
LMNP	Lake Manyara National Park.
MLDF	Ministry of Livestock and Fisheries Development.
MNRT	Ministry of Natural Resources and Tourism.
NBS	National Bureau of Statistics.
NCAA	Ngorongoro Conservation Area Authority.
NGOs	Non-Governmental Organizations.
PES	Payments for Ecosystem Services.
PRA	Participatory Rapid Appraisal.
SCE	Simanjiro Conservation Easement.
SCEA	Simanjiro Conservation Easement Area.
SPSS	Statistical Package for Social Sciences.
STATA	Statistics and Data.
t DM/ha	Tone Dry Matter per Hectare.
TALIRI	Tanzania Livestock Research Institute.
TANAPA	Tanzania National Parks.
TAWIRI	Tanzania Wildlife Research Institute.

TNC	Tanzania National Census.
TNP	Tarangire National Park.
WMAs	Wildlife Management Areas.

CHAPTER ONE

Introduction

1.1 Background of the study

Sustainability of many rangelands including Maasai steppe rangelands of northern Tanzania and Simanjiro district, in particular, is limited in part by invasive plant species. Invasive plant species refers to plant species whereby grow and spread in ways that do modify natural native ecosystems functionally and structurally, eventually disrupts human wellbeing (McNeely, 2001; Radosevich *et al.*, 2007).

Maasai steppe ecosystem (i.e. Tarangire), which covers about 35,000 km² is a potential area to both Maasai pastoralists and wild ungulates whose interactions should be managed in a sustainable way. Part of the ecosystem outside the park represents important wildlife recruitment sites, such as the rangelands bordering Tarangire National Park (Kahurananga and Silkiluwasha, 1997).

However, herbage biomass productivity and nutritive value of Maasai steppe rangelands around Tarangire ecosystem are threatened by invasive plant species including *Parthenium hysterophorus*, *Ipomoea* spp. such as *I. hildebrandtii* and *I. kituiensis*, as well as other unidentified forb species.

Threats to declining herbage productivity in terms of biomass and quality due to invasive plant species are similarly noted elsewhere (Bosco *et al.*, 2015). For instance, invasive plant species such as *Ipomoea hildebrandtii* and *I. kituiensis* have been associated with reduced biomass productivity of native grass ranging from 28% - 47% in Kenya (Mworia *et al.*, 2008). Also, invasive *Ipomoea* spp. are reported to

lower herbage species composition, number and richness, Sadek (2015); and herbage basal cover (Mworia *et al.*, 2008).

Declining both rangeland herbage biomass productivity and quality affects negatively globally and East Africa in particular, the livelihoods of many communities including Maasai pastoralists of northern Tanzania and Simanjiro plains in particular (Mworia, 2011; Mworia *et al.*, 2008). This is due to the declining of the associated wildlife and livestock productivity (Bosco *et al.*, 2015).

Herbage species with no browsing value and being poisonous may hinder productivity of foraging herbage species including *Cynodon* spp., *Dichanthium radicans*, *Digitaria* spp., and *Eragrostis* spp., native to Simanjiro plains due to grazing pressure (Kahurananga, 1979). Other native herbage species whose both biomass productivity and quality could be depressed by plant species with no browsing value and being poisonous include *Eustachys paspaloides*, *Harpachne schimperi*, *Microchloa kimthii*, *Panicum coloratum*, *Pennisetum mezianum*, *Sporobolus festivus* and *Themeda triandra*. These diverse native herbage species are under threat due to invasive plant species exacerbated by human activities, including land clearing and associated crop farming due to rangelands fragmentation, overgrazing, human settlements in Maasai steppe rangelands (Foxcroft *et al.*, 2006).

Invasive plant species represent a potential next threat to global biodiversity, and many African conservation areas in particular including Serengeti, Ngorongoro, Lake Manyara and Tarangire ecosystems as well as the Simanjiro Conservation Easement rangelands.

Negative effects of invasive plant species on the rangelands include replacement of ecological systems, alteration of edaphic characteristics that in part have been associated with extinctions of native superior increaser herbage species, and even livestock loss during extreme conditions (Foxcroft *et al.*, 2006).

The current study aimed to determine herbaceous loss due to *Ipomoea hildebrandtii* and *I. kituiensis*; as well as mitigations of the distributed invasive *Ipomoea* spp. in the Maasai steppe rangelands of Simanjiro district.

1.2 Statement of the research problem

Sustainable productivity of livestock and wild ungulates in the Maasai steppe ecosystem in northern Tanzania and Simanjiro plains is threatened by rangelands deterioration due to “increaser” herbage species including invasive plant species such as *Ipomoea hildebrandtii* and *I. kituiensis* at expense of declining proportion of highly nutritious herbages (“*decreasers*”). Deterioration of rangeland quality in part by *Ipomoea hildebrandtii* and *I. kituiensis* results to reduced herbage productivity of highly nutritious herbaceous layer due to suppression (Mworia *et al.*, 2008); increased food poisoning (Bosco *et al.*, 2015); as well as other negative interactions (Radosevich *et al.*, 2007). The extent of the problem is being increased by the high spreading nature of most invasive species (Bosco *et al.*, 2015).

According to Mworia *et al.* (2008), Eastern Africa rangelands for instance in Kenya, are depressed by increaser herbages such as invasive *Ipomoea* spp. due to their aggressive competition against grasses. *Ipomoea kituiensis* and *I. hildebrandtii* depress grass growth and thus suppress biomass productivity by 28 % in the

presence of grazing (Mworia *et al.*, 2008); while *Ipomoea carnea*, for instance, is toxic to livestock (Bosco *et al.*, 2015). Also, invasive *Ipomoea* spp. are reported to lower herbage species composition, number and richness, Sadek (2015); and herbage basal cover (Mworia *et al.*, 2008).

Data on invasive herbages in Tanzania is scanty. For example, the more reported invasive herbage species is *Parthenium hysterophorus* which induces grass loss in some rangelands of northern Tanzania as of 2013 (Rija *et al.*, 2013). Rangeland invasion by *P. hysterophorus* which is believed to originate from Ethiopia (Rija *et al.*, 2013). *P. hysterophorus* is a threat to rangelands of northern Tanzania including Arusha and Manyara regions (Kija *et al.*, 2013).

Despite these studies, in Tanzania, and the Simanjiro plains there is limited information on the effect of *Ipomoea hildebrandtii* and *I. kituiensis* on species composition, species richness, basal cover, and biomass productivity of herbages. Information on habitat distribution of *Ipomoea hildebrandtii* and *I. kituiensis* of Maasai steppe rangelands is scarce. Details on available mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands are also scarce. Less has been documented with respect to both spreading pattern and effect of *Ipomoea hildebrandtii* and *I. kituiensis* on rangeland herbage productivity and quality among the Maasai steppe rangelands adjacent Tarangire National Park specifically where wild ungulates migrate and coexist with livestock grazers.

A study was carried out to evaluate suppression effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbaceous loss in Maasai steppe rangelands of Simanjiro district.

1.3 Research objectives

1.3.1 General research objective

The current study aimed at determining the herbaceous loss due to *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands of Simanjiro district.

1.3.2 Specific research objectives

- i. To determine effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage species composition, species richness and basal cover between invaded and non-invaded Maasai steppe grazing lands;
- ii. To determine effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage biomass productivity between invaded and non-invaded Maasai steppe grazing lands;
- iii. To assess the distribution of *Ipomoea hildebrandtii* and *I. kituiensis* across grassland and woodland habitats of Maasai steppe rangelands;
- iv. To evaluate the available mitigation measures among the Maasai pastoralists on the effects of *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands of Simanjiro district.

1.4 Research hypotheses

A study was carried out based on the following research hypotheses:

- i. *Ipomoea hildebrandtii* and *I. kituiensis* suppress native herbage species in terms of species composition, richness, and basal cover;
- ii. *Ipomoea hildebrandtii* and *I. kituiensis* lower herbage biomass productivity of native herbage species;

- iii. Distribution of *Ipomoea hildebrandtii* and *I. kituiensis* vary across grassland and woodland habitats of Maasai rangelands;
- iv. Mechanical uprooting is a preferable mitigation measure for *Ipomoea hildebrandtii* and *I. kituiensis* in the Maasai rangelands.

1.5 Significance of the research

Invasive plant species impact negatively both wild ungulates and livestock productivity by decreasing yield and quality of rangeland forages, thus hindering rangelands grazing quality, poisoning nearby plants and their predators such as ruminant livestock. Invasive plant species in rangelands do lower herbage nutritive values. Invasive plant species also affect negatively soil by degrading soil and water resources and thus lead to local extinctions of native plant species (DiTomaso, 2000).

Findings from the current study enhance rangelands management for invasive plant species. Results presented in the current study are of high relevance among stakeholders and across actors such as Ministry of Livestock and Fisheries Development (MLDF), Tanzania Livestock Research Institute (TALIRI), neighbouring Local Government Authorities (Babati district Council, Kiteto district Council, Monduli district Council), and entire pastoral communities.

Presented results are also relevant to the Ministry of Natural Resources and Tourism (MNRT), Tanzania National Parks (TANAPA) such as Tarangire National Park, Lake Manyara National Park, Tanzania Wildlife Research Institute (TAWIRI), Game Reserves and Wildlife Management Areas (WMAs) as related to

strengthening management of wildlife migratory corridors and wildlife dispersal areas. Findings in the current study enhance the level of awareness among stakeholders as related to mitigation measures on effect of *Ipomoea hildebrandtii* and *I. kituiensis* on rangeland quality among the Maasai steppe rangelands.

In addition, findings from the current study are expected to contribute on enhancing biodiversity conservation as the baseline data on herbage species composition, species richness and basal cover and biomass productivity loss due to *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands of Simanjiro district.

1.6 Limitations of the study

The study was limited to Maasai steppe rangelands that are located in Simanjiro district, Manyara, Northern Tanzania, as well as herbage and *Ipomoea hildebrandtii* and *I. kituiensis*, and herbage biomass productivity only. This is due to the limited financial budget and time. Thus the study didn't include other invasive herbage species for assessment.

1.7 Scope of the study

The study focused on determining species composition, species richness, basal cover and biomass productivity of herbage species in Simanjiro Maasai steppe rangelands adjacent Tarangire national park, Tanzania. Invasive plant species of interest was *Ipomoea hildebrandtii* and *I. kituiensis* only. However, habitats of interest were grasslands and woodlands in Simanjiro Maasai steppe rangelands. Indigenous knowledge of interest about *Ipomoea hildebrandtii* and *I. kituiensis* was from among the Maasai ethnic community.

CHAPTER TWO

Literature review

2.1 Theoretical review

2.1.1 Definition of key terms and concepts

2.1.1.1 Species

These are basic units of all living organisms of the world, thus are descriptive units functionally and structurally of all living things (Swingland, 2001); implying from micro-organisms to micro-organisms of the world.

2.1.1.2 Diversity

The term is simply confined to species diversity. Therefore diversity is species' number in a given area and their relative composition. However, species diversity among other diversities is a component of biodiversity. Biodiversity is variety within and among living organisms, assemblages of living organisms, biotic communities, and biotic processes, where naturally occurring or modified by humans (Swingland, 2001). However, a meaning is flexible and allows for further modification.

2.1.1.3 Biomass

This term can be defined depending upon experts, ecologically is a physical dry matter in a natural ecosystem used as a source of foods and energy in a trophic system (food chains and webs) of organisms (Hagens and Smits, 2012). In a broad sense biomass is a body dry matter of an individual organism (Niklas and Enquist, 2001).

2.1.1.4 Herbage

Refers to herbaceous vegetation (grass associated with forb) especially when used for grazing. On another hand, it is applied to the above-ground parts when their most important characteristics are considered to be weight and nutritive value, i.e. plants are regarded as food for livestock (Thomas, 1980). Forage is a plant material, including herbage but excluding concentrates and other factory-processed feedstuffs, used as feed for herbivores (Thomas, 1980).

2.1.1.5 Native species

Native plants are plants occurring in, and/or naturalized in, a region to which it is indigenous to that ecosystem (Witt and Luke, 2017). It should be noted that most native species are useful and do not become invasive.

2.1.1.6 Alien species

Alien plants are exotic, non-native, non-indigenous plant species that have been introduced by people, either intentionally or unintentionally, outside of its natural range and outside of its natural dispersal potential (Witt and Luke, 2017). It should be noted that most alien species are useful and do not become invasive.

2.1.1.7 Invasive plant species

These are alien species established in new locations after their intentional or unintentional translocation without human interest, where they grow and spread in ways that do modify natural native ecosystems functionally and structurally, eventually disrupts human wellbeing (McNeely, 2001; Radosевич *et al.*, 2007).

2.1.1.8 Increasers

Increasers are forage plant species whereby in grasslands, their abundance is favoured away from grazing (Del-Val and Crawley, 2005). According to Reardon and Merrill (1976), ‘increasers’ are plants which increase when ‘decreasers’ decrease, until they begin to decrease because of excessive grazing. Increaser herbages are less nutritious, are characterized with deterring chemicals (Provenza *et al.*, 1990), and they have low palatability, low feed intake, low digestibility potential and therefore low animal utilization efficiency.

2.1.1.9 Decreasers

According to Reardon and Merrill (1976), ‘decreaser’ plants are those which decrease under excessive grazing pressure. Therefore ‘decreasers’ are forage plant species with promising nutritive value to grazers, for example, *Cenchrus ciliaris*, *Cynodon dactylon*, *Cynodon* spp. and *Eragrostis* spp. representing important grass species native to many rangelands in the semi-arid regions (Reardon and Merrill, 1976).

2.1.1.10 Rangeland

According to Allen *et al.* (2011), rangeland is a natural land on which the native vegetation like grasses, grass-like plants, forbs or shrubs are mainly dominant plants that are foraged or have the potential to be eaten by grazers, and which is used as a natural ecosystem for the production of grazing livestock and wild animals. Rangelands may include natural grasslands, savannas, shrub-lands, many deserts, steppes, tundras, alpine communities, and marshes.

2.1.2 Theories underlying the study

2.1.2.1 Grazing theories

Theories have been developed to predict the effects of grazing on rangeland plant communities (Milchunas *et al.*, 1988; Westoby *et al.*, 1989). It is hypothesized that each rangeland had a single climax vegetation community in the absence of grazing (Westoby *et al.*, 1989). It is hypothesized that each rangeland had a single successional-grazing axis that was reversible. Thus at the presence of grazing, the successional pathway of the system was set back along the succession-grazing continuum whereas, in the absence of grazing, the successional pathway would continue and in turn results in the climax community, which is site-specific.

Grazing pressure and drought both periodically cause damage to or loss of organs (i.e. leaves, shoots, roots etc.) in plants (Milchunas *et al.*, 1988). According to Milchunas *et al.* (1988), is hypothesized that in semi-arid grasslands that have a long history of grazing, grazing will not have much of an effect on the plant communities. The effect is coped with the evolution of plant communities with the selective pressure of grazing and drought. Species richness with time may decline linearly with increasing grazing intensity, but only slightly. Rare herbage species may be reduced in numbers or eliminated due to their reduced tolerance of grazing pressure.

2.1.2.2 Plants invasion theories on herbage productivity

According to Rai (2015) success of invasive plant species is supported with the hypothesized ecological attributes namely, enemy release, novel weapon, empty niche, herbivore pressure etc. For instance plant invaders negatively impacts plant

natives through novel pathways, such as allelopathic chemicals, Callaway *et al.* (2004); also, plant native populations are depressed by pathogens and herbivores that do not prey on the plant invaders (Keane and Crawley, 2002). Moreover, invasive plant species can act synergistically with other elements of global change, including land-use change, climate change, increased concentrations of atmospheric carbon dioxide and nitrogen deposition (Broennimann *et al.*, 2007; Rai, 2015). Meanwhile, these theories predict that functionally similar plant invaders should impose the greatest harm on plant native communities, MacDougall *et al.* (2009) but case studies often counter this prediction, with similar plant invaders entering habitats with little negative impact (Bulleri *et al.*, 2008; Mitchell and Power, 2003). The little negative impacts are subject to invasion success of the invader plants. Therefore, greatest harm posed by invasive plants such as herbs on native herbage communities in turn lower herbage productivity of native herb plants.

2.1.2.3 Invasive plants and herbaceous extinction theory

Invasive plant species currently are a leading threat to natural native biodiversity, whereby in general they displace native ecosystems, by altering soil chemistry, nutrient cycling, water availability and wildfire regimes. It is hypothesized that invasive species globally are a second threat to biodiversity loss. Thus even the presence of these plants makes the future of herbage species diversity in rangelands to be in doubt (Bosco *et al.*, 2015; Rija *et al.*, 2013).

