2023-07

Reconstructing historical distribution of large mammals and their habitat to inform rewilding and restoration in central Tanzania

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RECONSTRUCTING HISTORICAL DISTRIBUTION OF LARGE MAMMALS AND THEIR HABITAT TO INFORM REWILDING AND RESTORATION IN CENTRAL TANZANIA

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A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Biodiversity and Ecosystem Management of the Nelson Mandela-African Institution of Science and Technology

Arusha, Tanzania

July, 2023

ABSTRACT

In the anthropogenic landscapes where historically wildlife existed, there can be a potential for rewilding to reverse extinction. However, there is limited literature providing approaches to achieving successful rewilding. The current study aimed at providing empirical based methodological procedures for the successful rewilding of large mammals at the University of Dodoma (UDOM) and nearby degraded landscapes by assessing past and current vegetation and wild mammals' occurrence and soil fertility. The past occurrence of mega-herbivores and their habitat was assessed using literature survey, past vegetation maps and key-informant interviews. The EBSCOhost-database and Google Scholar search-engine were used for literature searching. A field survey was conducted at UDOM, one of the remaining habitat patches in central areas of Dodoma, Tanzania to examine present plant diversity, soil nutrients and seedbank status. The results indicated that historically, the study area was Savanna-woodland but later anthropogenic activities had resulted in Land-Use Land-Cover Changes (LULCC) that led to wild animals' extirpation leaving remnants in the surrounding protected areas. While the key informant interviews verified the local loss of mega-herbivores, data collected at UDOM in 2022 indicated vegetation transformation to *Dichrostachys cinerea*-dominated bushland. The study further revealed moderate soil fertility with relatively high seedbank. These results indicated that the study area occupied specular wild-mammal populations that were later extirpated leaving the area transformed into bushland. For rewilding programmes, among other things, the information generated from this study is essential and should be used to guide the long-term success of re-introduction at UDOM and its adjacent areas with/without modification.

DECLARATION

I, Paulo Chiza Athumani, declare that this dissertation is my own. It is being submitted for the Master's degree in Biodiversity and Ecosystem Management of Life Sciences of the Nelson Mandela African Institution of Science and Technology. It has not been submitted for any degree or examination at any other university.

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CERTIFICATION

The undersigned certify that all supervisors have read and hereby recommend for acceptance by the Senate the Nelson Mandela African Institution of Science and Technology a dissertation entitled "*Reconstructing historical distribution of large mammals and their habitat to inform rewilding and restoration in Central Tanzania*", in partial fulfillment of the requirements for the degree of Master of Science in Biodiversity and Ecosystem Management of the Nelson Mandela African Institution of Science and Technology.

1|8|2023

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ACKNOWLEDGMENTS

To begin with, I would like to thank the almighty God for his kindness and unconditional love and for granting me good health during the whole research period.

I would also like to acknowledge and give my sincere thanks to my supervisors Dr. Issakwisa Ngondya and Prof. Linus Munishi for making this work possible. Their invaluable guidance and advice kept me on the right track.

Furthermore, I would like to extend my warmest thanks to my family; my dearest wife and two sons for the moral support and understanding while undertaking my research; I cannot thank them enough.

To add more, I am indebted to my classmate Mr. Emmanuel Sisya for being there when I needed his support; I really appreciate.

Finally, I would like to thank Mr. Emmanuel Mboya, the Botanist who helped me to identify plant species in my study area; I am so grateful.

DEDICATION

I dedicate this work to my mentor and role model Prof. Donald Gregory Mpanduji for paving the way for me, my wife Ms. Hildegalda Mng'anya and my two sons Brayden and Jayden, for without them, I couldn't have reached these heights.

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ANOVA	Analysis of variance
B	Boron
C	Concentration
Ca	Calcium
$CaCl_2$	Calcium chloride
$CaCO_3$,	Calcium carbonate
CCMA	Corangamite Catchment Management Authority
CEC	Cation Exchange Capacity
Cmol	Centimole
CO_2	Carbon dioxide
Cu	Copper
$CuSO_4$	Copper Sulphate
DTPA	Diethyletriaminepentaacetic acid
Ec	Electrical conductivity
ESRI	Environmental System Research Institute
Fe	Iron
HCl	Hydrochloric Acid
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
K	Potassium
Kg	Kilogram
LULCC	Land-Use Land Cover Changes
Mg	Magnesium
MgO	Magnesium oxide
Mn	Manganese
N	Nitrogen
Na	Sodium
NSS	National Soil Services
OC	Organic carbon
P	Phosphorus

pH	Potential of Hydrogen
ppm	parts per million
S	Sulphur
Spp/sp	species
TEA	Triethanolamine
TFA	Trifluoroacetic acid
TMA	Tanzania Meteorological agency
UDOM	University of Dodoma
UN	United Nations
US$	United States dollars
USA	United States of America
UTM	Universal Transverse Mercator
VEO	Village Executive Officer
Zn	Zinc

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

Ecosystems across the globe have been altered resulting into decline and extirpations of both fauna and flora, mainly due to anthropogenic activities which have increased over the past century (Mendiratta *et al.,* 2021; Stalmans *et al.,* 2019). While changes in response to novel ecological interactions may be unpredictable, catastrophic decline of large mammal populations has significant impacts to the landscape; including for example, conversion of grasslands to woodlands in savanna ecosystems. Surveys of large mammals between 2000 and 2002 in Gorongosa National Park, Mozambique revealed a significant decline of diverse populations of species while some e.g., leopard, wild dog, spotted hyena had been extirpated with significant changes in plant and animal biomass (Bouley *et al.,* 2021). Evidence further shows that the effects of megaherbivore removal on vegetation in an ecosystem vary in space and time and may be influenced by the extent of their decline, species' traits, habitat requirements, among other factors (Bakker *et al.,* 2016).

Anthropogenic pressures that are being exacerbated by man have led to habitat loss and degradation, contributing significantly to global biodiversity loss and eventually towards the sixth mass extinction (Pearse & Altermatt, 2013; Pimm & Raven, 2000; Wagler, 2011). Megaherbivores such as elephant, rhinoceros and giraffe among others are at the highest risk of extinction due to overhunting and habitat loss compared to birds and reptiles due to their position in trophic level and their body sizes (Tomiya, 2013; Atwood *et al.,* 2020). The highest risk of extinction is attributed to loss of forage (Pearse & Altermatt, 2013), isolation and loss of connectivity and interactions between populations (Miyazono & Taylor, 2013).

Rewilding is defined as restoration to enhance self-regulating complex ecosystems by restoring non-human ecological aspects and processes while minimizing human control and pressures (Svenning, 2020). Besides, restoration is returning the system to its original function and composition (Corlett, 2016). Rewilding has the main goal of maintaining or increasing biodiversity while reducing the impact of intervention of human beings through reintroduction of species and ecological processes (Lorimer *et al.,* 2015). Restoration is a part of rewilding as rewilding involves different practices including species restoration, assisted migration and natural recolonization (Corlett, 2016). Rewilding is considered central for overcoming the global crisis of biodiversity loss and key for restoration efforts (Svenning, 2020). This concurs with the UN decade of ecosystem restoration 2021-2030 with the main focus on recovering damaged, destroyed and degraded ecosystems to make them ecologically functional so that people can accrue benefits from them (Fischer *et al.,* 2021). Similarly, trophic rewilding is of great importance to ensure that vegetation cover is utilized efficiently to maintain vegetation stability over a long period of time and reduce the impact of climate change (Cromsigt *et al.,* 2018).

Dodoma region in the central area of mainland Tanzania is not far from the fact that population increase has resulted into land use land cover changes (LULCC), habitat loss and fragmentation leading to significant loss in biodiversity (Kangalawe & Lyimo, 2010). Due to increased anthropogenic activities such as urbanization, overgrazing and crop cultivation coupled with climate change, some areas in the region have changed into bushed grassland resulting into tremendous loss of biodiversity including decline and/or local extirpation of large mammal populations (Prakash & Verma, 2022).

Given the UN declaration of 2021-2030 as the decade of restoration (Fischer *et al.,* 2021) and the relatively higher current rate of habitat loss (Kerr & Deguise, 2004) as well as local and global wildlife extinction (Pimm *et al.,* 2014), there is a need to reconnect and restore areas often needed to conserve metapopulations. Reconnecting and restoring such areas are important as a solution to mitigate further extinction by improving the population viability and persistence of species. The current study aimed at providing stepwise evidence-based rewilding procedures and generating past and current information necessary for the successful rewilding in Central Tanzania as a way to support UN restoration agenda of 2021-2030.

1.2 Statement of the Problem

Habitat loss, fragmentation and degradation are major drivers of population decline and local extinction of wildlife species globally (Brewster *et al.,* 2018; Johnstone *et al.,* 2014). The main reasons for habitat loss, fragmentation and degradation are land use and/cover changes (LUCC) triggered by anthropogenic activities and climate change (Kairuki *et al.,* 2021, 2022; Kija *et al.,* 2020; Odjugo & Ikhuoria, 2003). Likewise, herbivores (grazers/browsers) play a significant role in vegetation cover dynamics favoring more woody plants or grassland depending on their balance in a given ecosystem. Large mammals such as elephants, rhinos and buffaloes among others, are at the highest risk of extinction compared to other taxa (Tomiya, 2013; Atwood *et al.,* 2020). While this creates the need to rewild and/or reintroduce the species at risk in areas where they extirpated or reinforce the declining population, the empirical information guide specific rewilding process is largely in the literature.

In central Tanzania, most wildlife mammal species have gone extinct in man-dominated landscapes, leaving remnants in the nearby protected areas (Debonnet & Nindi, 2017; Riggio & Caro, 2017). Though, there are remained habitat patches that have the potential to reestablish connectivity and harbor wildlife. One of those patches is the University of Dodoma campus, where management wants to rewild/reintroduce wildlife species. However, there is a need to reconstruct past and present information in terms of both fauna and flora that existed in the area to generate the relevant specific information that can inform rewilding of the area.

1.3 Rationale of the Study

At UDOM area there used to be populations of the wild mammals in the past from small to large herbivore and meso- and mega predators. Nevertheless, these spectacular population went extinct due to habitat loss resulted from anthropogenic pressure particularly LULCC (Debonnet & Nindi, 2017; Riggio & Caro, 2017). Thus, the management of UDOM and other stakeholders are already seeking for the ways to rewild the area into its prime state. However, their intent is missing empirical evidence to guide the re-introduction programme. Therefore, the current study aimed at establishing evidence-based information necessary to inform re-introduction at UDOM area and serve as a guide to other reintroduction and/or rewilding programmes elsewhere in the world.

1.4 Research Objectives

1.4.1 General Objective

To reconstruct historical distribution of large mammals, their habitat and vegetation to inform rewilding and restoration in central Tanzania.

1.4.2 Specific Objectives

(i) To assess how is the vegetation composition and structure of the central part of Dodoma Tanzania changed over time.

(ii) To assess historical distribution and diversity of large herbivores (grazers and browsers) at the proposed UDOM re-introduction site and adjacent areas.