2.1.2.4 Herbage richness and biomass productivity theory

Herbages of either short or tall vegetation are of great importance as preys to herbivore grazers, whereby grazers feed on herbages to obtain nutrients and energy

in form of biomass. Herbivores number increases in the presence of high plant herbage biomass, thus herbage richness is correlated with high biomass productions and eventually high grazers populations (DiTomaso, 2000; Pimentel *et al.*, 2005).

2.1.2.5 Herbage, habitat requirements and grazers population development theory

It is hypothesized that the majority of the vegetation in rangelands are herbage (Kahurananga, 1979). This means that rangeland habitats require herbages. Therefore, the presence of herbages is correlated with a high number of grazers' population in rangeland areas (Kahurananga, 1981; Rija and Hassan, 2011).

2.1.2.6 Loss of rangeland herbage means loss of life theory

Rangelands are habitats of various animal species both livestock and wildlife (Kahurananga, 1981; Rija *et al.*, 2013; Rija and Hassan, 2011). This is because of the presence of herbage in an area whereby grazers depend upon them (feeding) for survival. Like any other natural land, rangelands are under pressure of invasions by plant species, which are a great threat to herbage loss. Thus a loss of rangeland herbages means loss of grazer's life (Bosco *et al.*, 2015; Foxcroft *et al.*, 2006).

2.1.2.7 Rangeland herbage' importance for biodiversity and people theory

It is argued that rangeland herbages do support strongly life of animals as a source of feed (Kahurananga, 1981). Thus nourishes biodiversity ecologically, and livelihood of people (Obiri, 2011). Therefore rangeland and their herbages are of great importance to wildlife animal and livestock populations (Rija *et al.*, 2013). Thus

rangelands play a great role in the socio-economic and cultural activities of people (Bosco *et al.*, 2015).

2.2 Empirical review

2.2.1 Overview on invasive plant species

Ecological studies on invasive plant species globally and regional wise have been described in the United States of America (DiTomaso, 2000; Pimentel *et al.*, 2005); in South Africa (Foxcroft *et al.*, 2017); in Egypt (Sadek, 2015); in Kenya (Bosco *et al.*, 2015; Mganga *et al.*, 2010a; Mganga *et al.*, 2010b; Mworira, 2011; Mworira *et al.*, 2008; Obiri, 2011; Okach and Omari, 2015); and even in Tanzania (Foxcroft *et al.*, 2006; Kija *et al.*, 2013; Rija *et al.*, 2013).

Invasive plant species are a threat to rangeland sustainability due to their effects on displacing native habitats that harbour various species of animals (McNeely, 2001).

Invasive plant species impact negatively livestock populations by decreasing yield and quality of forages, hindering normal grazing, poisoning nearby plants and their predators including ruminants, and lower grazing land value of many rangelands in East Africa and the globe (DiTomaso, 2000). For instance, Ethiopian rangelands are suffering due to the presence of *Parthenium hysterophorus* which had disrupted grass pastures, and it encroaches towards southern Kenya (Rija *et al.*, 2013). In Kenya, for instance, it had been reported that a livestock population is declining due to a shortage of grass in invaded grazing lands by *Ipomoea* spp. (Bosco *et al.*, 2015). In Tanzania few studies are in place, for instance, in Ngorongoro Conservation Area, it was reported in the year 2002 about 39 invasive woody plant species affecting a life of herbivores livestock and wild ungulates specifically their habitats and foraging pastures (Foxcroft *et al.*, 2006). Studies concerning rangeland herbage loss

due to invasive plants are scarce, few studies alerting on issues in Tanzania are available.

2.2.2 Potential of Maasai steppe rangelands on enhanced livestock and wildlife management

Reports by Kahurananga (1981), Rija *et al.* (2013), and Bosco *et al.* (2015) outline extensively the potential of Maasai steppe rangelands on enhanced livestock and wildlife management. Wild ungulates such as wildebeest as well as livestock depend upon herbage for their survival. Also, herbage nourish a soil and become fertile suitable for their growth as pastures in the Maasai steppe rangelands.

Rangelands through the provision of feed for livestock do impact positively livestock population by increasing yield and quality of meat and milk (Bosco *et al.*, 2015). Also, rangelands outside protected areas such as national parks, are used by wild ungulates specifically wildebeest and zebra as places for breeding and recruitment sites (Kahurananga, 1981). Based on ecosystem goods and services, some societies obtain construction materials from herbage of rangelands. Thus rangeland grasses do support both ecologically and socio-economically as well as cultural activities of the people (Rija *et al.*, 2013).

Simanjiro rangelands secure life of livestock and wild ungulates, as well as their dependants like Maasai pastoralists (Kahurananga, 1981); and natural resource and tourism sectors (Rija *et al.*, 2013).

Rangelands, when it happens, are invaded by invasive plant species, cultural and socio-economic adverse effects occur (Obiri, 2011). Since rangeland productivity is a function of various types of fodder species as related to inherent nutrient density, palatability, and concentration of secondary plant metabolites (Bryant *et al.*, 1991; Provenza *et al.*, 1990). Also, rangeland productivity is a function of various types of fodder species as related to animal intake (Forbes, 2007), digestibility (Hall *et al.*, 2017) and animal productivity (Ahmad *et al.*, 2012).

2.2.3 Wildlife population and migratory pattern in Simanjiro rangeland plains

Rangelands support large numbers of livestock and are home to the largest number of wild grazers and browsers than are other ecosystems. They have, additionally, a vital importance to the survival and economic livelihood of many peoples, and play a significant ecological role on a worldwide scale. Simanjiro rangeland plains are within the Simanjiro Game Controlled Area (Game Reserve) administered by the Game Department, whereby licensed wildlife hunting are carried out (Kahurananga and Silkiluwasha, 1997). Simanjiro rangeland plains are the migration and dispersal areas outside TNP, and also are crucial to the Tarangire ecosystem (Rija and Hassan, 2011). During the early 1970s to 1990's as many 55,000 zebra and wildebeest migrated in and out of Tarangire National Park on a seasonal basis for nutrient search such as phosphorus-rich grazing areas outside the park during the wet season (Kahurananga, 1981; Kahurananga and Silkiluwasha, 1997).

The pathway from TNP to the northern border of LMNP is one of the major wet season dispersal routes within the wider Tarangire-Simanjiro ecosystem, for up to 10,000 wildebeest and 100–800 zebra (Mwalyosi, 1991). In the early 1970s, the

Simanjiro herds were estimated at about 6,000 zebra and 10,000 wildebeest (Kahurananga, 1981). And by 1995 it was estimated 23,000 zebra and 11,000 wildebeest migrated from the park to Simanjiro areas (Kahurananga and Silkiluwasha, 1997). However, the wild ungulates continue to migrate in recent years (Rija and Hassan, 2011). The wild ungulates Migration is ascribed to the persistence of herbaceous species such as *Panicum coloratum* and *Digitaria macroblephara* which have been considered as critical for calving and lactating for both wild (and domestic) ungulates (Kahurananga and Silkiluwasha, 1997).

2.2.4 Land use management of Simanjiro district

The Simanjiro plains had been heavily utilized by wild ungulates and shared by pastoralists (Kahurananga and Silkiluwasha, 1997). Although in recent decades the number of wild ungulates migrating to Simanjiro plains had been declining (Mwalyosi, 1991; Rija and Hassan, 2011). Simanjiro district's pastoralists have indigenous livestock (cattle, goats, and sheep) as of 2012 were 1,167,632 (NBS 2012).

The Simanjiro district has a land area of 20,591 km² of which 600 km² is fertile land, 12,682 km² is hunting blocks and the rest is a hilly area (Yanda and William, 2010). This situation of heavy utilization of Simanjiro district's rangeland plains by wildlife and shared by pastoralists had led to the creation of the land use plan in the district specifying an area proportion for pastoralism, settlements, agriculture, and agencies. For instance, Terrat is a community of about 3500 residents and a land area of roughly 40,000 ha (Nelson *et al.*, 2010). Sukuro village has a total area of 69,582 ha as by Sachedina (2006) of which in part are conserved as pastoral grazing

lands including Simanjiro Conservation Easement Area (SCEA). Terrat village with 19,233 cattle, 23,424 goats and 22306 sheep had 9,300 ha set aside for the grazing lands as SCEA only (Nelson *et al.*, 2010).

2.2.5 Integrated livestock-wildlife management approaches

2.2.5.1 Ngorongoro Conservation Area Authority

Ngorongoro Conservation Area Authority (NCAA) model is the multiple land use model for a protected area and a world heritage site involving the peaceful co-existence of human and wildlife in a natural and traditional setting (Charnley, 2005). The model allows activities such as pastoralism and tourism coupled with conservation of natural resources. However, human settlement and subsistence farming near water sources in the crater are restricted. The Ngorongoro Conservation Area Authority is the one with the mandate to manage the conservation area. This model safeguards both traditional livestock grazing settings and wildlife habitats.

2.2.5.2 Simanjiro Conservation Easement Area approach

The Simanjiro Conservation Easement Area model is a conservation model involving local communities, tour operators, and conservation partners to protect the main calving grounds for wild ungulates in the Simanjiro plains of Terrat, Sukuro and Emboreet villages (Nelson *et al.*, 2010).

Following an agreement between tour operators and village leaders, three important villages established conservation easements on their land that only allows livestock and wildlife use and prohibits all agriculture and permanent settlement in the

designated area. In thereafter, annually the participating villages get yearly payment from the tour operators. Game scouting and wildlife monitoring and anti-poaching patrols are conducted by local villagers who are also trained and employed for the SCE program. This model protects both traditional livestock grazing areas and wildlife habitats while contributing additional income returns to the participating villages.

2.2.6 Simanjiro Conservation Easement scheme

SCE scheme was established in the southern parts of Simanjiro Maasai steppe rangeland plains of the Simanjiro district in northern Tanzania. According to Nelson *et al.* (2010), the SCE involves a unique payment for ecosystem services scheme in the Simanjiro plains of Tanzania, an important wet-season grazing area for wild ungulates from TNP. This pledged agreement between individual villages and a group of Tanzanian tourism operators that necessitated local communities to sacrifice settlement and the associated agricultural activities and the entire livelihood derived from the areas in return for annual cash payments (Nelson *et al.*, 2010).

Efforts to enlist local community support for wildlife conservation had since the 1970s been undermined by conflicts over land tenure and resource use. In order to address the deteriorating status of wildlife populations and their habitat on the Simanjiro plains, an alternative framework for community-based conservation was developed starting in 2005 through payments for ecosystem services (PES) agreement (Nelson *et al.*, 2010). This agreement emerged from the collaboration of local communities with a diverse group of Non-Governmental Organizations

(NGOs) and private tourism companies, several of which have extensive and long-term experience in the area.

The agreement builds on customary pastoralist land use practices to build village-level incentives for wildlife conservation. The agreement has produced an important new framework for community-based conservation in village lands of Tanzania by overcoming existing institutional impediments to community involvement in wildlife conservation through a cost-effective and administratively simple PES structure.

The SCE, payments for ecosystem services (PES) in Simanjiro plains is focused on the three villages which contain virtually all the key short grass plains habitat; mainly Emboreet, Terrat and Sukuro comprising 38,072 ha, 40,000 ha, and 69,582 ha, respectively, (Nelson *et al.*, 2010). The SCE program at Terrat village was initiated in 2004 and 2005 and then become operational in 2006 (Woodhouse and McCabe, 2018). Another SCE program at Sukuro village was initiated in 2008 and then become operational in 2009.

The SCE grazing lands before and after evictions of human settlement and agricultural activities, it seems the grazing area has an invasion of plant species such as *Ipomoea* spp. The presence of invasive plant species such as *Ipomoea hildebrandtii* and *I. kituiensis* in the SCEA pose threat to conservation of the main breeding and recruitment sites for wild ungulates as well as livestock grazing in the Simanjiro plains.

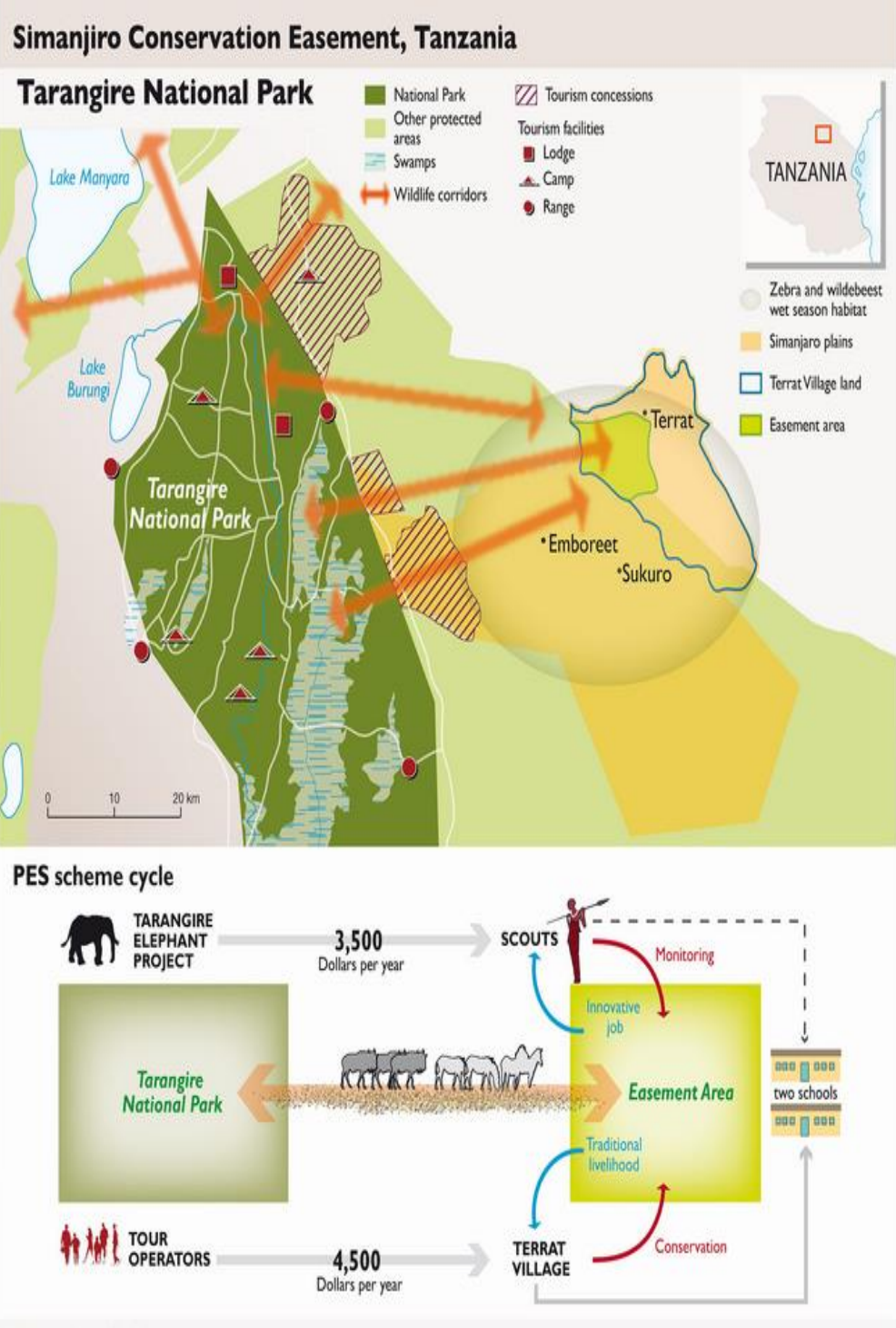


Figure 1: Location of Simanjiro Conservation Easement Area and the associated integrated livestock and wildlife management.

Source: http://old.grida.no/graphicslib/detail/simanjiro-conservation-easement-tanzania_42db

2.2.7 Factors affecting sustainable integrated livestock-wildlife approaches

Pastoralists and wildlife have co-existed in African rangelands for many hundreds of years, though with few of the tensions evident today (Niboye, 2010). In the past, human and livestock populations were relatively small and widely dispersed, and domestic animals were managed to minimize the risks of predation and disease transmission. However, recently competition for limited pasture and water sources is increasing, and the potential for conflicts between wildlife managers and livestock pastoralists is growing as pastoralists and agro-pastoralists move into new areas and/or live encroached in the protected areas.

2.2.7.1 Overgrazing

Large pastoral herds as are generally been excluded, as in the relatively protected areas such as National Parks which have been established in the rangelands (Boyd *et al.*, 1999). This eviction accelerates overgrazing to the area where groups of livestock are transferred. Overgrazing has particularly impacted negatively on vegetation resources and biodiversity in general, thus affects the sustainable integrated livestock-wildlife management in the game plains as an indirect consequence of the general pasture decline.

2.2.7.2 Land degradation

The reduction in rangeland resources, through privatization for commercial agriculture and ranching, and nationalization for conservation coupled with increased livestock productivity have resulted in different degrees of degradation (Boyd *et al.*, 1999). Degradation eventually, in turn, affects negatively the

sustainable integrated livestock-wildlife management in the game plains as an indirect consequence of the general decline in wild and livestock animals.

2.2.7.3 Invasive plant species

Invasive plant species are a major threat to ecological diversities and environment, threatening productivity of many rangeland ecosystems (Didham *et al.*, 2005). Invasive plant species cause herbage species loss due to competition. They also affect negatively wildlife herbivores on their habitats, forages, foraging behaviours. Invasive plant species finally lead to local extinctions of native plant species (DiTomaso, 2000); as they are heavy colonizers of new ecosystems as expressed by their fast spreading.

Also, invasive plants are a hazard in the rangelands, causing the death of livestock by poisoning and accelerating biodiversity loss via suppression of native plants such as pastures (Obiri, 2011). Most wildlife and livestock depend upon rangelands for survival (DiTomaso, 2000). The forages reduction affects the sustainable integrated livestock-wildlife management in the game plains as an indirect consequence of the general pasture decline.

Dispersal origin of the invasive plant species such as *Ipomoea hildebrandtii* and *I. kituiensis* have been reviewed extensively in the reports of Bosco *et al.* (2015). According to Bosco *et al.* (2015), the dispersal origin of the invasive species in Kenya was reported as livestock overgrazing and climate change (*El Nino*) specifically in the 1997/98 season. In as much as frequent droughts and rainfall events also cause changes in vegetation attributes, the plant is reported to have been

in the East Africa region as early as the 1960s (Bosco *et al.*, 2015). In Tanzania, origins and patterns of the introduction of invasive species such as *Ipomoea* spp. are however not known.

2.2.8 Dispersal mechanisms of invasive plant species

Invasive plants species like seed plants their spread is influenced by seed dispersal through wind, air, water, animal eating plants, and animal skin fir from one place to another (DiTomaso, 2000; Gosper *et al.*, 2005; Mworira, 2011). Invasive plant species since are strong competitors and aggressive they take over the area dominance in a short period of time.

2.2.9 Factors influencing dispersal of invasive plants species

Factors influencing dispersal of invasive plants species have been reviewed extensively in the reports of DiTomaso (2000), Gosper *et al.* (2005), Foxcroft *et al.* (2006), Mganga *et al.* (2010a), Mworira (2011), Rija *et al.* (2013) and Bosco *et al.* (2015). Invasive plant species since are strong competitors and aggressive one spread through dispersal mechanisms, climate changes, fire disturbances, secrete chemicals to soil, and lack of understanding of the problem.

2.2.9.1 Climate change

Invasive plants species spread from one area to another through a change in climate. If climate changes are taking place, this facilitates their spreads to that area where native plant species are suffering due to climate changes (Bosco *et al.*, 2015).

2.2.9.2 Fire disturbances

Invasive plants species spread from one area to another through fire disturbance. Fire disturbance in the natural land when occurs it disrupts the natural regulation of vegetation; this can influence encroachments of invasive species (Bosco *et al.*, 2015; Rija *et al.*, 2013).

2.2.9.3 Secretion of chemicals in soil

On the other hand, other invasive species do secrete chemical in nearby soil, and in doing so kill nearby plants, thus maximizes their domination by allelopathic (chemical suppression of other plants) that inhibit germination and growth of other plants (Mganga *et al.*, 2010a).

2.2.9.4 Lack of understanding plant invasion problems

Invasive plants species spread from one area to another through human migration where people to find a new area for settlements by establishing vegetative gardens, constructing buildings and cultivating crops; these activities are major routes for invasive species to move from one location to another (Foxcroft *et al.*, 2006; Rija *et al.*, 2013).

2.2.10 Habitat distribution of *Ipomoea hildebrandtii* and *I. kituiensis*

Distribution of invasive *Ipomoea* species across grassland and woodland habitats has been studied extensively in the report of Mworira *et al.* (2008), Mworira (2011), and Bosco *et al.* (2015). The reported distribution of invasive *Ipomoea* species across grassland and woodland habitats varies from rangelands to ecosystems. However, as reported in most areas for example in Kenya (Southern pastoral rangelands) in

which *Ipomoea hildebrandtii* and *I. kituiensis* are found are degraded and disturbed grazing lands (Mworia, 2011), lowlands, and also fairly sloppy lands (Bosco *et al.*, 2015).

According to Bosco *et al.* (2015), studying grazing lands of semi-arid ecosystems in the southern region of Kenya, habitat distribution of invasive *Ipomoea* spp. were also found in overgrazed sites.

Moreover, habitat distribution for invasive *Ipomoea* spp. varies due to differences in land terrains, ground vegetation cover (Mworia *et al.*, 2008). For example, a study by Bosco *et al.* (2015) in the southern region of Kenya found that invasive *Ipomoea* spp. cover as much as 60% to 80% of grazing lands in red sand loamy soils and area with little rains. Less is known on habitat distribution of *Ipomoea hildebrandtii* and *I. kituiensis* across grassland and woodland habitats in Tanzania and the Simanjiro Maasai steppe rangelands in particular.

Table 1: Effect of alien *Ipomoea* species in Eastern Africa region.

S/N	<i>Ipomoea</i> species	Native region	Ecological effect in East Africa	Means of dispersal
1.	<i>Ipomoea alba</i>	North and south America.	Smothering plants by climbing upon native plants.	Human, ornaments
2.	<i>Ipomoea cairica</i>	Probably tropical Africa and some parts of Asia.	Smothering plants by climbing upon native plants.	Human, ornaments
3.	<i>Ipomoea hederifolia</i>	North and south America	It out-competes native herbage for nutrients, water, and sunlight.	Human, ornaments
4.	<i>Ipomoea indica</i>	Unclear, but possibly tropical America.	Climbs and collapses native canopy.	Human, ornaments
5.	<i>Ipomoea nil</i>	Tropical America.	Smothering vegetation.	Human, ornaments
6.	<i>Ipomoea purpurea</i>	North and south America.	Smotherers trees and shrubs, causing them to collapse.	Human, ornaments
7.	<i>Ipomoea carnea</i>	North and south America.	Shrub as a hedge plant is toxic, containing several alkaloids.	Human, barrier/hedge, and ornament.
8.	<i>Ipomoea hildebrandtii</i>	East and central Africa.	Overgrows since its flowers are toxic to livestock and even to poultry.	Human, ornaments

Source: Witt and Luke (2017).

2.2.11 Effect of invasive plant species on herbage species composition, species richness and basal cover

Effect of invasive plant species on herbage species composition, species richness and basal cover, as well as dominant grass and forb species has been studied extensively in the report of Pratt and Gwynne (1977), DiTomaso (2000), Estes *et al.* (2006), Foxcroft *et al.* (2006), Mworira *et al.* (2008), Mganga *et al.* (2010a), Mganga *et al.* (2010b), Okach and Omari (2015), Bosco *et al.* (2015) and Sadek (2015). They reported that effect of invasive plant species such as *Ipomoea* species varies from rangelands to ecosystems. However, as reported in the arid and semi-arid ecosystem of the northern coastal region of Egypt, invaded lands by invasive *Ipomoea* species had lower herbage species composition and species number (27 species) compared to uninvaded lands (50 species). Also, species richness was lower in the invaded lands (0.905) than the uninvaded ones (0.940) (Sadek, 2015). The reported reduction in herbage species composition and species richness is associated with invasive *Ipomoea* spp. which are annual herb, widespread in semi-arid areas which colonize and spreads rapidly immediately after onset of rain seasons (Mganga *et al.*, 2010a). *Ipomoea hildebrandtii* and *I. kituiensis* are also capable of effective competition with local species for nutrients, space, light, and water (Bosco *et al.*, 2015). In addition to invasive *Ipomoea* species, also, overgrazing as a result induced by herbivore populations could exert pressure on the semi-arid ecosystems leading to degraded pastures (Mganga *et al.*, 2010b). Grass species such as *Aristida* spp. and *Cenchrus* spp. are good indicators of semi-aridity zones of East Africa (Pratt and Gwynne, 1977).

According to Sadek (2015), the common associated species with *I. carnea* are *Cynodon dactylon* (Presence= 72.5%) and *Phragmites australis* (Presence= 67.5%) in the arid and semi-arid ecosystem of the northern coastal region of Egypt. Also, Kahurananga (1979), addresses that *Digitaria-Panicum* represents the dominant grass species of the Simanjiro plains including rangelands consisting of herbage with no browsing value and being poisonous. Detailed herbage species in the Simanjiro plains include *Aristida adscensionis*, *Cynodon dactylon*, *Dichanthium radicans*, *Digitaria macroblephara*, *Eragrostis superba*, *Eustachys paspaloides*, *Harpachne schimperi*, *Microchloa kunthii*, *Panicum coloratum*, *Pennisetum mezianum*, *Sporobolus festivus*. Other herbage species were *Themeda triandra*, *Astripomoea hyoscyamoides*, *Burleria ramirlosa*, *Cassia mimosoides*, *Crotalaria spinosa*, *Euphorbia inaequilatera*, *Indigofera basiflora*, and *Macrotyloma maranguense* (Kahurananga, 1979). Low nutritive value herbage species reported are *Ipomoea hildebrandtii*, *Astripomoea hyoscyamoides*, *Solanum incanum*, *Tephrosia subtriflora* and *Crotalaria barkae* (Kahurananga, 1979).

Mganga *et al.* (2010a), reported that *Digitaria* spp. were among other dominant grass species in the invaded grazing lands of semi-arid ecosystems in the southern region of Kenya. Other dominant herbage species were *Ocimum* sp., *Aconthospernum hispidum*, *Commelina benghalensis*, *Oxygonum sinuatum*, *Lactuca capensis*, *Datura stramonium* and *Cynodon dactylon*.

Native forb *Gutenbergia cordifolia* was reported to dominate the grazing lands of semi-arid ecosystems in the Ngorongoro Conservation Area of Tanzania (Estes *et al.*, 2006). Other dominant herbage species reported in Ngorongoro conservation

area were *Chloris gayana* and *Bidens schimperi*. *Gutenbergia cordifolia* is mostly explained by their successional colonization as a native species which frequently grow and recover large areas, establishing tall, dense herb stands that can persist after a dry season.

Moreover, invasive *Ipomoea* spp. are reported to reduce herbage productivity in terms of basal cover (Mworia *et al.*, 2008). For example in the invaded grazing lands of semi-arid ecosystems in the southern region of Kenya, invasive *Ipomoea* spp. dominates basal cover approximately 69.5% compared to other herbages. Also, in the invaded Simanjiro plains, northern Tanzania, basal cover of *Ipomoea* spp. had been reported as 2.52% compared to other herbages in the grazing lands of semi-arid ecosystems (Kahurananga, 1979).

Influence of soil on the distribution of invasive *Ipomoea* spp. among other factors hinders their invasiveness capacity in the grazing lands (Okach and Omari, 2015). *Ipomoea* species when becomes aggressive invasive plant species pose threat by depressing native herbages nearby or under their canopies (DiTomaso, 2000; Foxcroft *et al.*, 2006). In addition, a fresh and heavy biomass of *Ipomoea* also suppresses a growth and development of herbages underneath it resulting in high incidences of seedling mortality. This consequently results in poor establishment and much of bared areas remain bare after a disappearance of weed at end of rain seasons as noted elsewhere (Mganga *et al.*, 2010b).

Generally; grassland of Simanjiro plains is comprised of increaser herbages such as *Ipomoea hildebrandtii* and *I. kituiensis*. While the majority are decreaseers such as

Cynodon spp., *Dichanthium* spp., *Digitaria* spp., *Eragrostis* spp. and so on (Kahurananga, 1979). Moreover, less is known on the effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage species composition, species richness and basal cover between invaded and non-invaded grazing lands in Tanzania and the Simanjiro Maasai steppe rangelands in particular.

2.2.12 Effect of invasive plant species on herbage biomass productivity

Effect of invasive plant species on herbage biomass productivity in the invaded lands has been outlined extensively in the reports of DiTomaso (2000), Foxcroft *et al.* (2006), Mworira *et al.* (2008), Mganga *et al.* (2010a), Mganga *et al.* (2010b) and Bosco *et al.* (2015). The reported effect of invasive plant species such as *Ipomoea* species on herbage biomass productivity varies from rangelands to ecosystems. However, as reported in the grazing lands of the arid and semi-arid ecosystems in the southern region of Kenya, invaded grazing lands had relatively lower herbage biomass productivity than non-invaded grazing lands (Mworira *et al.*, 2008). The reported biomass productivity reduction was 28% in the presence of grazing compared to non-invaded grazing lands. The reported reduction in herbage biomass productivity is associated with invasive *Ipomoea* spp. which are annual herb, widespread in semi-arid areas which colonize and spreads rapidly immediately after onset of rain seasons (Mganga *et al.*, 2010a). Invasive *Ipomoea* spp. as have an effective competition with native species for nutrients, space, light, and water do cause a decline in herbage biomass productivity (Bosco *et al.*, 2015). Decline in herbage biomass productivity among other factors is ascribed to *Ipomoea* species as invasive herbage species which depresses native herbages nearby or under their canopies (DiTomaso, 2000; Foxcroft *et al.*, 2006; Mganga *et al.*, 2010b). Less is

known on effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage biomass productivity between invaded and non-invaded grazing lands in Tanzania and the Simanjiro Maasai steppe rangelands in particular.

2.2.13 Mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands

Globally, effect of invasive plant species can be prevented and mitigated (IUCN, 2001). Management options for invasive plant species as reported by the International Union for Conservation of Nature (IUCN, 2001) are continuously survey and monitoring associated with prevention of alive plant importation (preventing immigration of alive plant species, cultivation and construction). Other management options for invasive plant species are mitigation/control (mechanically, chemically, biologically and habitat management), adaptation (coping with their impacts), legislation implementations (species importations of immigrants). Also, mitigation measures options for invasive plant species might be coupled with the provision of public educational awareness (Foxcroft *et al.*, 2006; McNeely, 2001).

2.2.13.1 Eradication of invasive plant species

This is associated with prevention of alive plant species importation (thus preventing importation through animal immigrants, cultivation, and construction) from invaded rangelands to non-invaded rangelands coupled with tight legislation implementations (McNeely, 2001).

2.2.13.2 Manual uprooting

This involves mitigation/control (mechanically), through mechanical, hand or manual uprooting of the invasive plant species such as invasive herbage e.g. *Ipomoea* spp. (Bosco *et al.*, 2015).

2.2.13.3 Herbicides application

This involves mitigation/control (chemically), through the application of herbicides such as Soda Ash and wood ash as well as spray chemicals to the invasive plant species such as invasive herbage e.g. *Ipomoea* spp. (Bosco *et al.*, 2015).

2.2.13.4 Cultural practices

This involves traditional practices for mitigating effect of invasive plant species through burning as habitat management (McNeely, 2001). Generally; mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands have been outlined extensively in the studies by Mganga *et al.* (2010b), Bosco *et al.* (2015) and Okach and Omari (2015). The reported mitigation measures among the Maasai pastoralists on effects of invasive *Ipomoea* spp. varies from rangelands to ecosystems. However, as reported by Bosco *et al.* (2015), invasive *Ipomoea* spp. were mainly found covering as high as 50% to 65% of village pasture fields. A study in Kenya addresses that no cases for livestock mortality due to invasive *Ipomoea* spp. had been reported (Mganga *et al.*, 2010b). Road construction is reported as a reason for invasive *Ipomoea* spp. spread (Okach and Omari, 2015). Mainly invasive *Ipomoea* spp. distribution is by the roadside (Okach and Omari, 2015). However, even if communities experience effect of invasive *Ipomoea* spp., it is reported that there were no uprooting involvements by Maasai communities (Bosco *et al.*, 2015).

Mitigation measures by Maasai communities reported among other methods were through the use of mechanical removal and manual uprooting coupled with eradication through fencing of grazing land for pasture re-growth, or range rehabilitation practices at home compound only or family level only (Bosco *et al.*, 2015). Mechanical removal and manual uprooting were perceived more fairly effective than other mitigation measures. Moreover, the Maasai communities do prefer the applications of herbicides and extensive uprooting (seedlings) as proposed alternative mitigation measures for invasive *Ipomoea* spp. (Bosco *et al.*, 2015). Maasai communities are reported to decide the applications of chemical usage in form of Ash and spray for controlling invasive *Ipomoea* spp. (Bosco *et al.*, 2015). Less is known on available mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Tanzania and the Simanjiro Maasai steppe rangelands in particular.

2.2.14 Effect of invasive plant species on soil fertility

Reports by McNeely (2001), and Rija *et al.* (2013) outline extensively the effect of invasive plants on soil fertility. Invasive plant species when are in new locations they alter water and nutrient cycling and biogeochemical processes of an area, thus, in general, lowering soil fertility (McNeely, 2001). After a ground cover is displaced soil erosion occurs (Rija *et al.*, 2013).