(iii) To determine soil physical and chemical properties and essential elements in the proposed UDOM’s re-introduction area.

(iv) To assess soil seedbank status for grasses and forbs and weather variation at proposed UDOM’s re-introduction site to inform future vegetation restoration efforts.

1.5 Research Questions

(i) How is the vegetation composition and structure of the central part of Dodoma Tanzania changed over time?

(ii) What is the historical distribution and diversity of large herbivores (grazers and browsers) at the proposed UDOM’s re-introduction site and adjacent areas?

(iii) What is the status of the soil physical and chemical properties and essential elements in the proposed UDOM’s re-introduction area?

(iv) What is the status of the soil seedbank for the grasses and forbs and how the weather varies at proposed UDOM’s re-introduction site?

1.6 Significance of the Study

Rewilding and restoration are vital for reversing wild flora and fauna extinction in landscapes where they are extirpated. The fact that many rewilding and restoration projects are done without baseline information to complement the current information of the rewilding site, renders most of them unsuccessful. Presence of step-by-step evidence based methodological procedures is necessary for successful rewilding projects and eventually save valuable resources such as capital and time. This work contributes to the solution by providing step-by-step evidence-based rewilding and restoration procedure which would be used not only for the success of UDOM proposed re-introduction project but also any similar rewilding programme elsewhere.

1.7 Delineation of the Study

The current study aimed at providing stepwise evidence-based rewilding procedures and generating past and current information necessary for the successful rewilding in Central Tanzania as a way to support UN restoration agenda of 2021-2030. It involved to reconstruct historical distribution of large mammals, their habitat and vegetation to inform rewilding and restoration in central Tanzania. The investigation covered vegetation composition and structure of the central part of Dodoma Tanzania, historical distribution and diversity of large herbivores (grazers and browsers) at the proposed UDOM's re-introduction site and adjacent areas, the status of the soil physical and chemical properties and essential elements in the proposed UDOM's re-introduction area, and the status of the soil seedbank for the grasses and forbs and how the weather varies at proposed UDOM's re-introduction.

CHAPTER TWO

LITERATURE REVIEW

2.1 Environmental Degradation and Land Use and/Cover Change

Environmental degradation is a matter of global concern that is attributed to many factors. In Turkey, industrialization and urbanization are known to be the sources of environmental degradation leading to habitat loss and ecosystem disturbance and thus threatening biodiversity (Kavzoğlu, 2008). The increase in population in Nigeria, for example, has contributed significantly to environmental degradation as a result of high concentration of people in urban areas who are involved in economic activities that increases Carbon dioxide (CO_2) emission (Yahaya *et al.,* 2020). Similarly, in India, population growth and urbanization have remarkably negatively impacted the environment due to air pollution and increased solid waste deposition (Azam & Khan, 2016; Maiti & Agrawal, 2005). Increased habitat loss and degradation due to land-use and land-cover change (LULCC) is the main threat to terrestrial ecosystems (Makwinja *et al.,* 2021). Together with climate change, LULCC are potential drivers of species extinction (Jantz *et al.,* 2015). Land cover dynamics might be influenced not only by land use and climate change but also by the proportion of herbivore (grazers and browsers) species in a given ecosystem (Soininen *et al.,* 2021). More grazers without browsers will promote wood encroachment, while the inclusion of relatively many browsers will reduce higher plants in favour of grassland (Maron & Crone, 2006). Thus, understanding these dynamics is crucial for successful rewilding of degraded rangelands.

Environmental degradation is associated with the relatively higher costs that cannot be matched by the benefits accrued from economic development (Ma *et al.,* 2020). The costs are the consequence of air, land and water pollution which in turn affect human health, water shortage, crop yields and materials loss (Ali *et al.,* 2020). The world loses about US$ 231 billion annually due to land degradation and LULCC (Nkonya *et al.,* 2016). It is projected that, West Africa coastal areas of Ghana, Ivory Coast, Togo and Benin would incur environmental degradation cost of approximately US$ 3 billion by the year 2100 due to flooding and erosion (Bolle *et al.,* 2021). In Tanzania, environmental cost associated by deaths caused by air pollution, unsafe water and sanitation was US$ 28.7 billion in the year 2013 (World Bank, 2019) while the cost of land degradation due to LULCC is approximately US$ 18.47 billion yearly (Kirui, 2016). Basically, the reverse of these costs is the economic value of the rewilding which can be obtained directly or indirectly through ecosystem services and economic activities (e.g., ecotourism) associated by restored biodiversity (Hall, 2019; Moorhouse & Sandom, 2015). Thus, there is a huge need for rewilding and/or restoration in order to reverse the extinction and promote biodiversity in the proposed area while converting the cost of conservation into benefits.

2.2 Rewilding and Restoration

Restoration and rewilding are very closely related concepts that describe the reverse of the current biodiversity crisis into well-diverse and complex ecosystem services and processes (Anderson *et al.,* 2019). In addition, there is little difference between the two terms; while ecological restoration focuses on returning the ecosystem to its benchmark historical condition, rewilding seeks to recognise and regenerate wilderness for current and future ecosystem functioning (Du & Pettorelli, 2019). The importance of rewilding is not only limited to the provision of ecosystem services but also as a key for tourism activities (Hall, 2019).

Rewilding has become a very important tool in conservation in the current changing world occupied by marginal lands as a result of land degradation crises (Corlett, 2016). It is indisputably central for global restoration efforts (Svenning, 2020). Trophic rewilding has proven to be successful in climate change-impacted landscapes through the introduction of large herbivores, particularly grazers (Pedersen *et al.,* 2020).

Nevertheless, rewilding faces a number of limitations which delay and/or render a number of projects unsuccessful (Torres *et al.,* 2018). In Europe, uncooperative policies and persecution of restored key stone species has limited progress of several rewilding projects (Segar *et al.,* 2022). This is coupled by lack of innovative sources of finance, political and professional interest of deploying and experimenting rewilding as a new approach adding up to competing socio-economic interests (Jepson *et al.,* 2018; Segar *et al.,* 2022). Moreover, challenges in establishing quantitative information about the impacts of landscape changes led to poor progress of rewilding projects in Netherland and Argentina (Torres *et al.,* 2018). Likewise, inadequate quantitative information, technical capacity, lack of baseline information (Cortina-Segarra *et al.,* 2021; Wells & Winowiecki, 2017) and shifting of baselines due to climate change have hindered effective and largescale implementation of restoration efforts (Hirsch, 2020). The researcher may have current composition and abundance of species but lack the historical information which is the key for successful restoration (Humphries & Winemiller, 2009). In that regard, this study focused on generating past and present information as an important part of successful restoration and rewilding to ensure that relevant interventions are performed.

2.3 Feed Preference for Selected Large Herbivore Species

Herbivores have feed preferences that vary with seasons and availability (Chinomona *et al.,* 2018). Below are some selected large herbivores (> 5 kg) (Du & Pettorelli, 2019) from different guilds and their feed preferences.

2.3.1 Plain Zebra and Blue Wildebeest

Blue wildebeest (*Connochaetes taurinus*) and plain zebra (*Equus burchelli*) harbour the savanna woodland (Thaker *et al.,* 2010) and are known to be specialist grazers (Groom & Harris, 2009). They graze in a close association with each other in the field, and there is diet overlap in their feed selection (Owaga, 1975). Zebra has a body weight between 220 kg and 250 kg for male and female, respectively (Neuhaus & Ruckstuhl, 2002), while wildebeest have a body weight of 210-260 kg for male and 170-200 kg for female (Hoffman *et al.,* 2011). They feed on a variety of species, including *Urochloa mossambicensis, Panicum maximus, Heteropogon contortus, Themeda triandra, Brachiaria deflexa* and *Panicum colaratum* (Bodenstein *et al.,* 2000). Likewise, they prefer *Aristida congesta, Bothriochloa radicans, Cymbopogon plurinodis, Dactyloctenium aegypteum, Digitaria eriantha, Eragrostis gummiflua, Eragrostis superba, Panicum maximum, Sporobolus fimbriatus* and *Themeda triandra* (Ben-Shahar & Coe, 1992). Furthermore, they forage on *Setaria spp., Digitaria macroblephara, Cynodon dactylon, Themeda triandra* and *Aristida spp.* (Owaga, 1975).

2.3.2 Giraffe and Greater Kudu

Giraffe (*Girafla camelopardalis tippelskirchi*) and greater kudu (*Tragelaphus strepsiceros*) inhabit savanna woodland dominated by *Acacia*, *Commiphora*, *Terminalia* and *Combretum* (Blomqvist & Renberg, 2007). They share most of their diet but at different heights (Du & Pettorelli, 2019). Giraffe (*Girafla camelopardalis tippelskirchi*) is known to be the largest ruminant and the tallest mammal weighing 550-1930 kg (Sabeer *et al.,* 2012) browsing in different species depending on availability. The species include but are not limited to *Ziziphus mucronate, Acacia robusta, Acacia tortilis, Acacia welwitschia, Grewia spp., Combretum zeyheri, Dicrostachys cinerea, Acacia nigrescens, Acacia exuvialis, Maytenus heterophylla, Acacia xanthophloea, Terminalia prunioides, Schotia brachypetala, Peltophorum africanum, Euclea divinorum, Combretum imberbe, Combretum hereroense, Acacia nilotica, Combretum* *apiculatum, Lannea stuhlmannii* and *Sclerocarya birrea* (Furstenburg & van Hoven, 1994; Pellew, 1984). Furthermore, they feed on *Acacia geradii, Balanites aegyptiaca, Albizia harveyi, Albizia amara, Phyllanthus sepialis, Maytenus senegalinsis, Dichrostachys cinerea, Acacia siberiana, Cordia ovalis, Acacia senegal, Grewia fallax* and *Commiphora trothae* (Breebaart, 2000; Pellew, 1984). Additionally, they prefer *Acacia caffra, Acacia erubescens, Acacia fleckii, Acacia grandicornuta, Acacia mellifera, Acacia nilotica, Carissa bispinosa, Combretum apiculatum, Combretum imberbe, Dicrostachys cinerea* and *Dombeya rotundifolia* (Blomqvist & Renberg, 2007). They as well feed on *Ehretia rigida, Euclea spp., Grewia bicolor, Grewia erubescens, Grewia flava, Grewia flavescens, Grewia monticola, Maytenus sp., Pappea capensis, Peltophorum africanum, Rhus sp., Sclerocarya birrea, Spirostachys africana, Tarchonantus camphoratum, Terminalia sericea, Vitex sp., Vitex zeyheri* and *Ziziphus mucronata* (Blomqvist & Renberg, 2007).