2.3 Research gap

Various scientific studies reviewed have shown that next to habitat degradation and climate changes, invasive plant species are threats to global biodiversity through suppression of native plants (Didham *et al.*, 2005; McNeely, 2001; Vilà *et al.*, 2011). However, in Tanzania, less has been reported on effect of *Ipomoea*

hildebrandtii and *I. kituiensis* on herbage productivity in terms of quality and quantity. Mworira *et al.* (2008) reported that invasive *Ipomoea* spp. depress native grass biomass productivity by 47% in the absence of grazing and 28% in the presence of grazing. Also, invasive *Ipomoea* spp. are reported to lower herbage species composition, number and richness, Sadek (2015); and herbage basal cover (Mworira *et al.*, 2008).

In Tanzania, studies concerning invasive plant species are limited to two protected areas namely, Serengeti National Park and Ngorongoro Conservation Area Authority and mostly rely on woody invasive plant species (Foxcroft *et al.*, 2006). Studies on effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage productivity in Maasai steppe rangelands and the Simanjiro plains of Tanzania are scarce. Therefore, the current study aimed to determine herbaceous loss due to *Ipomoea hildebrandtii* and *I. kituiensis*; as well as mitigations of the distributed invasive *Ipomoea* spp. in the Maasai steppe rangelands of Simanjiro district.

2.4 Conceptual framework

2.4.1 Independent variables

Simanjiro Maasai steppe rangelands are characterized by semi-desert type of climate, as area falls within a semi-arid ecological zone (Kahurananga and Silkiluwasha, 1997). An average rainfall is of high variability. Its temperature varies by altitude. The Simanjiro rangelands harbour 178,693 people and thousands of indigenous livestock such as cattle (472,028), goats (509,129) and sheep (186,475) (NBS, 2012) in the areas of 20,591 km². The main type of soil is the dark red sandy clay loam of the semi-arid Simanjiro plains. The variation in climates like the

existence of *El Nino* may influence some species to become invasive in that area (Bosco *et al.*, 2015). Therefore such plain climatic conditions together with animal and human disturbances through grazing pressure as factors may accelerate “increasers” such as invasive *Ipomoea* spp. to invade or change herbage species composition, species richness, and basal cover and biomass productivity. In turn, invasive *Ipomoea* spp. affects herbages growing in the nearby plain soil.

2.4.2 Intermediate variables

Plain climatic conditions changes when occurs leading to droughts or rains, results in shifting of human activities from one place to another. The shifting of activities coupled with management of Maasai steppe rangelands through grazing, crop cultivations, and settlements may accelerate “increasers” such as invasive plants, in particular, *Ipomoea hildebrandtii* and *I. kituiensis* to impose competitions and eventually kill the nearby plants by toxins they secrete (Bosco *et al.*, 2015). Grazing lands when are under grazing pressure results in the reduction of ‘decreaser’ herbages in the rangelands. Also, crop cultivations and settlements are the routes for invasive species spread from invaded area to another non-invaded area through crop farming, gardening, and constructions (Foxcroft *et al.*, 2006). When invasion occurs the ‘increaser’ plant species could affect herbage species composition, species richness and basal cover and biomass productivity of “decreaser” in Maasai steppe rangeland plains. Therefore, the presence of invasive plant species can affect a biodiversity of native ecosystems by changing, for instance, herbage species composition, species richness and basal cover and biomass productivity, as well species distribution through negative impacts they create.

2.4.3 Dependent variables

Climatic conditions changes, animal and human disturbances (grazing pressure) coupled with management of Maasai steppe rangelands through grazing, crop cultivations, and settlements may accelerate “increasers” such as *Ipomoea hildebrandtii* and *I. kituiensis* to invade or change herbage species composition, species richness and basal cover and biomass productivity. Thus herbage species composition, species richness and basal cover and biomass productivity, as well species distribution depends upon their abundances and competitive growth against *Ipomoea hildebrandtii* and *I. kituiensis* of plants of Maasai steppe rangelands.

Competition can be regulated by temperature, rainfall, and wind; soil; animal and human disturbances, plus interventions of grazing, crop cultivations, and settlements. Therefore any direction of outcomes of competition and toxicity brought by *Ipomoea hildebrandtii* and *I. kituiensis* can influence the future of herbage species composition, species richness and basal cover and biomass productivity.

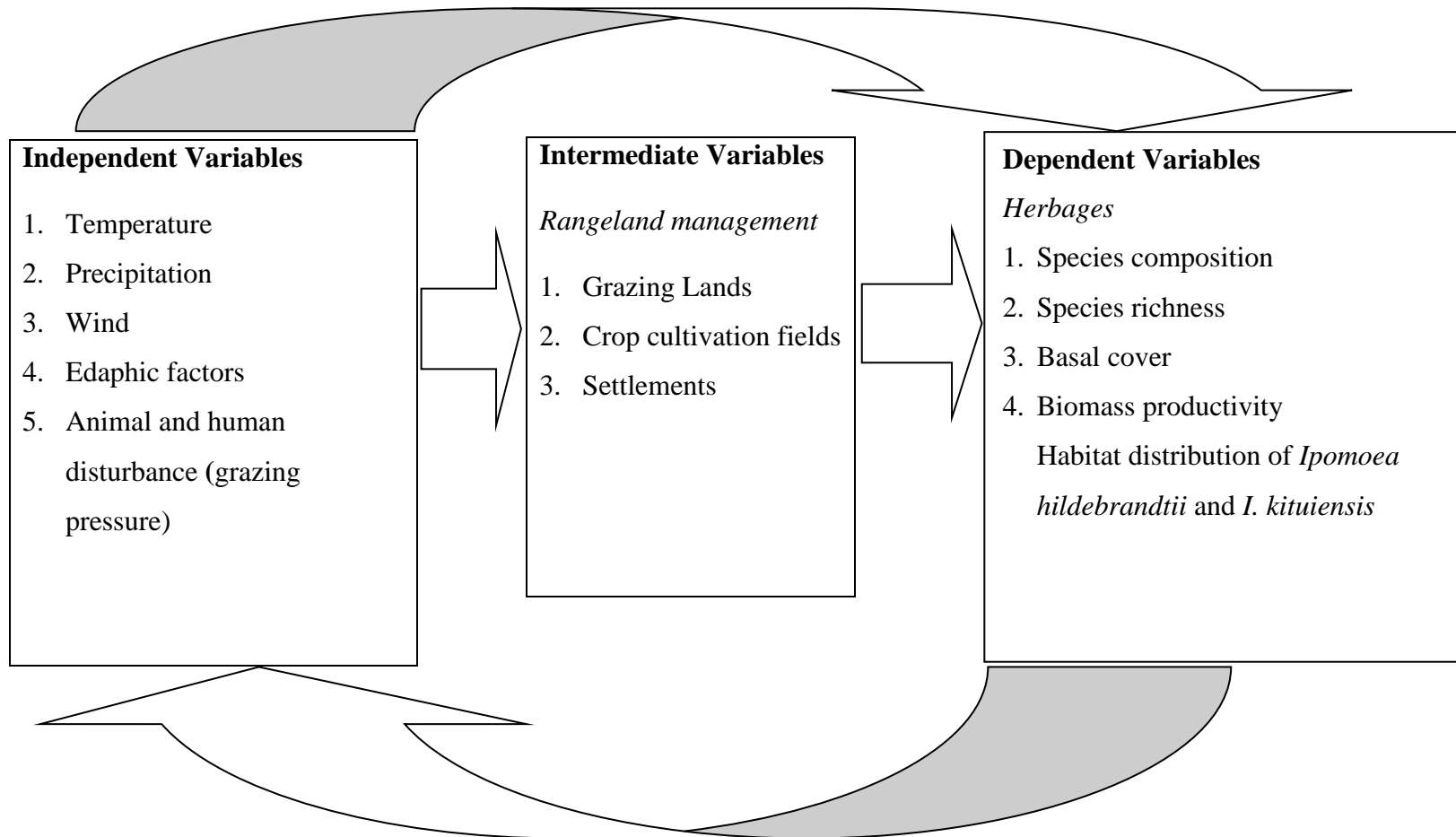


Figure 2: Conceptual Framework. **Source:** Researcher (Ndaki Manyanza).

CHAPTER THREE

Research methodology

3.1 Description of the study area

3.1.1 Study area

The study area comprises primarily of the Simanjiro plains. The study was conducted at the Terrat and Sukuro villages to represent other grazing lands where livestock and wild ungulates coexist in Simanjiro district and the entire Maasai steppe rangelands of north-eastern Tanzania. The study was conducted in two villages with grazing lands, namely, Terrat (40,000 ha) and Sukuro (69,582 ha); whereby Simanjiro district has a land area of 20,591 km² (Yanda and William, 2010). The selection of these villages was based on the fact that these villages are among the villages highly affected by the *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands. This has been done deliberately so as to get the effectiveness of the data where livestock and wild ungulates coexist.

3.1.2 Location

Simanjiro plains are located in the southern parts of Simanjiro Maasai steppe rangelands of the Simanjiro district, Manyara of northern Tanzania. Simanjiro plains are located in the middle of Maasai steppe lands, northern Tanzania. Simanjiro plains are found between 36°05' E longitude to 36°39' E longitude and 3°52'S latitude to 4°24' S latitude (Kahurananga and Silkiluwasha, 1997).

The Simanjiro plains are of high potential in terms of Maasai livelihood in Maasai rangelands, as well as wild ungulates survivals as breeding and recruitment sites (Nelson *et al.*, 2010). Purposefully, the villages were selected partly because they have areas having *Ipomoea* spp. invasion and non-invasion. The village grazing

lands are part of the destinations to wild ungulates from Tarangire National Park migrating toward them during the rainy season. Also, Terrat and Sukuro villages use the wildlife-livestock coexisted areas in the dry season for livestock grazing.

3.1.3 Edaphic characteristics

According to Kahurananga (1979), Simanjiro Maasai steppe rangelands consist of gently undulating plains combined with ridges and the general slope is about 2%. There are depressions or sumps in the middle and in the extreme east and west. The plains area is on a raised plateau varying in altitude from 1356 masl in the southeast to 1605 masl in the northwest of the Simanjiro district. Simanjiro lies on the northern extremity of the Archean basement complex. Consequently, the main type of soil is the dark red sandy clay loam of the semi-arid plains, the red colour deriving from the ferro-magnesium within gneiss, the parent rock material. Within the depressions where drainage is delayed, there is black clay commonly known as black cotton soil. On some flat localities, there is grey clay which is less waterlogged.

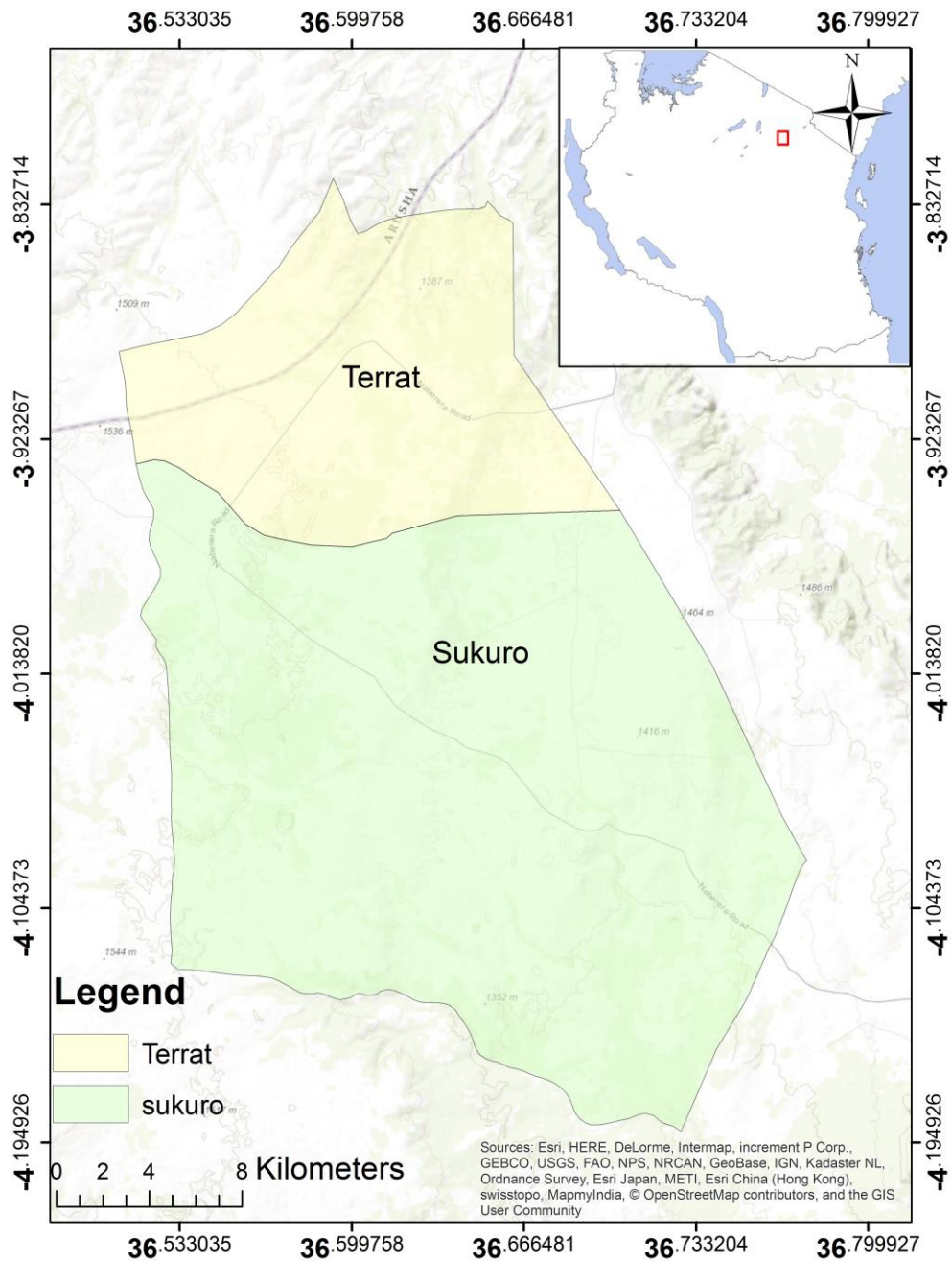


Figure 3: Map of Simanjiro plains showing the two selected villages of the Simanjiro district.

Source: Researcher (Ndaki Manyanza).

3.1.4 Climate

The climate of Simanjiro district is hot as the area is characterized by semi-desert type of climate. Simanjiro district area falls within a semi-arid ecological zone (Kahurananga and Silkiluwasha, 1997). Temperature varies with altitude but ranges between 19⁰C at the coolest and 26⁰C at the warmest. The average rainfall is 450–600 mm annually (Kahurananga and Silkiluwasha, 1997). Simanjiro rangeland plains have two rainy seasons occurring in these areas. Short duration rains fall between October and December, and long duration rains fall between February and May (Kahurananga and Silkiluwasha, 1997).

3.1.5 Vegetation

Characteristic vegetation of Simanjiro rangeland plains include grasslands dominated by *Digitaria macroblephara-Panicum coloratum* grasslands. The tree canopy is dominated by *Acacia tortilis-Commiphora schimperi* woodlands. Other flora include *Acacia-Dichrostachys-Balanites* woodlands, *Acacia stuhlmannii* bushlands, and *Pennisetum mezianum* as seasonally water-logged grasslands. Other flora include *Acacia stuhlmannii* seasonally water-logged bushlands which are widespread throughout the area. The vegetation grows in dark red sandy clay loamy as well-drained soils (Kahurananga, 1979).

3.1.6 Demographic characteristics

According to the 2012 Tanzania National Census (TNC), Simanjiro district had about 178,693 people in area of 20,591 km², whereby Komolo ward (i.e. including Sukuro village) had an area of 1,294 km², and human density of 8.927/km², while Terrat ward (i.e. including Terrat village) had an area of 287 km², and human

density of 29.90/km² (NBS, 2012). Both Terrat and Sukuro villages administratively are within Terrat division of the Simanjiro district.

3.1.7 Main socio-economic activities

Maasai ethnic communities dominating surrounding villages in Simanjiro rangeland plains are engaged in pastoralism, agro-pastoralism, crop farming, wildlife and cultural tourism as well as business to sustain their lives. In some cases, their main source is selling of local medicinal plants to gain money for household expenditure.

Pastoralists in the Simanjiro district have thousands of indigenous livestock such as cattle (472,028), goats (509,129) and sheep (186,475) (NBS, 2012). Agro-pastoralists and crop farmers mainly engage in cultivations of maize and beans. The Simanjiro plains are heavily utilized by wildlife animals (Kahurananga and Silkiluwasha, 1997). Simanjiro plains near the Tarangire and Manyara National Parks are utilized by thousands of zebra (*Equus burchelli*) and wildebeest (*Connochaetes taurinus*) migrating to that areas during wet season pastures (Kahurananga, 1981).

3.2 Research design and study settings

3.2.1 Experimental design

The study involved the use of an experimental design as a quantitative approach specifically Informal Experimental Design (IED). IED as with and without treatment design was coupled with the point sampling technique. IED and point sampling technique were used for data collection on effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage species composition, species richness, basal cover and biomass

productivity between invaded and non-invaded grazing lands. Also, IED and point sampling technique were used for data collection on habitat distribution pattern of *Ipomoea hildebrandtii* and *I. kituiensis* across grassland and woodland habitats.

3.2.2 Non-experimental design

Also, the study employed socio-economic surveys through the use of non-experimental (cross-sectional) design as a qualitative approach (i.e. Participatory Rapid Appraisal, mainly, focus group discussions; key informants interviews and questionnaire survey). Socio-economic survey was used for data collection on the available mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands.

3.3 Population, sample and sampling procedure

3.3.1 Study population

The targeted population in the study were the Simanjiro Maasai steppe rangelands and Maasai communities. The targeted samples in the study were herbage of the grazing lands where livestock and wild ungulates coexist, and hamlet representatives of the two villages, namely Terrat and Sukuro.

3.3.2 Sampling techniques

3.3.2.1 Herbage species composition, species richness and basal cover

The study involved the use of point sampling technique for both invaded and non-invaded grazing lands in Simanjiro Maasai steppe rangelands, as described by Crowder and Chheda (1982). The study involved systematically taking temporally rectangle sample plots of 70 m, their pace transects of 30 m and temporally rectangle

sample quadrats of 1 meter in each grazing land. Determination of effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage species composition, species richness and basal cover were conducted in each quadrat. The inter-plot distance was maintained at an interval of 300 m to 550 m, as described by Philip (1994).

3.3.2.2 Herbage biomass productivity

The study involved the use of point sampling technique for both invaded and non-invaded grazing lands in Simanjiro Maasai steppe rangelands, as described by Crowder and Chheda (1982). The study involved systematically taking temporally rectangle sample plots of 70 m, their pace transects of 30 m and temporally rectangle sample quadrats of 1 meter in each grazing land. Determination of effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage biomass productivity was conducted in each quadrat. The inter-plot distance was maintained at an interval of 300 m to 550 m, as described by Philip (1994).

3.3.2.3 Habitat distribution of *Ipomoea hildebrandtii* and *I. kituiensis*

Ipomoea hildebrandtii and *I. kituiensis* habitats' distribution across grassland and woodland habitats was determined by non-probability sampling technique which include quota sampling, purposive sampling, and opportunistic/convenience sampling; specifically purposive sampling for specified habitats was used (Kija *et al.*, 2013); coupled with point sampling technique for both Terret and Sukuro village grazing lands.

3.3.2.4 Mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands

A socio-economic survey was adopted for an evaluation of the available mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands. Two villages namely Terrat and Sukuro were selected for the study to represent other villages by non-probability sampling technique through purposive sampling.

Respondents for key informants' interviews (KIIs) and focus group discussions (FGDs) as methods were selected by non-probability sampling technique specifically purposive sampling was used to obtain their indigenous knowledge and skills views (Bosco *et al.*, 2015).

Respondents for the questionnaire survey method were selected by simple random sampling to obtain their indigenous knowledge and skills views (Bosco *et al.*, 2015). However, a probability-sampling technique as a technique it include also systematic-random sampling and stratified-random sampling of which were not used in the current study. Hamlet representative questionnaire surveys were conducted randomly. After assigning of each hamlet a number to 10 at Terrat village and to 5 at Sukuro village, then using random numbers generated from a scientific calculator (fx-991-CASIO), the hamlets were selected until the required number of 5 hamlets for each village was attained.

3.3.3 Sampling design

3.3.3.1 Herbage species composition, species richness and basal cover

Five plots measuring 70 meters × 70 meters in each of the selected two blocks comprising invaded and non-invaded of rangeland were evaluated. Herbage species composition, species richness and basal cover were systematically collected using a metal frame quadrat (1 m x 1 m) thrown at 30 m paces in three transects (two-diagonals and a bisector) in each of the ten plots in the invaded and non-invaded grazing lands. 9 samples per plot were collected with slight modification to Crowder and Chheda (1982). However, a size of quadrat was subject to field reconnaissance survey.

3.3.3.2 Herbage biomass productivity

Five plots measuring 70 meters × 70 meters in each of the selected two blocks comprising invaded and non-invaded of rangeland were evaluated. Herbage biomass productivity was systematically collected using a metal frame quadrat (1 m x 1 m) thrown at 30 m pace in three transects (two - diagonals and a bisector) in each of the ten plots in the invaded and non-invaded grazing lands. 9 samples per plot were collected with slight modification to Crowder and Chheda (1982).

3.3.3.3 Habitat distribution of *Ipomoea hildebrandtii* and *I. kituiensis*

Many areas as possible across in each grassland and woodland habitats as blocks were used for the study, whereby invasive plant species of interest in habitats between grassland and woodland habitats were indicated based on percentage acre estimation coupled with their geographical location (Kija *et al.*, 2013).

3.3.3.4 Mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands

Collection of data on available mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands involved socio-economic survey. Two villages namely Terrat and Sukuro; and Maasai communities, were selected by non-probability sampling technique through purposive sampling. Participants for each qualitative method (i.e. questionnaire survey) were selected by probability sampling technique through simple random sampling. Key informant interview and focus group discussion participants were selected by non-probability sampling technique through purposive sampling (Bosco *et al.*, 2015).

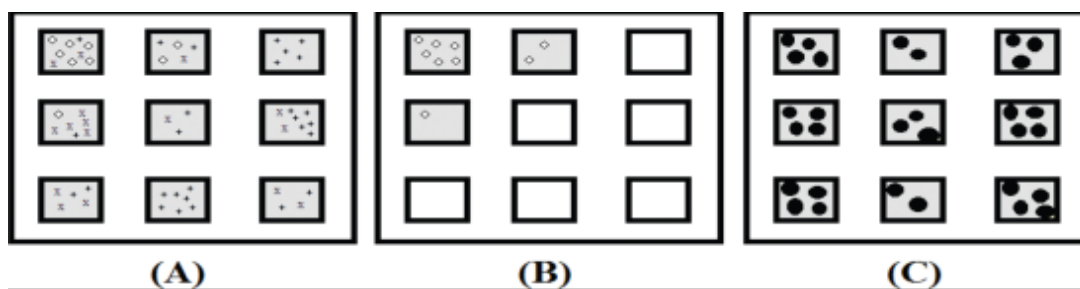


Figure 4: An experimental plot layout on data collection for herbage species composition, species richness, basal cover, and biomass productivity.

Source: Concenço *et al.* (2013).

Focus group discussion involved purposefully selected 12 participants per each group; 2 groups; a total of 24 participants with 1 session for each group per village; key informants interview involved purposefully selected, 10 participants; and questionnaire survey involved simple randomly selected 30 hamlets households representatives (10 hamlets) for both villages to obtain their indigenous knowledge and skills views for each qualitative method (Bosco *et al.*, 2015).

3.3.4 Sampling frame

Sampling frames in the study were the Simanjiro Maasai steppe rangelands and Maasai communities (i.e. rangeland herbage and hamlet representatives of the two villages, namely Terrat and Sukuro). Terrat and Sukuro village grazing lands were selected as representative of the Simanjiro district and in particular, the area where livestock and wild ungulates coexist. Maasai communities involved were hamlet representatives at Terrat and Sukuro villages for Questionnaires survey (Table 2). Focus group discussions participants were 24. Also, key informant interview participants were 10 official staffs and leaders from hamlet to district level.

Table 2: Maasai communities' participants for the socio-economic survey

Participants for a socio-economic survey	Terrat village	Sukuro village	% of the total at Terrat village	% of the total at Sukuro village
Maasai hamlet	10	5	50	100
Maasai hamlet representatives	15	15	50	100
Focus group discussions participants	12	12	100	100

3.3.5 Sampling unit

Temporally rectangle sample quadrats of 1 meter in each grazing land were the sampling unit in the current study within which determination of effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage species composition, species richness and basal cover and biomass productivity, respectively, was conducted. While % acre estimate was the sampling unit for habitat distribution of *Ipomoea hildebrandtii* and *I. kituiensis*. Also, the % of responses was the sampling unit for available mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands.

3.3.6 Sampling intensity and size

The current study adopted a sampling intensity of 0.04% which is equivalent to 20 ha as temporally rectangle sample plots with a total 180 temporally rectangle sample quadrats. Total area at Terrat is 23,000 ha and Sukuro is 23,000 ha for the SCEA grazing land hectares which are 76,000 ha for three villages. The sampling intensity in the current study was low. Financial status, time limitation, and purpose of the determination on the effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage species composition, species richness and basal cover and biomass productivity in the grazing lands, necessitate the sampling intensity to be small as adopted by Crowder and Chheda (1982). Although the sampling intensity in the current study was low compared to Crowder and Chheda (1982) but is still enough to provide conclusions on the effect of invasive *Ipomoea* spp. on herbaceous loss of native species. About habitat distribution of *Ipomoea hildebrandtii* and *I. kituiensis* sampling intensity of 100% and % 50% for Terrat and Sukuro village land areas, respectively, was adopted. Also, study adopted a sampling intensity of 50% which is equivalent to 5 hamlets at Terrat village, while at Sukuro village was 100% which is

equivalent to 5 hamlets for available mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands.

3.4 Data collection techniques

3.4.1 Types of data

Data on effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage species composition, species richness and basal cover and biomass productivity as well as habitat distribution of *Ipomoea hildebrandtii* and *I. kituiensis*; and mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands were collected in form of primary data only. These data were collected at the Terrat and Sukuro villages, during five months of data collection (from December 2017 to April 2018).

3.4.2 Data collection methods

A study involved field survey observations on determination of effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage species composition, species richness and basal cover and biomass productivity. Also, a study employed a field survey observations on habitat distribution of *Ipomoea hildebrandtii* and *I. kituiensis*. Socio-economic survey was employed on the evaluation of the available mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands.

3.4.3 Data collection tools

The current study relied on field survey for herbage observations and clipping as a quantitative method on the determination of effect of *Ipomoea hildebrandtii* and *I.*

kituiensis on herbage species composition, species richness and basal cover and biomass productivity. Determination of habitat distribution of *Ipomoea hildebrandtii* and *I. kituiensis* was through field survey observations. While PRA (focus group discussions), key informants interviews and questionnaire survey were used as a qualitative method on available mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands.

3.4.4 Field assessment

3.4.4.1 Herbage species composition, species richness and basal cover

Herbage species were identified into their respective botanical nomenclature by using an experienced rangeland specialist. Herbage species composition and basal cover (%) were visually estimated as a proportion of an area under vegetation in each quadrat, for every 10 plots (acres) in both invaded and non-invaded grazing lands (Crowder and Chheda, 1982).



(a)



(b)



(c)



(d)

Plate 1: Showing (a) setting of GPS; (b) demarcation of the plot; (c) recording of herbage species composition, species richness and basal cover and biomass productivity; (d) identifications of herbage species in the herbarium room.

A computation for species richness was according to formula following (Sadek, 2015):

Species richness (R): $R = S / A$

Where R is species richness; S is a total number of different species present in an area, a is an area under study.

3.4.4.2 Herbage biomass productivity

Herbage foliage was clipped by hand sickles at 2.5 cm above the ground. Fresh weight (W_1) was immediately determined in the field using a 0.01 precision digital scale. The harvested samples, after weighed in-situ fresh weight of sub-samples, were transferred into a forced air oven at 60°C (constant weight) for 48 hours in the laboratory to remove moisture contents. Dry sub-samples were reweighed to obtain a dry weight and recorded as W_2 to be used as a conversion factor to obtain an overall dry weight of herbage measured in-situ for DM determination and bulked by

plots and by grazing lands. Herbage yield (tonne, t DM/ha) was estimated (Crowder and Chheda, 1982).

Dry matter (DM) was computed as: -

$$\text{DM (\%)} = \frac{\text{Weight of oven dry sample}}{\text{Flesh weight sample}} * 100.$$

Herbaceous biomass productivity expressed in DM. The DM yield productivity (t DM/ha) was determined according to the formulae:

$$\text{Herbaceous biomass productivity (t DM/ha)} = \frac{\text{Average DM yield} * 10000 \text{ m}^2}{1 \text{ m}^2}$$



(a)



(b)



(c)



(d)



(e)



(f)

Plate 2: Showing (a) measurement of herbage height; (b) and (c) recording of herbage species composition, species richness and basal cover and biomass productivity; (d) measurement of sample fresh weight; (e) drying of sample in the oven; (f) measurement of sample dry weight.

3.4.4.3 Habitat distribution of *Ipomoea hildebrandtii* and *I. kituiensis*

Ipomoea plant species of interest across grassland and woodland habitats using a transect walk were indicated based on percentage acre estimation coupled with their geographical locations distribution by using a Global Positioning System (GPS) (Kija *et al.*, 2013).

3.4.4.4 Mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis*

Mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands were evaluated using focus group discussions (2 groups and 1 session of 1 hour to 2.5 hours for each group per village). Also, key informants interviews and questionnaire survey were used as qualitative methods (Bosco *et al.*, 2015).



(a)



(b)

Plate 3: Showing (a) focus group discussions at Sukuro village; (b) focus group discussions at Terrat village.

3.5 Data analysis techniques

3.5.1 Herbage species composition, species richness and basal cover

Data on effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage species composition, species richness and basal cover between invaded and non-invaded grazing lands in Simanjiro Maasai steppe rangelands were analysed in terms of two group *t*-test samples (Frost and Smith, 1991). Data on herbage species composition, species richness and basal cover due to effect of *Ipomoea hildebrandtii* and *I. kituiensis* were analysed into a mean and standard error using the STATA by independent two-sample *t*-test. However, STATA was used for Generalized Linear Model (GLM) procedure, under statistical model shown below:

$$Y_{ijk} = \mu_{ijk} + V_i + S_j + H_k + (V*S)_{ij} + (V*H)_{ik} + (S*H)_{jk} + (V*S*H)_{ijk} + \epsilon_{ijk}$$

Whereby;

Y_{ijk} = General response on herbage basal cover under investigation.

μ_{ijk} = General mean peculiar to each observation in each grazing land(s).

$V_i = i^{th}$ effect of villages on herbage basal cover.

$S_j = j^{th}$ effect of sites on herbage basal cover.

$H_k = k^{th}$ effect of herb type on herbage basal cover.

$(V*S)_{ij}$ = Interactive effect of villages and sites on herbage basal cover.

$(V*H)_{ik}$ = Interactive effect of villages and herb type on herbage basal cover.

$(S*H)_{jk}$ = Interactive effect of sites and herb type on herbage basal cover.

$(V*S*H)_{ijk}$ = Interactive effect of villages, sites and herb type on herbage basal cover.

\mathcal{E}_{ijk} = Random error term of each estimate.

3.5.2 Herbage biomass productivity

Data on effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage biomass productivity between invaded and non-invaded grazing lands in Simanjiro Maasai steppe rangelands were analysed in terms of two group *t*-test samples (Frost and Smith, 1991). Data on herbage biomass productivity due to effect of *Ipomoea hildebrandtii* and *I. kituiensis* were analysed into a mean and standard error using the STATA by independent two-sample *t*-test. However, STATA was used for Generalized Linear Model (GLM) procedure under the statistical model shown below:

$$Y_{ij} = \mu_{ij} + V_i + S_j + (V*S)_{ij} + \mathcal{E}_{ij}$$

Whereby;

Y_{ij} = General response on biomass productivity under investigation.

μ_{ij} = General mean peculiar to each observation in each grazing land(s).

$V_i = i^{th}$ effect of villages on biomass productivity.

$S_j = j^{th}$ effect of sites on biomass productivity.

$(V*S)_{ij}$ = Interactive effect of villages and sites on biomass productivity.

\mathcal{E}_{ij} = Random error term of each estimate.

3.5.3 Habitat distribution pattern of *Ipomoea hildebrandtii* and *I. kituiensis*

Data on the distribution pattern of *Ipomoea hildebrandtii* and *I. kituiensis* across grassland and woodland habitats were analysed into a descriptive statistics using the Microsoft software by excel based on percentage acre estimation coupled with their geographical locations distribution showing encroachment locations of an *Ipomoea hildebrandtii* and *I. kituiensis* (Kija *et al.*, 2013).

3.5.4 Mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis*

Data on available mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands were analysed quantitatively into a descriptive multiple response sets using the statistical packages for social sciences (SPSS) software. The SPSS output was generated as descriptions of tables (Bosco *et al.*, 2015).