On the other hand, greater kudu (*Tragelaphus strepsiceros*) has a weight of 224-260 kg (male) and an average of 155 kg (female) (Breebaart, 2000). They prefer *Dalbergia melanoxylon, Ficus coronata, Savanna dwababerry, Dalbergia nyassae, Gymnosporia senegalensis, Flacourtia indica, Dichrostachys cinerea, Bauhinia petersiana, Trichilia emetica, Combretum paniculatum, Grewia monticola., Ficus coronate, Ximenia caffra, Burkea africana, Diospyros mespiliformis, Acacia tortilis, Flacourtia indica, Colophospermum mopane, Combretum paniculatum, Dichrostachys cinerea, Acacia nigrescens, Grewia monticola, Julbernardia globiflora* and *Terminalia stenostachya* (Chinomona *et al.,* 2018; Kandume, 2012). Similarly, they feed on *Diplorhynchus condylocarpon, Tamarindus indica, Brachystegia boehemii, Bolusanthus speciosus, Terminalia sericea, Catunaregum taylorii, Bauhinia toementsa, Strychnos innocua, Diospyros senensis, Combretum paniculatum, Commiphora mossambiscensis, Albizia amara, Lecaniodiscus fraxinifolous, Lonchocarpus capassa, Xeromphis obovate, Euphobia cooperi, Hexalobus monopetalus, Antdesma venosum, Pseudolachnostylis maproumeifolia* and *Boscia albitrunca* (Chinomona *et al.,* 2018; Kandume, 2012; Waal, 2005).

2.3.3 Impala and Common Eland

Impala (*Aepyceros melampus*) and eland *(Tragelaphus oryx)* are intermediate feeders, grazers-browsers, grazing during the wet season and shifts to browsing during the dry season (Mramba, 2021; Watson & Owen-Smith, 2000). Impala is a Bovidae weighing 60 to 65 kg for male and 40 to 45 kg for female (Mramba, 2021). It is endemic to Africa inhabiting the bush, woodland and savannah of eastern and southern Africa, from Uganda to South Africa (Bastos-Silveira &

Lister, 2007). They graze on a variety of species, including *Cynodon dactylon, Panicum maximum, Urochloa spp., Eragrostis spp., Themeda triandra* and *Digitaria eriantha* (Mandinyenya *et al.,* 2019; Pieterse, 2018). Moreover, they browse on *Acacia spp.* (leaves and pods)*, Combretum spp., Boscia spp., Ziziphus spp., Grewia spp., Commiphora spp., Terminalia spp., Dichrostachys spp., Spirostachys africana* and *Combretum apiculatum* (Mandinyenya *et al.,* 2018; Pieterse, 2018).

Eland (*Tragelaphus oryx*) is the largest of all African antelopes, with average weights of 650 kg and 460 kg for male and female, respectively (Breebaart, 2000). Eland inhabits a range of habitats, such as savanna woodland, but avoids forest and very short grass (Breebaart, 2000; Lamprey, 1963). It feeds on a number of species depending on availability. The species include but are not limited to *Ancylobotrys capensis, Asparagus sp., Athrixia elata, Combretum sp., Diospyros lycioides, Dombeya rotundifolia, Englerophytum magalismontanum, Euclea crispa, Faurea saligna, Halleria lucida, Helichrysum kraussii, Indigofera sp., Lantana rugosa, Lippia javanica, Searsia lancea, Searsia lepodyctia, Searsia pyroides, Senegalia caffra, Solanum sp, Tagetes minuta, Vangueria parvifolia, Verbena bonariensis, Vernonia sp., Ziziphus mucronate*, woody forbs, ferns and herbaceous forbs (Fabricius & Mentis, 1990; Parrini *et al.,* 2019). In addition, they prefer *Cymbopogon plurinodis, Digitaria eriantha, Themeda triandra, Felicia muricata, Helichrysum dregeanum, Walafrida geniculate, Grewia occidentalis, Pentzia sphaerocephala, Rhus erosa, Setaria sphacelate, Acacia karroo, Eragrostis lehmanniana, Pentzia incana, Becium burchellianum, Walafrida saxatilis, Felicia filifolia, Pentzia sphaerocephala, Diospyros lycioides, Merxmuellera disticha, Selago corymbosa, Merxmuellera disticha, Euryops annuus*, *Heteropogon contortus* and *Rhus erosa* (Breebaart, 2000; Watson & Owen-Smith, 2000).

2.4 Savanna Ecosystem

Savanna is an ecosystem co-dominated by trees and grasses with relatively lower composition of woody and herbaceous vegetation (Mogashoa *et al.,* 2021). Savanna ecosystems are very diverse and dynamic influenced mostly by herbivory and fire (Shannon *et al.,* 2011). The diversity of most savanna has great ecological importance as they support a relative high diversity of wild flora and fauna (Mapfumo *et al.,* 2016). Nevertheless, savanna ecosystems face a number of challenges which include but not limited to habitat destruction induced by anthropogenic activities, woody plant encroachment, drought as a consequence of climate change topping up to the wildfire (Case *et al.,* 2019; Kouassi *et al.,* 2020; Mishra *et al.,* 2015; Liao *et al.,* 2018). Woody plant encroachment is known to decrease the grass species abundance, diversity and richness of the savanna ecosystem reducing forage for grazers (Ratajczak *et al.,* 2012). This is a similar case with UDOM rewilding proposed site where the area is under woody encroachment leaving only relatively few patches of grasses.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area Description

Central Tanzania where Dodoma region is a part (Fig. 1) is a semi-arid area historically characterized by savanna vegetation defined by wooded grassland occupied by different species of wild animals, including mega- and mesoherbivores (Vats & Safari, 2014). The area is found in the Central Plateau of Eastern Africa extending from Ethiopia in the North to the Transvaal in the South and elevated from 1200 m to 1500 m above sea level (Msabi & Makonyo, 2021). It receives 300 mm to 800 mm of rainfall from November to April and only 15 mm to 1 mm from May to October. The temperature varies between 15°C in July and 30°C in October (Msabi & Makonyo, 2021). The area is surrounded by several protected areas, including Swagaswaga, Muhesi, Kizigo and Rungwa game reserves and Ruaha, Mikumi and Udzungwa national parks (Fig. 1), allowing for massive movement of wild animals across the region.

Rewilding is anticipated to be done at UDOM area situated at its main campus (Fig. 1(c)). The UDOM area is located at $6^{\circ}10'32''$ S and $35^{\circ}49'19''$E (Rao & Murthy, 2017). The campus covers an area of approximately 6000 ha and the size proposed for rewilding is about 1.6 km^2. The area was once occupied by savanna woodland but now is bush encroached (Vats and Safari, 2014). The area was then inhabited by humans for more than 100 years. People inhabiting the area performed different activities, including crop cultivation and cattle grazing, until 2007, when they were evicted from the area. After eviction, most of the area was left intact, excluding the area where the buildings were erected. Due to anthropogenic activities, the vegetation that was once dry miombo and *acacia-commiphora* woodland is now transformed to bush-encroached land.

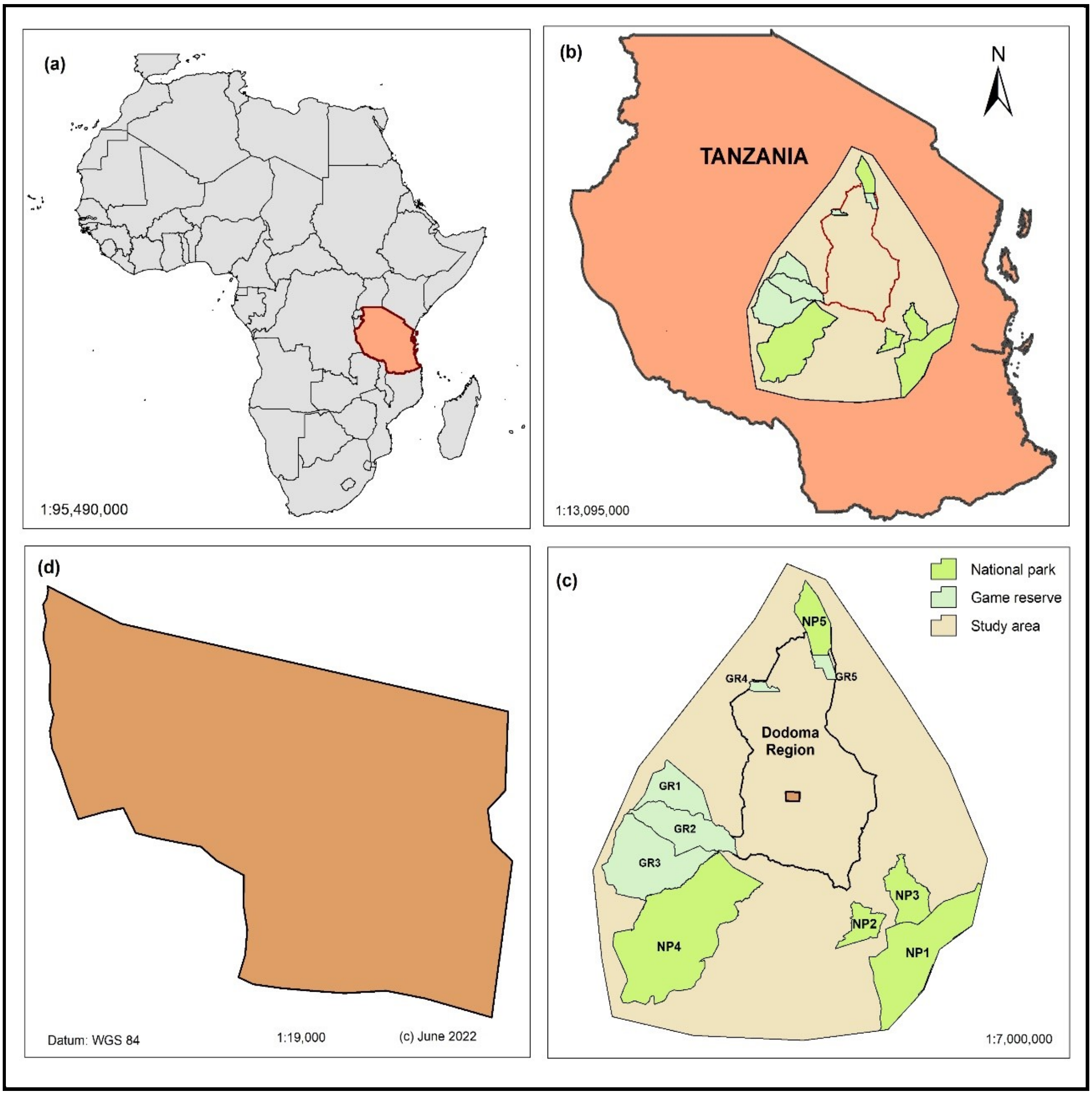


Figure 1: **A map showing the location of Tanzania (a), Dodoma region (b) and the area proposed for restoration and rewilding and the surrounding protected areas (c) and (d)). (NP1=Nyerere National Park; NP2=Udzungwa National Park; NP3=Mikumi National Park; NP4=Ruaha National Park; NP5=Tarangire National Park; GR1=Muhesi Game Reserve; GR2=Kizigo Game Reserve, GR3=Rungwa Game Reserve; GR4=Swagaswaga Game Reserve; GR5=Mkungunero Game Reserve)**

3.2 Research Design and Approach

The research design for the current study was longitudinal. Data were collected in two seasons; during dry season (November, 2021) and during wet season (April, 2022). The current study followed both quantitative and qualitative approaches. Soil, current vegetation status and seedbank experiment data were collected and analysed quantitatively while historical (vegetation and wild fauna) and key informant interviews data were collected and analysed qualitatively.

3.3 Types of Data

3.3.1 Primary data

The primary data included soil, current vegetation and key informant interviews data.

3.3.2 Secondary Data

Secondary data included historical vegetation and wild fauna data obtained from literature and temperature and rainfall data obtained from TMA.

3.4 Research Methods

While literature survey was performed to obtain information on historic mega herbivores and their habitats, field survey was conducted to assess current vegetation and soil fertility status in the rewilding proposed area. Key informant interviews were conducted to the community surrounding rewilding proposed area to backup past and current information obtained from literature survey on mega fauna and their habitats.

3.5 Sampling

For soil and vegetation sampling, the targeted population was the whole area under sampling. The sampling frame were all 155 established grids in the proposed rewilding site (Fig. 1 (d)). Thirty percent (30%) of 155 grids (47 grids) were randomly sampled for soil and vegetation. For key informant interviews, the target population were people who inhabited the rewilding proposed site for at least 20 years and who had the age of 50-70 years. The number of individuals who qualified to be the key informants in the UDOM nearby villages was ten (10) as determined by Village Executive Officers (VEOs) of the respective villages of Makulu, Nghoghona and Iyumbu and all (100%) were sampled. The number of key informants was based on the availability as most inhabitants moved to the remote places after they were evicted from UDOM area during establishment of the university in 2007.

3.5.1 Sampling Procedure

(i) Historical Vegetation and Large Herbivore Data Collection

Past vegetation information for the region was assembled by using historical vegetation maps created in ArcMap and conducted an extensive literature search from January to April 2022 to understand the historical changes in vegetation and wild fauna species in and around the study area over a span of sixty-two (62) years (1960-2022). The originality of the literature was randomly selected based on the search responses; therefore, the coverage was worldwide. The search based on relevance and not by period range. Relevant documents that were in English and/or Swahili were selected for this review. Searches were focused mainly on EBSCOhost database and Google Scholar search engine but sometimes involved consulting Tanzania Wildlife Research Institute (TAWIRI) and Tanzania Wildlife Management Authority (TAWA). The EBSCOhost database and Google Scholar search engine contained the most important and relevant literature, but sometimes failed to provide a direct link to a journal's webpage of the target literature. In such instances, the search was extended to a specific journal. The key words used to search the literature included "vegetation and central Tanzania" or Dodoma", "wild-fauna and central Tanzania or Dodoma", "vegetation history and central Tanzania or Dodoma", "wild-fauna history and central Tanzania or Dodoma".

Furthermore, the scanned topographical maps of 1960 with the scale of 1:50 000 which was obtained from the Department of Survey of Tanzania under Ministry of Lands, Housing and Human settlements Development, were used to generate the 1960 land use/cover types. Additionally, AFRICOVER map shape files with the scale of 1:2 000 000 based on the data (Land Use Systems) was deployed in this study. Moreover, ArcMap software version 10.5 (ESRI, 2005) was used to derive and analyze land use/cover classification and changes in all the data set.

To begin with, scanned topographical map sheets of 1960 were displayed and rectified using a coordinate system which is an area-specific standard UTM (zone 36) projection system for Tanzania with the ArcMap software version 10.5. The map was digitized, edited, and labeled by using the same software. The AFRICOVER map of Tanzania was then clipped by using the same software to obtain the map of the study area. Afterwards, the map of the study area was reclassified into simplified AFRICOVER map with six classes (savannah woodland, natural forest, bushland, urban areas and rural settlements, crops land and bare land) as done by Dewan and Yamaguchi (2008). Finally, vector land cover data from the topographical and AFRICOVER maps were used to generate the heat map (Fig. 2) for each vegetation type category by using the default settings of the Kernel density tool in ArcMap (DeBoer, 2015) in order to determine the most dominant vegetation layer. Eighty (80) reference point data that were collected in the field using a handheld GPS were used for evaluation of the result by cross checking the land cover change through field validation. This information was then applied into ArcMap and overlaid with the heat map generated using data obtained from the topographical and AFRICOVER map shape files for ground truthing and classification accuracy. The wildlife corridors across the study region adopted from Riggio and Caro (2017) and supported by Debonnet and Nindi (2017) were overlaid on the same map.

Additionally, key informant interviews were randomly conducted and subsequent focused group discussion for 10 elders who inhabited the proposed and nearby rewilding (UDOM) area in the past, one Tanzania wildlife management officer at UDOM station (to obtain information about the past vegetation and wild fauna in and around the area and one pioneer of the university of Dodoma (to capture the status of the area when the university was established). The key informants were obtained from the UDOM surrounding villages of Makulu, Nghonghona and Iyumbu. The VEOs suggested the names of qualified key informants (those inhabited the rewilding proposed area for the period of over 20 years and aged 50-70 years old). The number of key informants was determined by their availability as most of the past inhabitants of the rewilding proposed area had shifted to other remote areas. The data were summarized in excel and analyzed thematically in NVIVO 11 software.

(ii) Field Vegetation Assessment at University of Dodoma Area

Following assemblage of historical wildlife and vegetation data, this study further assessed the recent species composition, abundance and diversity of vascular plants (tree, shrubs, forbs and grass) for two seasons; dry (November, 2021) and wet (April, 2022) to compare extent of change from the historical plants and large mammal species. For the assessment of current plant diversity status, the study area was divided into 155 grids of 50 x 50 m (of which 30% (47) were randomly selected for inclusion in the study. The 50 x 50 m grids ensured maximum sampling of the area (Goslee, 2006; Bonham, 2013). In every selected grid of 50 x 50 m, three quadrats of 10x10 m, 5x5 m and 1x1 m were nested and laid diagonally across the grid for trees, shrubs and grasses/ forbs identification, respectively. While sampling the vegetation, the vegetation cover was visually estimated after consensus by a team of three experts. Five scales were assigned numbers from 1 to 5 where; 1 = less than 5% cover, 2 = 5–25% cover, 3 = 25–50% cover, 4 = 50–75% cover, and 5 = greater than 75% cover. Past vegetation will be used as a benchmark for restoration in relation to present vegetation cover and species composition during commencement of the restoration project.

(iii) Determination of the Status of the Soil Physical and Chemical Properties and Essential Element at UDOM Area

A composite soil sample was taken from each of the quadrats (10 x 10 m) laid for vegetation sampling. The holes (15 cm deep) were dug at all four corners and the centers of quadrats, the soil sample was collected and put together in one pocket to make a composite sample. Three (3) kg of soil was then taken whereby two (2) kg were used for the seed bank pot experiment and one (1) kg was used for soil chemical properties analysis. The soil samples for soil chemical properties analysis were then taken to the TARI-Uyole laboratory in Mbeya for chemical and essential element analysis. The soil physical properties were determined in the field. Soil texture was determined by using a protocol adopted from Brewer and McCann (1982), while soil colour was determined by using a Munsell soil colour chart. A total of 47 soil samples were collected.

Laboratory Soil Chemical Analysis

- **Determination of Soil pH**

Soil pH was determined by pH meter (Peech, 1965) as follows: 10 g of soil sample was soaked in 25 mL of distilled water. A ratio of soil weight to water of 1:2.5 was maintained. Samples were shaken with a mechanical shaker for 30 min at 220 rpm and left to settle for 10 min. pH of supernatant was determined using a calibrated pH meter.

- **Determination of Total Nitrogen**

Available N was determined following the Kjeldal method (Bremner, 1965) as follows: 1 g of catalyst mixture ($CuSO_4$, Selenium powder, $K_2(SO_4)_3$) and 10 mL of concentrated Sulphuric Acid (H_2S0_4) were added on 1 g of soil sample sieved using 0.5 mm sieve. The mixture was heated at 300°C for about 2 h, and then 50 mL of 32% NaOH was added. Distillation of the sample was performed and 35 mL of the distillate was collected with 20 mL of Methylated Boric Acid. Back titration of the distillate was performed by adding 0.01 M (2 Normal) H_2S0_4. Available Nitrogen (N) was calculated as follows:

$$N = \frac{\text{Vol. of acid used for back titration x Normality of the acid x 1.4}}{\text{Sample weight (g)}}$$

- **Determination of Available Phosphorous**

Available P was extracted following the Bray I procedure (Bray & Kurtz, 1945), and determined by ascorbic acid-molybdate blue method (Murphy & Riley, 1962).

- **Determination of Cation Exchange Capacity**

The CEC was determined by the Ammonium saturation method (Chapman, 1965) as follows: 35 mL of Ammonium acetate ($CH_3COO\ NH_4$) was added into 10 g of soil sample and the mixture was left overnight. The mixture was then filtered using Watsman filter paper number 40 by adding $CH_3COO\ NH_4$. The remaining soil in the filter paper was further leached using 80% Ethanol to remove excess Ammonia (washing) and the Ethanol filtrate was discarded. The remaining soil was further leached with 1M KCl (1 Normality) to a volume of 100 mL. The 25 mL of the filtrate were collected and 40 mL of 32% NaOH was added to make it alkaline, distillation of the sample was performed and the 35 mL of the distillate was collected with 20 mL of Methylated Bolic Acid. Back titration of the distillate was performed by adding 0.01 M (2 Normal) H_2S0_4. The CEC was calculated as follows:

$$\text{CEC} = \frac{(\text{Vol. of acid used for back titration x Normality of the acid})}{\text{Sample weight (g)}} \text{X}100$$

- **Exchangeable Bases (Na, K, Ca, and Mg) and Available Zn, Fe, Cu and Mn**

Exchangeable bases and available Cu, Fe, Mn and Zn were determined by atomic absorption spectrophotometer (Hesse, 1971) as follows: 35 mL of Ammonium acetate (CH_3COONH_4) was added into 10 g of soil sample and the mixture was left overnight. The mixture was then filtered using Watsman filter paper number 40 by adding CH_3COONH_4 to a final filtrate volume of 100 mL. Exchangeable bases and available Cu, Fe, Mn and Zn in the filtrate were determined using Atomic Absorption Spectrophotometer (AAS). Exchangeable Na (%) was calculated according to Robbins (1984) as follows:

Exchangeable Na (%) = (exchangeable Na / CEC) 100%

(iv) Assessment of soil Seedbank Status at University of Dodoma Area

From forty-seven (47) randomly selected grids, soil samples were collected and used to set up an experiment for the seed bank. From an initial 3 kg soil sample, two (2) kg were used for the seed bank pot experiment. For soil seed bank analysis, the seedling emergence method was applied (Price *et al.,* 2010). The soil was placed into plastic bags with drainage holes under greenhouse environment. The experiment lasted for four months (January-April, 2022) when there were no more seeds emerging.