3.6 Validity and reliability of the study

Validity and reliability address issues concerning the quality of data and an appropriateness of the methods used in carrying out the research project (Kothari, 2004).

3.6.1 Validity

Validity refers to the degree to which an instrument measures what it is supported to measure (Kothari, 2004). In the current study, different strategies were used to ensure the validity of the study included prior research, reconnaissance and

preliminary surveys in Simanjiro rangeland plains and pre-testing of data collection tools. Invaded and non-invaded areas were systematically identified. In addition, duplicates and triplicates of samples during data analysis where applicable was employed. Clear set up of the field and experimental procedures to match the objectives were taken into account during field and laboratory works. As a result of a survey, square plots, their pace transects and square quadrats between invaded and non-invaded Maasai steppe grazing lands were identified.

Reconnaissance survey first was employed to define in detail parameters of detailed assessment, test efficiency of methods and materials, and solve all problems which were encountered on the determination of herbage species composition, species richness and basal cover and biomass productivity loss due to *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe grazing lands.

3.6.2 Reliability

Reliability refers to the extent to which the results are consistent over time an accurate representation of the total population under study (Robson *et al.*, 2002). It is concerned with making sure that the methods of data collection lead to consistent results. In the current study, various techniques were employed to ensure the reliability of the study, such that data collection tools were pre-tested (trial administration of an instrument to identify flaws), (Polit and Hungler, 1995). Also, training of research assistant, a local interpreter in both Maasai and rangeland management, and experienced rangeland specialist was conducted. Similarly, tools were constructed very carefully based on the theories and objectives of the study and

frequently reviewed during data collection as well as verification of findings being certain.

A current study used a mixture of techniques which were experimental field survey and observations and measurements; and questionnaires, key informant interviews, and focus group discussions. Careful review and triangulation of data collection instruments in data collection were employed. If techniques came out with related data then data were valid and reliable.

CHAPTER FOUR

Results

4.1 Effect of invasive *Ipomoea* species on herbage species composition, species richness and basal cover

4.1.1 Effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage species composition

Results on grass species composition between invaded and non-invaded grazing lands are presented in Table 3. There was no difference in grass species composition between invaded and non-invaded grazing lands ($P>0.05$). *Digitaria* spp. were dominant grass species in both invaded and non-invaded grazing lands by (27.1%) and (20.5%), respectively, followed by other grasses species as indicated in Table 3. *Brachiaria* spp. (21.4%) emerged as dominant grass species in non-invaded grazing lands only. However, grass species such as *Digitaria* spp., *Cynodon dactylon*, *Aristida stipoides*, *Urochloa* spp., *Nandi setaria*, *Cyperus rotundus*, *Melinis minutiflora*, *Sporobolus spicatus* and *Themeda* spp. were much more frequent in invaded than non-invaded grazing lands. Moreover, grass species such as *Cenchrus ciliaris*, *Brachiaria* spp., *Hyperrhenia* spp., *Eragrostis* spp., *Bothrochloa insculpta* and *Dactyloctenium aegyptium* were much less frequent in invaded than non-invaded grazing lands.

Table 3: Grass species composition (%) between invaded and non-invaded grazing lands

Grass species	Species composition (%)	
	Invaded lands	Non-invaded lands
<i>Digitaria</i> spp.	27.1	20.5
<i>Cynodon dactylon</i>	21.8	14.4
<i>Aristida stipoides</i>	11.4	1.4
<i>Urochloa</i> spp.	8.3	4.7
<i>Nandi setaria</i>	7.0	3.7
<i>Cyperus rotundus</i>	6.6	6.5
<i>Melinis minutiflora</i>	5.2	0.0
<i>Sporobolus spicatus</i>	2.6	1.9
<i>Cenchrus ciliaris</i>	2.3	7.8
<i>Themeda</i> spp.	2.2	1.9
<i>Brachiaria</i> spp.	1.7	21.4
<i>Hyperrhenia</i> spp.	1.7	2.8
<i>Eragrostis</i> spp.	1.3	6.5
<i>Bothrochloa insculpta</i>	0.4	0.9
<i>Dactyloctenium aegyptium</i>	0.4	5.6
Total	100.0	100.0

Results on forb species composition between invaded and non-invaded grazing lands are presented in Table 4. There was no difference in forb species composition between invaded and non-invaded grazing lands ($P>0.05$). *Gutenbergia cordifolia* was a dominant forb species in both invaded and non-invaded grazing lands by (14.3%) and (24.3%), respectively, followed by other forb species as indicated in Table 4. However, forb species such as *Justicia exigua*, *Convolvulus sagittatus*, *Macrotyloma maranguense*, *Commelina benghalensis*, *Pentas lanceolata*, *Stylosanthes* spp., *Asytasia schimperii*, *Leonotis nepetifolia*, were much more frequent in invaded than non-invaded grazing lands. Other forb species such as *Crotalaria spinosa*, *Euphorbia crotonoides*, *Justicia nyassana*, *Sida ovate*, *Solanum incunum*, *Leucas globrata*, *Senecio ruwenzoriensis* and *Zehneria scabra* were also much more frequent in invaded than non-invaded grazing lands. Moreover, forb species such as *Gutenbergia cordifolia*, *Oxygonum sinuatum*, *Tephrosia ehrenbergiana*, *Cyathula cylindrical*, *Crotalaria* sp., *Barleria ramulosa*, *Emilia javanica*, *Crotalaria polysperma*, and *Centroschema* spp. were much less frequent in invaded than non-invaded grazing lands.

Table 4: Forb species composition (%) between invaded and non-invaded grazing lands

Forb species	Species composition (%)	
	Invaded grazing lands	Invaded grazing lands
<i>Gutenbergia cordifolia</i>	14.3	23.4
<i>Oxygonum sinuatum</i>	14.3	14.7
<i>Cyathula cylindrica</i>	2.2	11.9
<i>Tephrosia ehrenbergiana</i>	10.2	11.2
<i>Solanum incunum</i>	13.1	10.4
<i>Convolvulus sagittatus</i>	10.8	8.6
<i>Commelina benghalensis</i>	5.6	3.6
<i>Crotalaria</i> sp.	0.0	3.2
<i>Macrotyloma maranguense</i>	6.7	2.9
<i>Barleria ramulosa</i>	1.3	2.5
<i>Emilia javanica</i>	0.0	2.5
<i>Justicia exigua</i>	11.8	2.2
<i>Crotalaria polysperma</i>	0.0	1.4
<i>Leucas globrata</i>	1.9	0.7
<i>Pentas lanceolata</i>	3.2	0.4
<i>Centroschema</i> spp.	0.0	0.4
<i>Stylosanthes</i> spp.	1.6	0.0
<i>Asytasia schimperi</i>	0.6	0.0
<i>Leonotis nepetifolia</i>	0.6	0.0
<i>Crotalaria spinosa</i>	0.3	0.0
<i>Euphorbia crotonoides</i>	0.3	0.0
<i>Justicia nyassana</i>	0.3	0.0
<i>Sida ovata</i>	0.3	0.0
<i>Zehneria scabra</i>	0.3	0.0
<i>Senecio ruwenzoriensis</i>	0.3	0.0
Total	100.0	100.0

4.1.2 Effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage species richness

Results on herbage species richness between invaded and non-invaded grazing lands during the study are presented in Table 5. Invaded grazing lands had higher species richness plus 2 species of *Ipomoea* (*Ipomoea hildebrandtii* and *I. kituiensis*) (total 36, range 14-23) than non-invaded grazing lands (total 30, range 12-18). Thus species richness between invaded and non-invaded grazing lands was relatively variable.

4.1.3 Effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage basal cover

Table 6 show results on herbage basal cover between invaded and non-invaded grazing lands. Terrat grazing lands had higher basal cover (51.86%±1.84%) of *Ipomoea hildebrandtii* and *I. kituiensis* than Sukuro grazing lands (40.15%±2.44%), ($P<0.001$), Table 6.

Generally, invaded grazing lands in the study area had 46.01%±2.14% as the mean basal cover of *Ipomoea hildebrandtii* and *I. kituiensis* compared to grasses and forb, Table 6. Invaded grazing lands had lower basal cover (29.38%±1.34%) for grasses than non-invaded grazing lands (54.71%±1.95%), ($P<0.001$), Table 6. Moreover, invaded grazing lands had lower basal cover (24.70%±1.20%) of forb species than non-invaded grazing lands (45.29%±1.95%), ($P<0.001$), Table 6.

Invasive *Ipomoea* spp. were associated with a 46% reduction in basal cover for both grass and forb species as separate herbage type or as a combination of the two

herbage type. Invaded grazing lands had herbage basal cover reduced by 46% due to the presence of invasive *Ipomoea* spp.



Plate 4: Showing spread of *Ipomoea kituiensis* across a tree.



(a)



(b)

Plate 5: Showing (a) observations of herbage basal cover and biomass productivity in non-invaded grazing lands; (b) spread of *Ipomoea hildebrandtii* and *I. kituiensis*.

Table 5: Herbage type with respect to the number of species between invaded and non-invaded grazing lands

Range number of species per herb type and grazing lands		
Herb type	Invaded grazing lands (No Spp.)	Non-invaded grazing lands (No Spp.)
Grasses	Total 15 (range 5 to 11)	Total 14 (range 5 to 10)
Forb species	Total 21 (range 7 to 18)	Total 16 (range 6 to 10)

Table 6: Herbage basal cover between invaded and non-invaded grazing lands

Herbage type	Mean basal cover (%)		Effect of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> on basal cover
	Invaded grazing lands	Non-invaded grazing lands	
<i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i>	46.01±2.14 ^a	n.a	n.a
Grasses	29.38±1.34 ^b	54.71±1.95 ^a	*
Forb species	24.70±1.20 ^c	45.29±1.95 ^b	*

n.a = not applicable

a, b, c Means with the same superscripts along the same column do not significant ($P>0.05$) different. NS: Not significant ($P>0.05$). * Significantly different ($P<0.05$).

GLM Source	DF	Type I SS	Mean Square	F Value	Pr > F
Village	1	0.32000	0.32000	0.00	0.9703
Site	1	30233.78704	30233.78704	131.39	<.0001
Herb	2	25902.93519	12951.46759	56.29	<.0001
Village*Site	1	0.31148	0.31148	0.00	0.9707
Village*Herb	2	4887.21296	2443.60648	10.62	<.0001
Site*Herb	1	457.87778	457.87778	1.99	0.1591
Village*Site*Herb	1	2602.84444	2602.84444	11.31	0.0008

GLM Source	DF	Type III SS	Mean Square	F Value	Pr > F
Village	1	204.81446	204.81446	0.89	0.3460
Site	1	47794.17778	47794.17778	207.71	<.0001
Herb	2	25902.93519	12951.46759	56.29	<.0001
Village*Site	1	745.34444	745.34444	3.24	0.0726
Village*Herb	2	4887.21296	2443.60648	10.62	<.0001
Site*Herb	1	457.87778	457.87778	1.99	0.1591
Village*Site*Herb	1	2602.84444	2602.84444	11.31	0.0008

4.2 Effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage biomass productivity

Table 7 and 8, indicate results on herbage biomass productivity between invaded and non-invaded grazing lands. Invaded grazing lands had lower herbage biomass productivity (0.202 ± 0.02 t DM/ha) than non-invaded grazing lands (0.289 ± 0.03 t DM/ha), ($P < 0.01$), Table 8. Invaded grazing lands in the study area had herbage biomass productivity reduced by 30% in the presence of grazing by wild ungulates mammals.

Table 7: Range – biomass productivity with respect to the village and grazing lands

Grazing land	Invaded grazing land (t DM/ha)	Non-invaded grazing land (t DM/ha)
Terrat	0.06 - 0.33	0.02 - 0.75
Sukuro	0.01 - 0.85	0.05 - 2.07

Table 8: Herbage biomass productivity between invaded and non-invaded grazing lands

Grazing land	Mean biomass productivity (t DM/ha)
Invaded grazing lands	0.202±0.021 ^a
Non-invaded grazing lands	0.289±0.030 ^b

^{a, b}, Means with the same superscripts along the same column do not significant ($P>0.05$) different.

GLM Source	DF	Type I SS	Mean Square	F Value	Pr > F
Site	1	0.33687427	0.33687427	8.06	0.0051
Village	1	0.17703347	0.17703347	4.24	0.0410
Site*Village	1	0.00654014	0.00654014	0.16	0.6929

GLM Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	1	0.33687427	0.33687427	8.06	0.0051
Village	1	0.17703347	0.17703347	4.24	0.0410
Site*Village	1	0.00654014	0.00654014	0.16	0.6929

4.3 Habitat distribution of *Ipomoea hildebrandtii* and *I. kituiensis*

Results on the distribution of *Ipomoea hildebrandtii* and *I. kituiensis* across grassland and woodland habitats of Maasai steppe rangelands are also demonstrated Table 9.

Habitat distribution of *Ipomoea hildebrandtii*, *I. kituiensis* per acre estimation in % was variable in range. Woodland (3-70%); bush woodland (0%); grass woodland (1-90%). Woodland, wood grassland and grass woodland, as 70.0%, 80.0%, and 90.0%, respectively, had maximum higher distribution of *Ipomoea hildebrandtii* and *I. kituiensis* in the study area.



(a)



(b)

Plate 6: Showing (a) spread of *Ipomoea hildebrandtii* and *I. kituiensis*; (b) spread of unpalatable perennial herb species.

Table 9: Habitat distribution of *Ipomoea hildebrandtii*, and *I. kituiensis*

Habitat	Range distribution (%)
Grass bushland	1-30
Grassland	3-20
Wood grassland	3-80
Woodland	3-70
Bush woodland	0
Grass woodland	1-90

4.4 Available mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands

Results on available mitigation measures among the Maasai pastoralists on effects of *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands of Simanjiro district are also indicated in Table 10, 11, 12 and 13.

4.4.1 Dispersal mechanism and spread of *Ipomoea hildebrandtii* and *I. kituiensis* invasion in the rangelands

The extend coverage of *Ipomoea hildebrandtii* and *I. kituiensis* were 50.0% and 70.0% at Sukuro and Terrat villages, respectively. However, Maasai communities of both Terrat and Sukuro villages were aware of the adverse effect of *Ipomoea* plants by 100.0%. Moreover, during the study, there were no documented casually cases about domestic animals affected, or killed by *Ipomoea* plants.

Spread of *Ipomoea hildebrandtii* and *I. kituiensis* it was perceived that were mainly ascribed to the immigration of livestock and wildlife immigrants (73.3%) as indicated in Table 10. Invaded rangelands were adjacent to roads mostly dominated by invasive *Ipomoea* species such as *I. hildebrandtii*.

4.4.2 Mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in the rangelands

There were no any mitigation measures for controlling of *Ipomoea hildebrandtii* and *I. kituiensis* at the community level. However, reported mitigation measures was at a family level only. Available mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands are indicated in Table 11.

Mechanical uprooting (100.0%, N=30) was the preferable eradication control for *Ipomoea hildebrandtii* and *I. kituiensis* in both Terrat and Sukuro villages. Moreover, in both Terrat and Sukuro villages, there was (100.0%) no use of herbicides for the eradication of *Ipomoea hildebrandtii* and *I. kituiensis*. The study generally found that more practised mitigation measures were uprooting.

Table 10: Dispersal mechanism and spread of *Ipomoea hildebrandtii* and *I. kituiensis* invasion in the rangelands

Dispersal mechanism and spread	Responses (N=30)	
	Cases (n/30)	Per cent (%)
Movements of materials for construction	15	50.0
Movements of materials for gardens	12	40.0
Movements of materials for crop cultivation	14	46.7
Human immigrants	13	43.3
Livestock and wildlife immigrants	22	73.3
Invasion by other reasons	4	13.3

Table 11: Mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in the rangelands

Mitigation measures for invasive <i>Ipomoea</i> spp.	Responses (N=30)	
	Cases (n/30)	Per cent (%)
Preventing alive plant species importation via immigrants	12	40.0
Mitigation mechanically by uprooting	30	100.0
Sward burning of uprooted staff	14	46.7

4.4.3 Effectiveness of mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in the rangelands

Effectiveness of practised mitigation measures among the Maasai pastoralists on effect of *Ipomoea hildebrandtii* and *I. kituiensis* it was perceived by Maasai communities of the Terrat and Sukuro villages, Table 12. Mechanical uprooting (80.0%), the application of herbicides (93.0%) were mitigation measures with high effectiveness.

4.4.4 Proposed alternative mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in the rangelands

Proposed mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* by Maasai communities of both Terrat and Sukuro villages, with respect to perception (%), are presented in Table 13. The proposed alternative mitigation measures were applications of herbicides (83.3%) and mechanical uprooting (16.7%).