Soil Sample Preparation for Seedbank Assessment

The soil samples were air dried for 7 days as suggested by Wu *et al.* (2020) to stop microbial activities and chemical reactions and enhance germination (Obalium & Chibuike, 2017; Price *et al.,* 2010). From an initial amount, 2 kg soil sample was measured using an electronic compact scale and placed in 25 cm diameter x 8 cm depths plastic bags that had drainage holes. This provided the soil with a depth of 8 cm, which was sufficient surface area for germination according to He *et al.* (2016) and Fowler (1986) who suggested soil depths between 5 and 10 cm, respectively. Before placing the plastic bags in the screen house, the ground was covered by sand and gravel to avoid predation by ants and termites and importantly to allow free drainage (Menezes *et al.,* 2019; Fowler, 1986). Plastic bags were then placed in a screen house established away from full sunlight and exposure to environmental changes. At the beginning, the samples were irrigated ad libitum three times a day (in the morning, afternoon and evening) (Rabopape, 2021). After the samples were saturated, the watering was done at the rate of 50 ml/kg once or twice a day (depending on the ambient temperature) simulating the average daily rainfall at the study area. The experiment lasted for four months where there were no more emerging seedlings.

Soil Seed Bank Data Collection and Monitoring

The numbers of emerging seedlings were identified to the species or genus level, counted, recorded and discarded on the 30th day after commencement of the experiment and on the weekly basis thereafter as suggested by Price *et al.* (2010). The interval of 30 days allowed most grasses and forbs to germinate and bloom and therefore making identification easier (Mahé *et al.,* 2021). Identified seedlings were removed to reduce the competitive effect, allowing further seedlings to germinate (Padonou *et al.,* 2022). The soil samples in plastic bags were tendered regularly to reduce compactness after the rate of seedling emergence has slowed. Additionally, the plastic bags were randomized regularly to ensure the conditions are constant to all samples (Menalled *et al.,* 2001).

(v) To determine Rainfall and Temperature Variation in the Dodoma Region over the Past 7 Years

The temperature and rainfall data for the past seven years (2015-2022) were obtained from the Tanzania Meteorological Authority (TMA). These data were used to determine whether there was weather variation from one year to another.

3.6 Data Analysis

3.6.1 Plants Species Diversity

The plants species diversity was calculated using the Shannon–Wiener Wiener diversity index as per Equation 1.

$H=-\sum_{n-1}^{s} pi \ln pi$ …………………………………………………...………..……… (1)

Whereby:

> p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), ln is the natural log, Σ is the sum of the calculations and s is the number of species.

3.6.2 Key Informant Interviews

The information from the key informants was transcripted and coded into themes and then thematic analysis was performed by using NVIVO 11 software.

3.6.3 Statistical Analysis

Shapiro-Wilk test for normality was performed on species diversity and richness data, soil pH, available P and N, CEC, available Cu, Fe, Mn and Zn and exchangeable Ca, Mg, K and Na, soil seed bank data, rainfall and temperature data. For all data that passed normality test, paired and one sample student's t tests was performed (Tererai *et al.,* 2013) whereas for non-normally distributed data a Wilcoxon Signed-Rank test was executed (Tererai *et al.,* 2013) to determine whether there is statistically significant variation in diversity between and within dry and wet seasons, soil chemical properties among selected sampling grids, seedbank among the selected grids and temperature and rainfall over the past seven years (2015-2022). The statistical software used was R-software version 4.2.1 and the level of significance was set at α=0.05.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Historical Background

(i) Past Vegetation Classification

The vegetation map of 1960, showing past vegetation and corridors that were once present but now are severely impacted due to LULCC, created in ArcMap suggested that the study area was dominated by Savanna woodland vegetation (Fig. 2). The southern and eastern blocks which are occupied by the Rungwa-Ruaha ecosystem were covered by Miombo woodland (Backéus, 1994; Gillman, 1949; White, 1983). The northern block occupied by the Tarangire-Manyara ecosystem was covered by Acacia-commiphora woodland (Ludwig *et al.,* 2008 & White, 1983) while the western block that was occupied by Itigi and surrounding areas was covered by thickets.

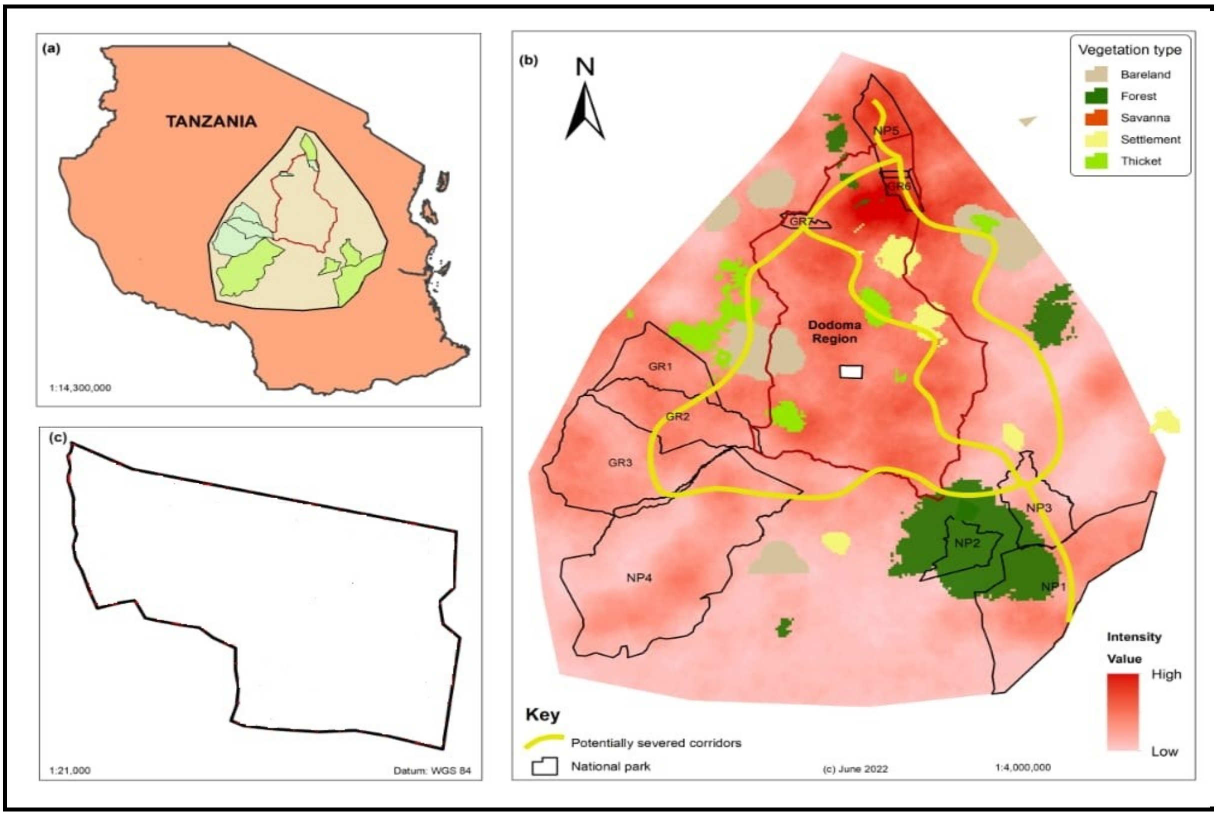


Figure 2: A map of the Dodoma and the surrounding protected areas

(NP1=Nyerere National Park; NP2=Udzungwa National Park; NP3=Mikumi National Park; NP4=Ruaha National Park; NP5=Tarangire National Park; GR1=Muhesi Game Reserve; GR2=Kizigo Game Reserve, GR3=Rungwa Game Reserve; GR4=Swagaswaga Game Reserve; GR5=Mkungunero Game Reserve)

Information from literature and the interviews indicated that anthropogenic activities such as settlements establishment and smallholder agriculture expansion resulted into LULCC which eventually led to local extirpation of key large mammals in the area (Debonnet & Nindi, 2017; Riggio & Caro, 2017). While some populations were locally extirpated, leaving remnant populations in the surrounding protected areas (Hariohay *et al.,* 2019; Prakash & Verma, 2022), respondents from interview indicated that some species such as elephants have been observed to cross in the area from and to nearby protected areas. The vegetation map of 1960 showed the vegetation cover but it was not able to reveal the floristic composition. However, based on the past studies in the area; from 1933 (Greenway, 1933; Gillman, 1949; Backéus *et al.,* 1994; Ludwig *et al.,* 2008; Kayombo *et al.,* 2020); the area proposed for rewilding (Fig. 1(c)) comprised a mixture of nineteen (19) species of grasses (33%), 17 species of herbs (29%), 12 species of shrubs (21%) and 10 species of trees (17%) (Table 1 and Fig. 3).

Table 1: Past floristic composition of the study area

Common floristic types			
Grasses	**Herbs**	**Shrubs**	**Trees**
Digitaria milanjiana	*Bidens Pilosa*	*Indigofera rhynchocarpa*	*Brachystegia microphylla*
Setaria sphacelate	*Ruellia tuberosa*	*Solanum incanum*	*Brachystegia spiciformis*
Dichanthium annulatum	*Thunbergia sp*	*Markhamia obtusifolia*	*Albizia petersiana*
Hvparrhenia filipendula	*Tridax procumbens*	*Maerua angolensis*	*Euphorbia candelabrum*
Sporobolus festivus	*Vernonia glabra*	*Vangueria infausta*	*Cassia abbreviata*
Chloris virgata	*Stylosanthes fruticose,*	*Grewia bicolor*	*Combretum mole*
Eragrostis patens	*Waltheria indica*	*Lippia javanica*	*Terminalia sericea*
Pennisetumn polystachyon	*Acanthospermum hispidum*	*Agave sisalana*	*Acacia tortilis*
Cynodon dactylon	*Tephrosia pumila*	*Caturanegam spinosa*	*Acacia Senegal*
Tragus berteronianus	*Triumfetta rhomboidea*	*Dodonaea viscosa*	
Setaria homonyma	*Commelina spp.*	*Conyza pyrrhopappa*	
Panicum maximum	*Crabbea velutina*	*Rhus natalensis,*	
Heteropogon contortus	*Triumfetta macrophylla*	*Clerodendrum myricoides*	
Eragrostis cylindriflora	*Hibiscus calyphyllus*		
Dactyloctenium aegypticum	*Acalypha sp.*		
Pogonarthria squarrosa	*Leucas deflexa*		
Rhynchelytrum repens	*Achyranthes aspera*		
Aristida congesta			
Harpachne schimper			

Backéus *et al.* (1994), Gillman (1949), Greenway (1933), Kayombo *et al.* (2020), and Ludwig *et al.* (2008)

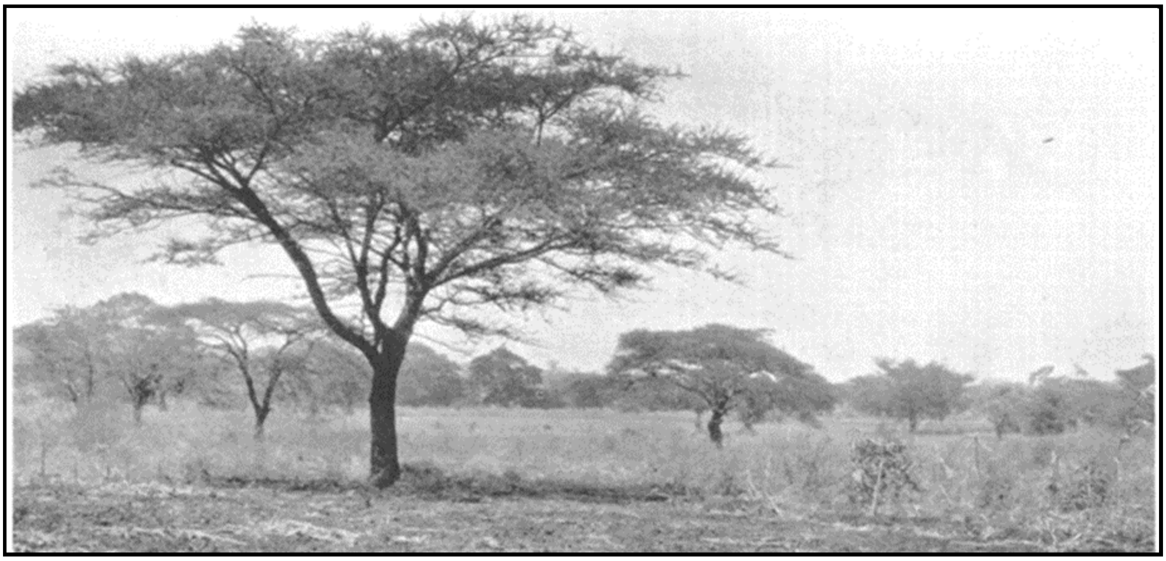
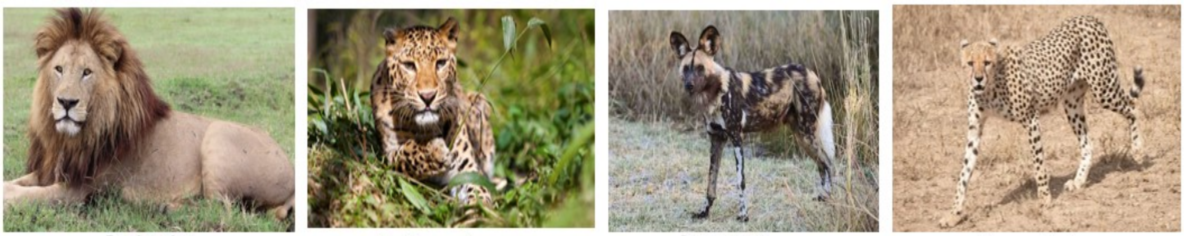


Figure 3: **Vegetation cover of the study area as observed by Greenway (Greenway, 1933)**

(ii) Historical Occurrence of Large Mammal Species

The herbivores that inhabited the proposed rewilding area in the past included *Loxodonta africana, Taurotragus oryx, Giraffa camelopardalis*, *Syncerus caffer, Aepyceros melampus, Equus quagga, Alcelaphus buselaphus, Phacochoerus africana, Hippopotamus amphibius, Tragelaphus strepsiceros, Tragelaphus imberbis* and *Hippotragus niger* (Riggio & Caro, 2017; Foley *et al.,* 2014; Barnes & Douglas-Hamilton, 1982; East, 1984; Lamprey, 1963) (Fig. 4). Common carnivores that dominated the area included *Panthera leo, Panthera pardus, Lycaon pictus* and *Acinonyx jubatus* (Caro *et al.,* 1998) (Fig. 4). These results are supported by the responses from the key informants who confirmed the notable populations of most of the large mammal species such as greater kudu, buffalo, zebra, and of ecosystem engineers such as elephants and hippos especially between the 1970s and 1990s.



Panthera leo *Panthera pardus* *Lycaon pictus* *Acinonyx jubatus*

Loxodonta africana *Taurotragus oryx* *Giraffa camelopardalis* *Aepyceros melampus*

Syncerus caffer *Connochaetes taurinus* *Equus quagga* *Phacochoerus* africanus

Figure 4: Some of the most common wild animal species that inhabited savanna woodland in central Tanzania in the past (East, 1981; Lamprey, 1963)

(iii) Results from the Interview Responses

Savanna vegetation (grasses and scattered trees) with several wildlife species were reported to dominate the rewilding proposed site in the past (100%, n = 10). The wildlife species included elephant (100%, n = 10), buffalo (100%, n = 10), hippopotamus (100%, n = 10), zebra (100% n = 10), giraffe (100%, n = 10), impala (100%, n = 10), grant gazelle (70%, n=10), bush pig (100%, n = 10), warthog (100%, n = 10), lion (100%, n = 10), hyena (100%, n = 10), bushbuck (100%, n= 10), wildebeest (80%, n = 10), eland (80%, n = 10), kudu (80%, n = 10), civet cat (80%, n = 10) and genet (60%, n= 10). Wild animals that are seen occasionally to date are red duiker (100%, n = 10), elephant (100%, n = 10), civet cat (60%, n = 10) and genet (60%, n = 10). It was further reported that the area was put under anthropogenic pressure through cattle grazing and crop cultivation which involved clearing of the vast areas (100%, n=10).

4.1.2 Current Vegetation Status

(i) Current Vegetation Structure

Approximately fifty (50%) of the study area vegetation is a bush land that is dominated by *Dichrostachys cinerea* as estimated during vegetation sampling. The remaining fifty (50%) was observed to be occupied by grasses, forbs and relatively few and scattered trees (Fig. 5).

The dominant trees are *Acacia tortilis*. Most grasses are annual and generally, species in the rewilding proposed area are more diverse during the wet season than during the dry season ($p<0.001$).

Figure 5: Photo showing the current (2022) vegetation structure in the study area and encroachment of Dichrostachys cinerea (Field survey, 2022)

(ii) Plant Species Composition and Abundance

During the seasons (wet and dry), the area comprised a mixture of grasses (18% and 9%), forbs (42% and 27%), shrubs (30% and 45%), trees (10% and 19%) respectively (Table 2 and 3). The family *Poaceae* dominated in both seasons with *Setaria pumila* (4218) and *Eragrostis cylindiflora* (725) being the most abundant grass species during wet and dry seasons respectively (Fig. 6).

Table 2: Current floristic composition of the study area as observed during field survey 2021-2022

Common floristic types			
Grasses	**Herbs**	**Shrubs**	**Trees**
Digitaria milanjiana	*Bidens Pilosa*	*Boscia mossambicensis*	*Lannea triphylla*
Digitaria macroblephara	*Cyathula orthocantha*	*Solanum incanum*	*Trichelia emetica*
Dactyloctenium aegyptium	*Cucumis aculeatus*	*Markhamia obtusifolia*	*Vitex sp*
Cyperus amabilis	*Tridax procumbens*	*Sida ovata*	*Croton macrostachyus*
Cynodon dactylon	*Vernonia glabra*	*Steganotaenea araliacea*	*Euphorbia candelabrum*
Panicum maximum	*Stylosanthes fruticose*	*Stereospermum kunthianum*	*Cassia abbreviata*
Heteropogon contortus	*Waltheria indica*	*Strophanthus eminii*	*Combretum apiculatum*
Eragrostis cylindriflora	*Cynanchum dregea*	*Trumfetta rhomboidea*	*Acacia sp*
Dactyloctenium aegypticum	*Tephrosia pumila*	*Waltheria indica*	*Acacia tortilis*
Digitaria ganzensis	*Triumfetta rhomboidea*	*Zanthoxylum chalybeum*	*Acacia Senegal*
Rhynchelytrum repens	*Crotalaria retusa*	*Ipomoea mombassana*	*Acacia nilotica*
Chloris gayana	*Crotalaria cylindrical*	*Dalbergia acariiantha*	*Albizia harveyi*
Cenchrus ciliarias	*Commicarpus plumbagineus*	*Acalypha fruticose*	*Balanites aegyptiaca*
Aristida keniensis	*Commelina benghalensis*	*Combretum aculeatum*	*Commiphora swynnertonii*
Bachiaria deflexa	*Cleome hirta*	*Commiphora schimperi*	*Delonix elata*
Digitaria milanjiana	*Chamaecrista mimosoides*	*Commiphora sp*	*Delonix regia*
Diheteropogon filifolius	*Chamaecrista hildebrandtii*	*Cordia sinensis*	
Eragrostis cylindiflora	*Acanthospermum hispidum*	*Dalbergia nitidula*	
Eragrostis tenuifolia	*Alysicarpus glumaceus*	*Dichrostachys cinerea*	
Tragus racemosus	*Asparagus africanus*	*Ehretia obtusifolia*	
Heteropogon contortus	*Bidens schimperi*	*Entada stuhlmannii*	
Urochloa trichopus	*Blepharis sp*	*Grewia bicolor*	
Rottboellia sp	*Desmodium sp*	*Grewia flavescens*	
Schimidtia sp	*Dicoma tomentosa*	*Indigofera arrecta*	
Setaria pumila	*Dyschoriste hildebrantii*	*Hibiscus micranthus*	
Sporobolus ioclados	*Euphorbia hirta*	*Senna singueana*	

Common floristic types			
Grasses	**Herbs**	**Shrubs**	**Trees**
Sporobolus pellucidus	*Dyschoriste trichocalyx*	*Indigofera garckeana*	
Themeda triandra	*Euphorbia crotonoides*	*Indigofera trita*	
	Euphorbia inaequilatera	*Ipomoea polymorpha*	
	Glossocardia bidens	*Jasmimum fluminense*	
	Glycine wightii	*Lagenaria sp*	
	Gutenbergia cordifolia	*Lannea humilis*	
	Hirpicium diffusum	*Lannea schweinfurthii*	
	Indigofera indica	*Lantana trifolia*	
	Justicia debilis	*Maerua decumbens*	
	Justicia matammensis	*Maytenus senegalensis*	
	Launaea cornuta	*Melhania velutina*	
	Leonotis nepetifolia	*Momordica boivinii*	
	Leucas grandis	*Mundulea sericea*	
	Ocimum sp	*Olax sp*	
	Oxygonum sinuatum	*Opilia campestris*	
	Sesamum angustifolia	*Opilia celtidifolia*	
	Spermacoce princeae	*Polygala sphenoptera*	
	Stylosanthes fruticose	*Rhoicissus tridentata*	
	Tephrosia alata	*Senna absus*	
	Tephrosia purpurea		
	Tribulus terrestris		
	Trichodesma zeylanicum		
	Tridax procumbens		
	Vernonia glabra		

Table 3: Summary of the species abundance and composition as observed during field survey 2021-2022

Life Form	Dry season		Wet season		Statistical Test	
	Species	Genus	Species	Genus	T statistic	p-value
Grasses	06	02	26	02	t=-1.9391	0.1478
Forbs	21	02	62	04		
Shrubs	36	03	45	03		
Trees	14	02	14	02		
Total	77	09	147	11		