Table 12: Effectiveness of mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in the rangelands

Mitigation measures	Effectiveness of mitigation measures (%)		
	Effective (N=30)	Fairly effective (N=30)	Not effective (N=30)
Importation via immigrants	0	50	50
Mechanical uprooting	3	77	20
The use of herbicides	40	53	7
Sward burning of uprooted staff	0	47	53

Table 13: Proposed alternative mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in the rangelands

Proposed alternative mitigation measures	Responses (N=30)	
	Cases (N)	Per cent (%)
Herbicides application	25	83.3
Mechanical uprooting	5	16.7
Total	30	100.0

CHAPTER FIVE

Discussions

5.1 Effect of invasive *Ipomoea* species on herbage species composition, species richness and basal cover

5.1.1 Effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage species composition

The reported dominant grass such as *Digitaria* spp., *Cynodon dactylon*, *Aristida stipoides*, *Urochloa* spp., *Nandi setaria*, *Cyperus rotundus*; and forb species for instance *Gutenbergia cordifolia*, *Oxygonum sinuatum*, *Cyathula cylindrical*, *Tephrosia ehrenbergiana*, *Solanum incunum*, *Convolvulus sagittatus*, *Commelina benghalensis* in rangeland both invaded and not-invaded with *Ipomoea* spp. in the current study denote grass and forb species native to semi-arid ecosystems and Maasai steppe rangelands of the Simanjiro plains as well as due to the presence of *Ipomoea hildebrandtii* and *I. kituiensis*. Grass species such as *Aristida* spp. and *Cenchrus* spp. are good indicators of semi-aridity zones of East Africa (Pratt and Gwynne, 1977).

The noted relatively similarity in terms of both grass and forb species composition between invaded and non-invaded lands in the current study contradict to previously finding of lower grass and forb species composition in invaded lands than non-invaded lands in the arid and semi-arid ecosystem of the northern coastal region of Egypt (Sadek, 2015).

The recorded similarities in grass and forb species composition between invaded and non-invaded grazing lands presented in the current study could largely be ascribed to

specific site characteristics such as edaphic factors including soil characteristics, soil fertility status and rainfall pattern with respect to less variability in moisture holding capacity. Some sites for instance on valley bottoms hold moisture relatively longer than sites on relatively loose soil/sandy/loamy and even on relatively higher elevations. However, the documented contradiction for similarities of grass and forb species composition between invaded and non-invaded grazing lands in the current study with other studies Sadek (2015) could largely be associated to sward management with respect to grazing pressure, difference between ecological sites, with respect to precipitation and soil characteristics as well as management intervention.

The observed dominant *Digitaria* spp. in the current study has been similarly reported Mganga *et al.* (2010a) among other to dominate the grazing lands of semi-arid ecosystems in the southern region of Kenya as well in the Maasai steppe rangelands (Kahurananga, 1979). The reported dominance of native *Gutenbergia cordifolia* in the current study has similarly been documented such as to dominate the grazing lands of semi-arid ecosystems of Ngorongoro Conservation Area Authority (NCCA) of Tanzania (Estes *et al.*, 2006).

Digitaria-Panicum represents the dominant grass species of the Simanjiro plains (Kahurananga, 1979). The noted domination of *Digitaria* spp. is mostly ascribed to their preference to soils with relatively higher moisture contents, for instance, the Simanjiro plain loamy soils. *Gutenbergia cordifolia* represents the dominant forb species of the Maasai steppe ecosystem in Tanzania (Estes *et al.*, 2006). The recorded dominance of *Gutenbergia cordifolia* could mostly be associated to their

relatively higher successional colonization as a native species which frequently grow and recover large areas, establishing tall, dense herb stands that can persist after a dry season. However, the documented similarities for dominant grass and forb species composition in both invaded and non-invaded grazing lands in the current study with other studies Kahurananga (1979), Estes *et al.* (2006) could largely be associated to similarities between ecological sites, with respect to precipitations edaphic factors and management intervention.

On the other hand, the observed more frequent *Digitaria* spp., *Cynodon dactylon*, *Justicia exigua* and others in invaded than non-invaded grazing lands could be mostly explained by their relative tolerances on competitions from *Ipomoea hildebrandtii* and *I. kituiensis*. The reported *Ipomoea hildebrandtii* and *I. kituiensis* were acting as obstacles to grass and forb species for their grazing and overstocking. Overgrazing as a result induced by herbivore populations could exert pressure on the semi-arid ecosystems leading to degraded pastures (Mganga *et al.*, 2010b).

The noted less frequent *Brachiaria* spp. *Gutenbergia cordifolia*, *Cyathula cylindrica*, and others in invaded than non-invaded grazing lands could be mostly explained by their relative intolerances on competitions from *Ipomoea hildebrandtii* and *I. kituiensis*. Invasive *Ipomoea* spp. are annual herb, widespread in semi-arid areas which colonize and spreads rapidly immediately after onset of rain seasons (Mganga *et al.*, 2010a). *Ipomoea hildebrandtii* and *I. kituiensis* are also capable of effective competition with local species for nutrients, space, light, and water (Bosco *et al.*, 2015).

5.1.2 Effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage species richness

The reported relatively higher species richness of invaded than non-invaded grazing lands in the current study denotes species richness for grass and forb native to semi-arid ecosystems and Maasai steppe rangelands of the Simanjiro plains as well as due to the presence of *Ipomoea hildebrandtii* and *I. kituiensis*.

The noted relatively higher species richness in invaded (36) than non-invaded (30) grazing lands in the current study contradict to previously finding of lower (27) herbage species richness than non-invaded lands (50) in the arid and semi-arid ecosystem of the northern coastal region of Egypt (Sadek, 2015).

However, the recorded relatively higher species richness in invaded (36) than non-invaded (30) grazing lands presented in the current study could largely be associated to the relative tolerances of many herbage species on competitions from *Ipomoea hildebrandtii* and *I. kituiensis*. The documented *Ipomoea hildebrandtii* and *I. kituiensis* were acting as obstacles to grass and forb species for their grazing and overstocking. Overgrazing as a result induced by herbivore populations could exert pressure on the semi-arid ecosystems leading to degraded pastures (Mganga *et al.*, 2010b).

Moreover, the observed variability for the relatively higher species richness in invaded than non-invaded grazing lands presented in the current study with other studies Sadek (2015) could largely be associated to more difference between ecological site, with respect to precipitation, soil characteristics, as well as sward management intervention.

5.1.3 Effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage basal cover

The reported relatively higher basal cover of *Ipomoea hildebrandtii* and *I. kituiensis* at Terrat than Sukuro invaded grazing lands in the current study denote the mean basal cover of *Ipomoea hildebrandtii* and *I. kituiensis* compared to other herbages to semi-arid ecosystems and Maasai steppe rangelands of the Simanjiro plains. Also, the noted relatively lower basal cover of grasses and forb in the invaded than non-invaded grazing lands in the current study denote basal cover for grasses and forb native to semi-arid ecosystems and Maasai steppe rangelands of Simanjiro plains as well as due to the presence of *Ipomoea hildebrandtii* and *I. kituiensis*.

The recorded relatively mean basal cover of 46% of *Ipomoea hildebrandtii* and *I. kituiensis* compared to other herbages in the current study is lower than 69.5% compared to other herbages in the grazing lands of semi-arid ecosystems in the southern region of Kenya (Mworia *et al.*, 2008). Also, the documented relatively mean basal cover of 46% of invasive *Ipomoea* spp. in the current study contradict to previously finding as 2.52% compared to other herbages in the grazing lands of semi-arid ecosystems in Simanjiro plains of Tanzania by 1972 (Kahurananga, 1979).

However, the observed higher basal cover of *Ipomoea hildebrandtii* and *I. kituiensis* at Terrat than Sukuro invaded grazing lands presented in the current study could largely be explained by the reason that Terrat grazing lands are within a village suspected to be the origin area for the invasion of *Ipomoea hildebrandtii* and *I. kituiensis*. *Ipomoea hildebrandtii* and *I. kituiensis* were there in the Maasai steppe rangelands plains since the early 1960s (Bosco *et al.*, 2015). *Ipomoea hildebrandtii*

and *I. kituiensis* then become invasive due to change in climate (*El Nino*) during 1998 season.

Also, the reported relatively mean basal cover of 46% of *Ipomoea hildebrandtii* and *I. kituiensis* compared to other herbage presented in the current study could largely be ascribed to grazing and overstock pressure. Overgrazing as a result induced by herbivore populations could exert pressure on the semi-arid ecosystems leading to degraded pastures (Mganga *et al.*, 2010b).

Moreover, the noted variability for the relatively mean basal cover of 46% of *Ipomoea hildebrandtii* and *I. kituiensis* compared to other herbage presented in the current study with other studies Mworira *et al.* (2008) could largely be associated with differences between ecological sites, with respect to precipitation and soil characteristics as well as sward management intervention. Also, the recorded variability for the relatively mean basal cover (46%) of *Ipomoea hildebrandtii* and *I. kituiensis* compared to other herbage in the grazing lands of semi-arid ecosystems in Simanjiro plains by 1972 Kahurananga (1979) and the current year 2018 could largely be associated to change in climatic factors and grazing pressure.

The documented relatively lower basal cover of grasses and forb in the invaded than non-invaded grazing lands in the current study have similarly been reported in grazing lands of semi-arid ecosystems in the southern region of Kenya (Mworira *et al.*, 2008).

The observed lower basal cover of grasses and forb in invaded than non-invaded grazing lands is mostly explained by their relative suppression due to competitions

from *Ipomoea hildebrandtii* and *I. kituiensis*. Invasive *Ipomoea* spp. are annual herb, widespread in semi-arid areas which colonize and spreads rapidly immediately after onset of rain seasons (Mganga *et al.*, 2010a). *Ipomoea hildebrandtii* and *I. kituiensis* are also capable of effective competition with local species for nutrients, space, light, and water (Bosco *et al.*, 2015). *Ipomoea hildebrandtii* and *I. kituiensis* which are invasive plant species depresses native herbage nearby or under their canopies (DiTomaso, 2000; Foxcroft *et al.*, 2006).

In addition, a fresh and heavy vegetative part of *Ipomoea* also suppresses a growth and development of herbage underneath it resulting in high incidences of seedling mortality. This consequently results in poor establishment and much of bared areas remain bare after a disappearance of weed at end of rain seasons as noted elsewhere (Mganga *et al.*, 2010b).

Moreover, the reported similarities for the relatively lower basal cover of grasses and forb in the invaded than non-invaded grazing lands presented in the current study with other studies Mworira *et al.* (2008) could largely be associated to similarity between ecological sites, with respect to precipitation and soil characteristics as well as sward management intervention.

5.2 Effect of *Ipomoea hildebrandtii* and *I. kituiensis* on herbage biomass productivity

The reported relatively lower herbage biomass productivity in the invaded than non-invaded grazing lands in the current study denote herbage biomass productivity native to semi-arid ecosystems and Maasai steppe rangelands of the Simanjiro plains

as well as due to the presence of *Ipomoea hildebrandtii* and *I. kituiensis*. The noted relatively lower herbage biomass productivity in the invaded than non-invaded grazing lands in the current study has similarly been reported in grazing lands of semi-arid ecosystems in the southern region of Kenya (Mworia *et al.*, 2008). It is reported that invasive *Ipomoea* spp. in the presence of grazing they led to the decline of 28% herbage biomass productivity.

The recorded lower herbage biomass productivity in invaded than non-invaded grazing lands could mostly be explained by their relative suppression due to competition from *Ipomoea hildebrandtii* and *I. kituiensis*. Invasive *Ipomoea* spp. are annual herb, widespread in semi-arid areas which colonize and spreads rapidly immediately after onset of rain seasons (Mganga *et al.*, 2010a). *Ipomoea hildebrandtii* and *I. kituiensis* are also capable of effective competition with local species for nutrients, space, light, and water (Bosco *et al.*, 2015). *Ipomoea hildebrandtii* and *I. kituiensis* which are invasive plant species depresses native herbages nearby or under their canopies (DiTomaso, 2000; Foxcroft *et al.*, 2006). This consequently results in poor establishment and much of the bared areas remain bare after a disappearance of weed at end of rain seasons (Mganga *et al.*, 2010b).

Moreover, the documented similarities for relatively lower herbage biomass productivity in the invaded than non-invaded grazing lands presented in the current study with other studies Mworia *et al.* (2008) could largely be associated to the similarity between ecological sites, with respect to precipitation and soil characteristics as well as sward management intervention.

5.3 Habitat distribution of *Ipomoea hildebrandtii* and *I. kituiensis*

The reported relatively higher distribution of *Ipomoea hildebrandtii*, *I. kituiensis* per acre estimation in woodland, wood grassland and grass woodland habitats in the current study denote unequal distribution of invasive *Ipomoea* spp. across grassland and woodland habitats to semi-arid ecosystems and Maasai steppe rangelands of the Simanjiro plains. The noted relatively habitat distribution of *Ipomoea hildebrandtii*, *I. kituiensis* in the current study based on location contradict to previously finding of semi-arid ecosystems in the southern region of Kenya (Bosco *et al.*, 2015; Mworira, 2011). Also, recorded relatively habitat distribution of *Ipomoea hildebrandtii*, *I. kituiensis* in the current study based on coverage has similarly been reported in grazing lands of semi-arid ecosystems in the southern region of Kenya (Bosco *et al.*, 2015).

The documented relatively variability in the range of habitat distribution for *Ipomoea hildebrandtii*, *I. kituiensis* in the current study based on location and coverage is mostly explained by differences in land terrains, edaphic factors, ground vegetation cover (Mworira *et al.*, 2008). However, the observed variability for relatively habitat distribution for *Ipomoea hildebrandtii*, *I. kituiensis* based on location in the current study with other studies Bosco *et al.* (2015) could largely be associated to more difference between land use. According to Bosco *et al.* (2015), invasive *Ipomoea* spp. were mainly found in lowlands, disturbed or degraded rangelands, overgrazed sites of the southern region of Kenya. In the current study, *Ipomoea hildebrandtii* and *I. kituiensis* were observed high in medium-land and up-land terrains, and medium ground vegetation cover.

Moreover, the reported similarities for relatively habitat distribution for *Ipomoea hildebrandtii*, *I. kituiensis* based on coverage presented in the current study with other studies could largely be associated to similarities between ecological sites, with respect to both precipitation and soil characteristics as well as management intervention.

Bosco *et al.* (2015) reported that invasive *Ipomoea* spp. were mainly found covering high as 60.0% to 80.0% of grazing lands in red sand loamy soils and little rains of the southern region of Kenya. While in the current study *Ipomoea hildebrandtii* and *I. kituiensis* were observed high in red/black sand loamy soils and medium land moisture. A similarity is brought by semi-arid ecosystems presence in both study sites. In addition, *Ipomoea hildebrandtii* also do not thrive in Woody bush-land probably because of light and space suppression.

5.4 Available mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands

The reported mitigation measures among the Maasai pastoralists on effects of *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands in the current study denote mitigation measures for effects of *Ipomoea hildebrandtii* and *I. kituiensis* in semi-arid ecosystems and Maasai steppe rangelands of the Simanjiro plains.

5.4.1 Dispersal mechanism and spread of *Ipomoea hildebrandtii* and *I. kituiensis* invasion in the rangelands

The noted high coverage of *Ipomoea hildebrandtii* and *I. kituiensis* as 50.0% and 70.0% for Sukuro and Terrat villages, respectively is mostly associated with poor removal of invasive *Ipomoea* spp. through mechanical uprooting. However, the recorded Maasai communities of both Terrat and Sukuro villages that were aware of *Ipomoea* plants by 100.0% is ascribed to the spread of invasive *Ipomoea* spp. all over the village area. Moreover, the recorded no documented casualty cases about domestic animals affected, or killed by *Ipomoea* plants is probably explained by the grazing avoidance of invasive *Ipomoea* spp. as unpalatable herb species. The documented spread of *Ipomoea hildebrandtii* and *I. kituiensis* was mainly ascribed to migrations of livestock, constructions, crop farming, and vegetation management.

The observed relatively dispersal mechanisms of *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands in the current study has similarly been reported in semi-arid ecosystems in the southern region of Kenya (Bosco *et al.*, 2015). The similarity is based on the extent of coverage of invasive *Ipomoea* spp. Bosco *et al.* (2015), mainly found covering as high as 50.0% to 65.0% of village pasture fields; no cases for livestock mortality due to invasive *Ipomoea* spp. (Mganga *et al.*, 2010b); road construction as a reason for invasive *Ipomoea* spp. spread (Okach and Omari, 2015); invasive *Ipomoea* spp. distribution was by the roadside (Okach and Omari, 2015).

The reported similarities for relatively dispersal mechanisms of *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands in the current study with

other studies could largely be associated with similarities in precipitation, soil characteristics and management intervention.