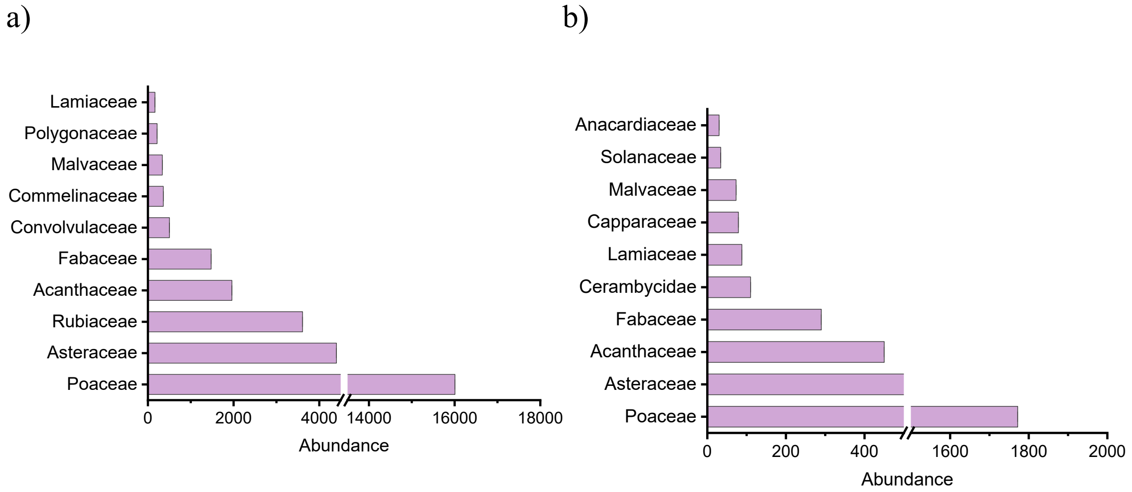


Figure 6: Ten dominant plant families that are found in the proposed rewilding site during the (a) wet and (b) dry seasons 2021-22

(iii) Plant Species Diversity

There was a significant difference between plant species diversity in the wet and dry seasons (t= 67.8, *p*<0.001). Similarly, the diversity differed significantly within the seasons (t=34.2, p<0.001 and t=14, *p*<0.001 in the wet and dry seasons, respectively). Moreover, there was a significant difference in plant species richness within the study site during both the dry and wet seasons (W=10011, *p*<0.01 and W=10011, *p*<0.01, respectively). Additionally, there was a significant difference between plant species richness in the dry and wet seasons (W=9138, *p*<0.01). The summary for the test statistics is given in Table 4, while Fig. 7 displays a summary of descriptive statistics which depict higher diversity in rainy season compared to the dry season.

Table 4: Wilcoxon Signed-Rank and Student's t test results for two indices; diversity and richness of the plant species

Index	Test	Statistic	*p*-value
Diversity (between dry and wet season)	Students' t	t=67.8	<0.001
Diversity (within wet season)	Students' t	t=34.2	<0.001
Diversity (within dry season)	Students' t	t=14	<0.001
Richness (between wet and dry)	Student's t	t=13.8	<0.001
Richness (within dry season)	Wilcoxon Signed-Rank	W=10011	<0.001
Richness (within wet season)	Wilcoxon Signed -Rank	W=10011	<0.001

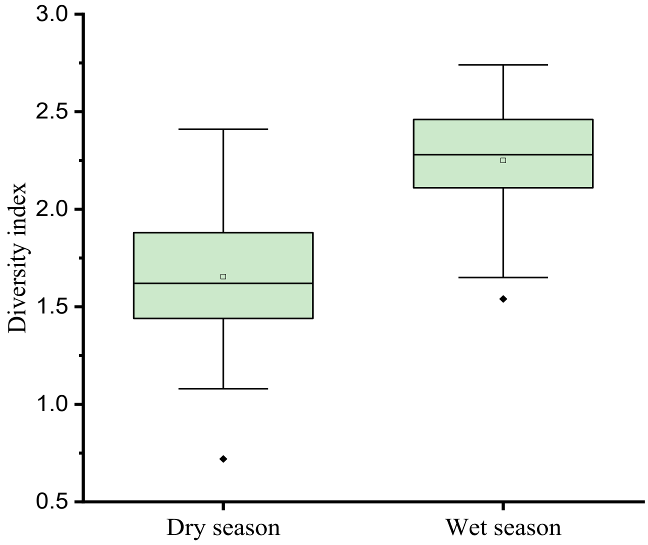


Figure 7: **Plant diversity at UDOM rewilding site during the wet and dry seasons of 2021-2022**

4.1.3 Soil Physico-Chemical Properties Results

(i) Soil Physical Properties

The soil in rewilding proposed site had the reddish brown and dark reddish brown colour dominated during dry and wet seasons respectively. The soil textures dominated in the study area were sandy-clay-loamy. The physical properties suggest that the soil type of the study area is sandy clay loam Acrisol.

(ii) Soil Chemical Properties Results

Generally, the soil chemical properties in the study site varied significantly as summarized in Table 5.

Table 5: **One-sample Student's t test for soil chemical analysis (n=15)**

Parameter	Mean ± SD	Statistics	d.f.	*p*-value
pH	6.35±0.28	t=86.66	14.0	<.001
Total N (%)	0.01±0.02	t=18.11	14.0	<.001
P (mg/kg)	1.57±0.49	t=12.32	14.0	<.001
Ca (Cmol/kg)	0.23±0.26	t=3.41	14.0	0.004
Mg (Cmol/kg)	27.47±16.41	t=6.44	14.0	<.001
CEC (Cmol/kg)	20.52±3.85	t=20.65	14.0	<.001
Fe (ppm)	93.23±0.08	t=9.71	14.0	<.001
K (Cmol/kg)	0.38±0.12	t=12.04	14.0	<.001
Mn (ppm)	138.26±48.9	t=11.21	14.0	<.001
Cu (ppm)	0.02±0.01	t=6.48	14.0	<0.001
Zn (ppm)	0.29±0.71	t=1.61	14.0	<.001

4.1.4 Soil Seed Bank Analysis

Of the forty-seven (47) samples that were collected for the seed bank pot experiment, only one (1) sample (2%) had no germinated plants. Seed bank abundance varied significantly from one grid to another (Table 6). Nine (9) species were found neither in the dry nor in the wet season in the field but were found in the seed bank pot experiment. These species were *Oxalis corniculata, Conyza bonariensis, Ageratum conyzoides, Argyrolobium sp., Chamaecrista absus, Eragrostis patens, Alysicarpus glumaceus, Chloris pycnothrix and Rorippa micrantha* (Fig. 8). Ten (10) dominant plant families were observed in the pot experiment (Fig. 9; Table 7).

Table 6: One-sample Student's t test for testing seed bank variation among selected grids

Test	Statistics	Mean ± SD	d.f.	*p*-value
Student's t test	t=12.8	1.05±0.551	46.0	<.001

Figure 8: Different plant species that were revealed in the seed bank pot experiment as of January- April, 2022

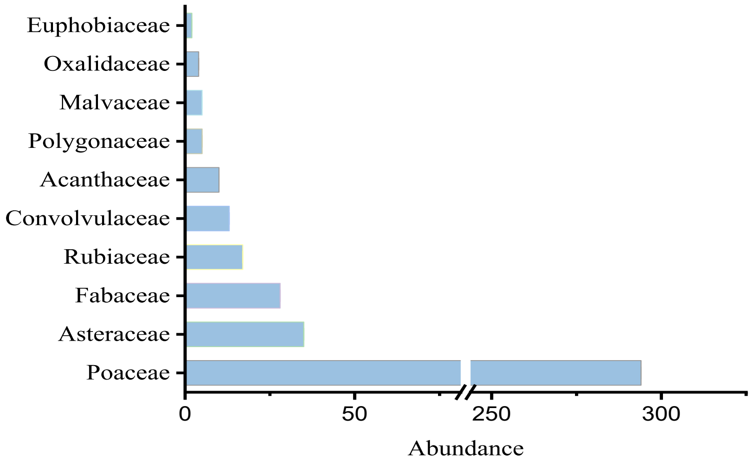


Figure 9: Ten dominant plant families that were found in the seed bank pot experiment as of January- April, 2022

Table 7: Plant species that were revealed in the seed bank pot experiment as of January- April, 2022

Grasses		Herbs
Brachiaria deflexa	*Spermacoce princeae*	*Vernonia glabra*
Setaria pumila	*Gutenbergia cordifolia*	*Ageratum conyzoides**
Digitaria milanjiana	*Glycine wightii*	*Euphorbia crotonoides*
Aristida kenyensis	*Ipomoea mombassana*	*Cyathula orthocantha*
*Eragrostis patens**	*Glossocardia bidens*	*Cleome hirta*
Rhynchelytrum repens	*Justicia matammensis*	*Sida ovata*
Digitaria ganzensis	*Oxygonum sinuatum*	*Chamaecrista absus**
Dactyloctenium aegyptium	*Triumfetta rhomboidea*	*Alysicarpus glumaceus**
Rottboellia sp	*Tephrosia elata*	*Rorippa micrantha**
Eragrostis cylindiflora	*Oxalis corniculate**	*Vernonia glabra*
Heteropogon contortus	*Conyza bonariensis**	*Ageratum conyzoides**
Sporobolus cylindiflora	*Bidens pilosa*	*Euphorbia crotonoides*
Eragrostis tenuifolia	*Crotalaria polysperma*	*Cyathula orthocantha*
Eragrostis contortus	*Euphorbia hirta*	*Argyrolobium sp**
*Chloris pycnothrix**	*Dyschoriste hildebrandtii*	
Eragrostis sp		

**Species that were revealed by the seed bank pot experiment but were not seen during sampling in the dry or wet season*

4.1.5 Temperature and Rainfall Pattern at the Proposed Rewilding Site

Temperature and rainfall in Dodoma municipality varied significantly in the past seven (7) years (Table 8) from one year to another ((F=31.3), p<0.001). The highest temperature was in November 2015 (31.7°C) while the lowest was in July 2020 (14.2°C) as shown in Appendix 1. The highest rainfall for the past seven (7) years was in January 2018 (320.7 mm), while several months experienced no rainfall at all, as revealed in Appendix 2.