5.4.2 Mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in the rangelands

The noted lack of Maasai communities involved in managing mitigation of *Ipomoea hildebrandtii* and *I. kituiensis*, except family level is associated with poor enforcement by the village rangeland committee. The recorded mechanical uprooting (100.0%) as the preferable mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* is ascribed to the easier uprooting of herb plants as it is.

The documented relatively mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands in the current study has similarly been reported in semi-arid ecosystems in the southern region of Kenya (Bosco *et al.*, 2015). For instance the lack of uprooting involvements by Maasai communities (Bosco *et al.*, 2015); mechanical removal and manual uprooting (Bosco *et al.*, 2015). The observed similarities for relatively mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands in the current study with other studies could largely be associated to similarities between ecological sites, with respect to precipitation and rangeland management intervention.

However, the reported relatively mitigation measures among the Maasai pastoralists on effects of *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands in the current study contradicts the previous reports in semi-arid ecosystems in the southern region of Kenya (Bosco *et al.*, 2015). Based on chemical usage in form of Ash and spray. The contrast also could largely be associated with avoidance of costs

of buying herbicide chemicals to control *Ipomoea hildebrandtii* and *I. kituiensis* grazing lands.

5.4.3 Effectiveness of mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in the rangelands

The noted effectiveness, mitigation measures such as mechanical uprooting (80.0%), the use of herbicides (93.0%) is ascribed to the easier uprooting of invasive *Ipomoea* spp. as herb plants, as well as Maasai, believe on effectiveness, had been shown by chemicals during application for controlling weeds in crop farming fields.

The recorded relatively effectiveness of mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands in the current study is similarly been reported in semi-arid ecosystems in the southern region of Kenya (Bosco *et al.*, 2015). For example, fairly effective of mechanical removal and manual uprooting (Bosco *et al.*, 2015). The documented similarities for relatively effectiveness of mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands in the current study with other studies could largely be associated to similarities between ecological sites, with respect rangeland management intervention.

5.4.4 Proposed alternative mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in the rangelands

The observed proposed alternative, mitigation measures such applications of herbicides (83.3%) and mechanical uprooting (16.7%) is ascribed to the belief on effectiveness had been shown by chemicals during application for controlling weeds

in crop farming fields, as well as the easier uprooting of invasive of *Ipomoea* spp. as herb plants.

The reported relatively proposed alternative mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands in the current study is similarly been reported in semi-arid ecosystems in the southern region of Kenya (Bosco *et al.*, 2015). This include the application of herbicides and mechanical uprooting as proposed alternative mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* (Bosco *et al.*, 2015). The noted similarities for relatively proposed alternative mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands presented in the current study with other studies could largely be associated with similarities in rangeland management intervention.

CHAPTER SIX

Conclusion and Recommendations

6.1 Conclusion

Results obtained from the current study on Effect of *Ipomoea hildebrandtii* and *I. kituiensis* on loss of native herbages of Maasai steppe rangelands of Simanjiro district revealed following: Regardless of villages, herbage basal cover (as a combination of grasses and forb species) between invaded and non-invaded grazing lands was reduced by 46% in invaded grazing lands.

Herbage grass species composition both in invaded and non-invaded grazing lands was dominated by *Digitaria* spp. (27.1%) and (20.5%), respectively. Herbage forb species composition both in invaded and non-invaded grazing lands was dominated by *Gutenbergia cordifolia* (14.3%) and (24.3%), respectively.

Herbage species richness as a number of species in an area, during the study, was higher in the invaded (36) than non-invaded (30) grazing lands.

Herbage biomass productivity between two grazing lands was reduced by 30% in invaded grazing lands in the presence of grazing by wild ungulates large mammals only.

Habitat distribution of *Ipomoea hildebrandtii*, *I. kituiensis* per acre estimation in % was as high in the woodland, wood grassland, and grass woodland, as 70%, 80% and 90%, respectively, as the higher distribution of *Ipomoea hildebrandtii* and *I. kituiensis* in the study area.

Mechanical uprooting (100.0%) was the preferable mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands. Moreover, in both Terrat and Sukuro villages, there was no use of herbicides for mitigating *Ipomoea hildebrandtii* and *I. kituiensis*.

It is evidenced by the study that *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands were the main cause of herbaceous loss compared to other factors.

High *Ipomoea hildebrandtii* and *I. kituiensis* spread in both Terrat and Sukuro villages in the study are caused by poor invasive plants management such as Maasai communities from the current study were not involved in managing mitigation of *Ipomoea* plants, and relying only on a family level as well as waiting for government efforts.

Results, therefore, answer study-stated questions, thus invasive plants such as *Ipomoea hildebrandtii* and *I. kituiensis* lowers herbage forage production. Lowered herbage forages production can have a negative impact on herbivore-carrying capacity in an area with consequent economic and conservation implications.

Findings of the research study do encourage to mitigate strongly *Ipomoea hildebrandtii* and *I. kituiensis*. However, this should be conducted to improve and retain the resilience of ecosystems, habitats, or species diversities. Moreover, considering cost-benefit analysis for the whole future coming project is necessary.

6.2 Recommendations

6.2.1 Recommendations for action

- The study revealed that herbaceous loss is due to *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands, which is caused by poor invasive plants management in rangelands.

Thus, it is recommended that Maasai communities should establish a committee for rangelands management which is responsible for the mitigations of invasive plants.

Moreover, Maasai communities should engage in mitigations of invasive plants and not rely on families alone or wait for government efforts.

- Local government authority in co-operation with Maasai communities should prevent alive plant species importation (invasive plants species immigrants), mitigate through mechanical uprooting, chemically, biologically invasive plants species, and habitat management.
- Local government authority in co-operation with Maasai communities should provide public educational awareness about effect of invasive plants species (Foxcroft *et al.*, 2006; McNeely, 2001).
- Wildlife conservation authorities should expand their controlling efforts against invasive plants species from national park and game reserve towards game controlled area (buffer zones).

6.2.2 Recommendation for further research

- Actual total area size invaded with *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands of Simanjiro district, Tanzania is not known, I, therefore, recommend for more study on it.
- Further study on invasive plants species apart from *Ipomoea hildebrandtii* and *I. kituiensis* of different species such as *Parthenium hysterophorus*, *Argemone mexicana* and plants causing disease like hooves enlargement, fur skin shade off in the study area is recommended.
- Generally; invasive plant species do create effects to livestock and wildlife herbivores on their habitats and forages, and finally, lead to local loss of plant species diversity, and lowering land value. Education awareness to local Maasai communities about the importance of conservation is recommended.

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APPENDICES

APPENDIX 1 SAMPLING SHEET

- i. To determine herbage species composition, species richness and basal cover between invaded and non-invaded Maasai steppe grazing lands.

Invaded grazing lands		Non-invaded grazing lands	
Area	Size	Area	Size
Grazing land = 02 @study grazing land	unknown	Grazing land = 02 @study grazing land	unknown
Plots = 10 @ invaded grazing land	70 m × 70 m	Plots = 10 @ non- invaded grazing land	70 m × 70 m
Quadrats = 09 @plot	1 m x 1 m	Quadrats = 09 @plot	1 m x 1 m
Pace transect between quadrat	30 m	Pace transect between quadrat	30 m

- ii. To determine herbage biomass productivity between invaded and non-invaded Maasai steppe grazing lands.

Invaded grazing lands		Non-invaded grazing lands	
Area	Size	Area	Size
Grazing land = 02 @study grazing land	unknown	Grazing land = 02 @study grazing land	unknown
Plots = 10 @ invaded grazing land	70 m × 70 m	Plots = 10 @ non- invaded grazing land	70 m × 70 m
Quadrats = 09 @plot	1 m x 1 m	Quadrats = 09 @plot	1 m x 1 m

Pace transect between quadrat	30 m	Pace transect between quadrat	30 m
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iii. To assess the distribution of *Ipomoea hildebrandtii* and *I. kituiensis* across grassland and woodland habitats of Maasai steppe rangelands.

- Subject to reconnaissance survey.

Grassland habitats = Invaded areas @study rangeland	Woodland habitats = Invaded areas @study rangeland
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iv. To evaluate available mitigation measures among the Maasai pastoralists on effect of *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands.

- a) Focus group discussion.
 - 12 participants per each group for each village. Two groups. Total participants = 24.
 - 1 session for each group.
- b) Key informants interview.
 - 10 participants, both Terrat and Sukuro villages for a whole study.
- c) Questionnaire survey.
 - 30 households/units, both Terrat and Sukuro villages for a whole study.

APPENDIX 2 HERBAGE SPECIES COMPOSITION, SPECIES RICHNESS, AND BASAL COVER SAMPLING

Date: Recorder: Location name:

Village: Ward: Division: District:

Altitude: (masl) Slope: Eastings: Northings:

Site: Block:..... Plot No:of Vegetation type:

Block	Plot	Trans	Qudrt	Code	Species name	% Comp	% Cover	Remark

GENERAL REMARKS ON GRAZING LANDS HEALTH AND HUMAN INTERFERENCES

.....

**APPENDIX 4 SAMPLING FOR HABITAT DISTRIBUTION OF
IPOMOEA HILDEBRANDTII AND *I. KITUIENSIS*
 ACROSS GRASSLAND AND WOODLAND HABITATS**

Date: Recorder: Location name:

Village: Ward: Division: District:

Altitude: (masl) Slope: Eastings: Northings:

Site: Vegetation type:

Habitat type	Longitude (Eastings)	Latitude (Northings)	Code	Species name	Vernacular name	Remark

GENERAL REMARKS ON RANGELANDS HEALTH AND HUMAN INTERFERENCES

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APPENDIX 5 FOCUS GROUP DISCUSSION

This focus group discussion will be conducted as one among tools for an **Effect of *Ipomoea hildebrandtii* and *I. kituiensis* on loss of native herbage of Maasai steppe rangelands in Simanjiro district.**

Checklist:

Following areas will be discussed:

S/N	Specific objective(s)	Measurable parameter(s) criteria
1.	To evaluate available mitigation measures among the Maasai pastoralists on effect of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> in Maasai steppe rangelands.	<ol style="list-style-type: none"> 1. The extent of invasion problem. 2. Mitigation measures. 3. Effectiveness of mitigation measures. 4. Alternative mitigation measures to solve invasion problem.

Participants

- 12 participants per each group.
- Two meeting groups under the supervision of one facilitator per group. One in-charge facilitator for both two groups.

S/N	Criteria for member(s)	Criteria by age	Criteria by education
1.	Chairperson	Elder	Diploma and above
2.	Secretary	Youth	Diploma and above
3.	Member - farmer	Youth	None
4.	Member - farmer	Elder	None

5.	Member - Maasai pastoralist	Youth	None
6.	Member - Maasai pastoralist	Elder	None
7.	Member - traditional medicine expert	Youth	None
8.	Member - traditional medicine expert	Elder	None
9.	Member - educated expert	Youth	Diploma and above
10.	Member - educated expert	Elder	Diploma and above
11.	Member - Small scale business	Youth	None
12.	Member - Small scale business	Elder	None

Note:

- Elder age: (45 and above years).
- Youth age: (18 – 45 years).

Triangulation note taking will be on:

The extent of invasion problem.

- i.
- ii.

Mitigation measures.....

- i.
- ii.
- iii.
- iv.
- v.

Effectiveness of mitigation measures

- i.
- ii.
- iii.
- iv.
- v.
- vi.

Alternative mitigation measures to solve invasion problem.

- i.
- ii.
- iii.
- iv.
- v.
- vi.

APPENDIX 6 KEY INFORMANTS INTERVIEWS

These key informants interviews will be conducted as one among tools for an **Effect of *Ipomoea hildebrandtii* and *I. kituiensis* on loss of native herbages of Maasai steppe rangelands in Simanjiro district.**

Checklist:

Following areas will be discussed:

S/N	Specific objective(s)	Measurable parameter(s) criteria
1.	To evaluate available mitigation measures among the Maasai pastoralists on effects of <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i> in Maasai steppe rangelands.	<ol style="list-style-type: none">1. The extent of invasion problem.2. Mitigation measures.3. Effectiveness of mitigation measures.4. Alternative mitigation measures to solve the invasion problem.

Participants

- 10 participants.
- One interviewer for both participants.

Note:

- Elder age: (45 and above years).
- Youth age: (18 – 45 years).

Key Informants interview with officers will be:

1. District rangelands management officers,
2. Ward livestock officers,
3. Ward executive officer,
4. Village executive officers,
5. Village administrative chairman, and
6. Hamlets administrative chairmen.

Note taking will be on:

Name:

Level of education:

Position in a community:

Nature of services/provided:

The extent of invasion problem.

i.

ii.

Mitigation measures

i.

ii.

iii.

iv.

v.

Effectiveness of mitigation measures

- i.
- ii.
- iii.
- iv.
- v.
- vi.

Alternative mitigation measures to solve invasion problem.

- i.
- ii.
- iii.
- iv.
- v.
- vi.

APPENDIX 7 QUESTIONNAIRE SURVEY

This questionnaire survey will be conducted as one among tools for an **Effect of *Ipomoea hildebrandtii* and *I. kituiensis* on loss of native herbage of Maasai steppe rangelands in Simanjiro district.** The study is specifically among other research objectives to **evaluate available mitigation measures among the Maasai pastoralists on effects of *Ipomoea hildebrandtii* and *I. kituiensis* in Maasai steppe rangelands.**

Questionnaire No:	Interviewer:	Date:
GPS Position:		
Village name:		

1. Personal information: **Put a tick (✓) or write a correct number in bracket(s)**

i. Respondents gender:	1. Male () 2. Female ()
ii. Place of birth (and age):	
iii. Ethnicity:	
iv. Place of origin:	
v. Marital status:	1. Married () 2. Single () 3. Divorced () 4. Widow ()
If immigrated to this village, what was an original village?	
If you immigrated to this village, what was a reason?	
1. Marriage () 2. Agriculture lands () 3. Grazing lands () 4. Education for kids ()	

5. Income generating activities ()	
6. Employment ()	
7. Hunting ()	
8. Health services ()	
9. Searching for water ()	
10. Other reasons (explain) ()	
How long have you lived in the village?	
Do you consider moving to another village?	1. Yes () 2. NO ()
Education and levels: 1. No education (), 2. Primary (), 3. Secondary (), 4. Others (specify.....)	
Have you ever been employed? 1. Yes (), 2. No ()	

Put a tick (✓) or write a correct number in the bracket(s)

2. What are the main household economic activities and sources of income?

Activities	Months (January – December)												Income
	1	2	3	4	5	6	7	8	9	10	11	12	
Agriculture													
Livestock													
Employment													
Hunting													
Business													
Charcoal making													
Others													

3. Do you own livestock? 1. Yes (), 2. No () If Yes, fill in a Table below.

SN	Livestock owned	Number/range	Animals slaughtered within (12) months and reasons	Animals sold within (12) months and reasons
1	Cattle			
2	Goats			
3	Sheep			
4	Pigs			
5	Chicken			
6	Donkeys			
7	Others (specify)			

4. Do you understand about *Ipomoea* plants in Maasai steppe rangelands? 1. Yes ()

2. No (). If yes, what are the reasons for *Ipomoea* invasions?

SN	Reasons	Yes	No	No idea	If yes (explain)
1	Movements of materials for construction				
2	Movements of materials for gardens				
3	Movements of materials for crop cultivation				
4	Human migration				

5	Livestock and wildlife immigrants				
6	Other				

5. Did you have any domestic animals killed, injured or affected by *Ipomoea* plants in the last 12 months? 1. Yes (), 2. No () If yes, how many?

Domestic animals	<i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i>	Problem types	Animals killed (12 months)

6. Are your communities involved in managing *Ipomoea hildebrandtii* and *I. kituiensis*? 1. Yes () 2. No (). If yes

SN	Mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i>	Ranking	
		1.Yes	2.No
1	Preventing alive plant species importation (through immigrants, cultivation, and construction)		
2	Mechanical uprooting		
3	The use of herbicides		
4	Sward burning of uprooted staff		

7. How are mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* effective at village level?

SN	Mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i>	How often
1	Preventing alive plant species importation (through immigrants, cultivation and construction)	1. Effective () 2. Fairly effective () 3. Not effective ()
2	Mechanical uprooting	1. Effective () 2. Fairly effective () 3. Not effective ()
3	The use of herbicides	1. Effective () 2. Fairly effective () 3. Not effective ()
4	Sward burning of uprooted staff	1. Effective () 2. Fairly effective () 3. Not effective ()

8. What alternative mitigation measures for *Ipomoea hildebrandtii* and *I. kituiensis* you like?

SN	Alternative mitigation measures for <i>Ipomoea hildebrandtii</i> and <i>I. kituiensis</i>	Expected efficacy (%)
1		
2		
3		
4		
5		