Table 8: One way ANOVA for the average temperature and rainfall data for the past seven (7) years in Dodoma municipality

Variables	2015	2016	2017	2018	2019	2020	2021	*Statistic*	*p-value*
Temperature (°C)	24.6	23.55	24	23.3	23.9	23.95	23.5	F=31.3	<0.001
Rainfall (mm)	64.7	77.9	63.4	102.6	110.1	159.6	85.4		

4.2 Discussion

4.2.1 Historical Occurrence of Large Mammal Species and their Habitats

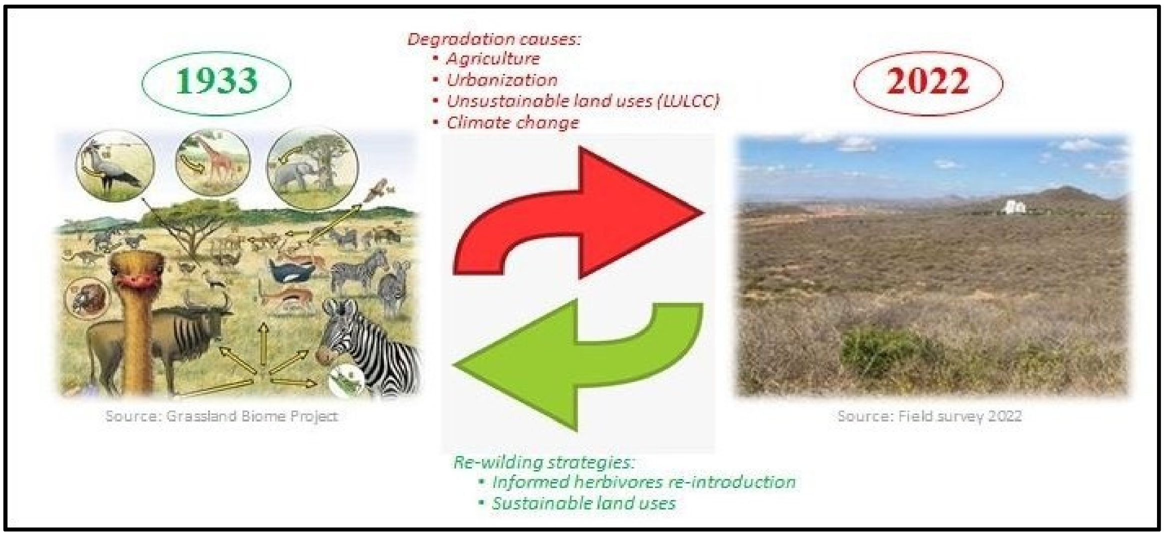
Humanity is facing a massive anthropogenic driven environmental emergency that constitutes the dual biodiversity and climate crises, with approximately a quarter of extant species being at risk of extinction, while wildlife populations are widely declining and extinction rates are several orders of magnitude higher than the natural norm (Svenning, 2020). Results from past literature and vegetation maps backed up with the responses from the key informants, suggest that, central Tanzania used to occupy huge population of wild fauna from an array of herbivores to different guilds of predators inhabiting savanna habitat. Recently, the population has declined tremendously and believed to undergone local extinction in most parts leaving the remnants in the surrounding protected areas. The main reason being ongoing destruction and fragmentation of natural vegetation cover mainly caused by agriculture, urbanization, and other unsustainable land use conversions (Broughton *et al.,* 2021; IPBES, 2019; Yannelli *et al.,* 2022).

Decline in herbivore population like what happened in central Tanzania has proved to impact the vegetation of the area as the removal of herbivores induces vegetation dynamics (Maron & Crone, 2006). Evidence shows that when mega herbivores decline in an area, bush encroachment can be widespread especially in areas where there is a single soil layer and where grazing is infrequent and light (Prins & van der Jeugd, 1993; Ward, 2005). This concur with the field results found in UDOM proposed rewilding site where the area is now bush encroached.

Given these threats, both rewilding and targeted ecosystem restoration are being regarded as effective approaches to mitigate the loss of natural ecosystems and their biodiversity (Bastin *et al.,* 2019; IPBES, 2019; Svenning, 2020). The effectiveness of these approaches requires, among other things, solid background knowledge of the flora and fauna native to an area to ensure that rewilding and restoration efforts are carried out with care and that the right species mix is selected considering reference vegetation types, in addition to suitability to the current biophysical conditions.

The current study at UDOM rewilding proposed area has generated historical information on the past occurrence of large herbivores and their habitats that is crucial for rewilding and restoration of an area. Results have shown that a number of wild mammal species inhabited the savanna woodland of central Tanzania in the past while recently the area has succumbed to bush encroachment as a result of increased anthropogenic activities. Nevertheless, the recently field survey indicates that most of the forage vegetation have been sustained in the area promising for successful rewilding and restoration. This information will contribute to the current need of rewilding in central Tanzania and the surrounding areas.

While passive rewilding is of paramount in restoring complex ecosystems and is regarded as the cheapest method of restoration (Morel *et al.,* 2020), the practice needs to be backed up with a good understanding of the past and present conditions of a particular site (Fig. 10). Understanding the past and present conditions ensure that the intervention would be successful and cost effective. Similarly, it would help to reintroduce species which can be well adopted to the surrounding community as they coexisted in the past. This can equally be explained well by the concept of ecological memory. The concept explains how biotic and abiotic materials and the past information legacy of ecosystem such as remnants of population of locally extirpated species can influence the current reintroduced species (Khalighi *et al.,* 2022; Schweiger *et al.,* 2019). The recently sightings of African elephants (*Loxodonta africana*) and other herbivores such as common duiker (*Sylvicapra grimmia*) at UDOM proposed rewilding site prove that there are some elements of the past information for the survival of herbivores and ultimately high possibilities of restoring the area to its past condition.



Source: Grassland Biome Project

Source: Field survey 2022

Figure 10: A hypothetical framework to depict how a good understanding of a site's prior conditions can aid in devising appropriate rewilding strategies

4.2.2 Current Vegetation Structure, Plant Species Composition, Abundance and Diversity

Semi-arid rangelands are known for their potential to provide ecosystem services and supporting lives of wild fauna (Koch *et al.,* 2022). Yet, in last decades, rangelands have succumbed into bush encroachment which led to reduced species diversity and richness of the vegetation essential for survival of herbivores (Liao *et al.,* 2018). The main driver of bush encroachment being anthropogenic activities (i.e., overgrazing) backed up by climate change (Kgosikoma & Mogotsi, 2013). Bush encroachment have been linked to extinction of wild fauna from herbivores to apex predators in a cascading way with an example of the Australian predator, the dingo (*Canis dingo*) which went extinct for the same reason (Gordon *et al.,* 2017).

The university of Dodoma proposed rewilding site is not far from this fact, the area which was once occupied by savanna woodland is now bush encroached with *Dichrostachys cinerea*. The latter occupies about 50% of the area reducing diversity and richness of grasses and forbs important for the existence of grazers. Therefore, trophic rewilding is vital for shaping vegetation and in due course to ensure the survival of wildlife species which are constantly threatened by loss of habitat due to human induced bush encroachment.

The observed current plant species composition and diversity at UDOM proposed rewilding site can support diverse herbivore species despite plant species abundance being reduced significantly by the presence of *Dichrostachys cinerea*. The results show that there is no statistically significant difference in abundance between the two seasons, but the diversity and richness are higher during wet season compared to dry season. The reintroduction of different guilds of herbivores (grazers and browsers) that were formally part of the native fauna can help to shape the vegetation while facilitating the natural vegetation succession. For instance, reintroduction of giraffe (*Giraffa camelopardalis*) and greater kudu (*Tragelaphus strepsiceros*), that are known as non-specialist browsers, browsing on different plant species (Mandinyenya *et al.,* 2018) will aid to open up the closed bush allowing more grasses and forbs to sprout. The two animals browse on similar species but at different heights (Makhabu, 2005) and are both known to prefer *Dichrostachys cinerea* (Levi *et al.,* 2022).

Apart from the giraffe and greater kudu, the observed plant species composition and diversity of the rewilding proposed area can similarly support specialist grazers such as zebra and wildebeest, which were historically present in the area (Foley, 2014). The presence of grasses such as *Setaria spp., Digitaria macroblephara, Cynodon dactylon, Themeda triandra* and *Aristida spp.,* which are foraged by zebra and wildebeest (Owaga, 1975), is an indication that they can survive in the area. Likewise, medium-sized antelopes such as Impala (*Aepyceros melampus*) and grant gazelle (*Gazella granti*) can also be reintroduced in the UDOM rewilding area to further rewild the site. Impala are intermediate feeders, grazer-browsers; grazing during the wet season and shift to browsing during the dry season (Mramba, 2021). They graze on a variety of species, including *Cynodon dactylon, Panicum maximum, Urochloa spp., Eragrostis spp., Themeda triandra* and *Digitaria eriantha* (Mandinyenya *et al.,* 2019; Pieterse, 2018). Moreover, they browse on *Acacia spp.* (leaves and pods)*, Combretum spp., Boscia spp., Grewia spp., Commiphora spp., Terminalia spp.* and *Dichrostachys spp.* (Mandinyenya *et al.,* 2019; Pieterse, 2018). Small mammals such as red duiker (*Cephalophus natalensis*), have already reestablished in the UDOM proposed rewilding site after the area was left intact for more than ten (10) years. The animals are spotted frequently in the area.

The reintroduced species will not only aid in further dispersing the tree species that have been observed to decrease in the rewilding site compared to past years but will also improve the ground cover of the area. Besides, an important activity to complement rewilding in the proposed area is to set up the monitoring plan that can inform the restoration and conservation efforts about responses of large mammal population recovery on the vegetation structure and composition over spatial and temporal scale.

4.2.3 Soil Physical and Chemical Properties

The soil physical properties suggests that UDOM proposed rewilding site soil is sandy clay loam Acrisol. These results concur with Msanya *et al.* (2018) who found the same in the study site. Acrisols are known to be found in tropical, subtropical and temperate regions supporting a wide range of ecosystems including agro ecosystems and rangelands (Turniˇski *et al.,* 2022). Therefore, presence of this soil type in UDOM rewilding proposed site signals that the rewilding and vegetation restoration would be supported. Furthermore, soil chemical properties and nutrient contents are among important factors that determine spatial and temporal pasture availability (Khan *et al.,* 2007). Likewise, they form the basis for pasture quality and animal health and productivity (Amorim *et al.,* 2020). Deficiency or excess of some nutrients may impair health and productivity of the animals and/or induce toxicity (Khan, 2004). The recommended critical nutrient levels for proper pasture performance in relation to the observed nutrient levels in the rewilding proposed site are given in Table 10.

Table 9: Recommended critical nutrient levels for proper pasture performance

Parameter	Level at the proposed rewilding site	Pasture critical levels	References
pH	6.35	6.0-7.0	Barnhart (2010)
CEC	20.5 cmol/kg	>12 cmol/kg	NSS (1990)
Ca: Mg	1:98	3:1-8:1	Allan *et al.* (1997)
K: Mg	0.01	≥1.5	CCMA (2016)
K/(Ca+Mg)	0.004	2.2	Kemp and Heart (1956)
Ca:P	57:1	1:1-1:7	Gao (2016)
Cu	0.02 mg/kg	>12 mg/kg	DiaryNZ (2016)
Fe	93.23 mg/kg	>4.5 mg/kg	DiaryNZ (2016)
Zn	0.29 mg/kg	>10 mg/kg	DiaryNZ (2016)
Mn	138.26 mg/kg	>500 mg/kg	DiaryNZ (2016)

Ngondya (2017)

(i) Soil pH, available P and available N

The soil pH can be used to determine the quality of the pasture by acting as an indicator of chemical processes taking place in the soil (Hazelton & Murphy, 2007). While the mean soil pH of the rewilding proposed site was 6.35 (Table 10) which is within critical range (6.0-7.0) for maximum pasture productivity (Barnhart, 2010), and therefore likely to support restoration of the UDOM proposed site, both P and N were below critical level similar to what was reported by Msanya *et al.* (2018). The main reasons for the deficiency are believed to be leaching of P and/or removal through harvesting without replenishing for both P and N (Li *et al.,* 2014; Diekow *et al.,* 2005) as the area was kept under constant tillage in the past (before people were evicted more than 15 years ago). This deficiency therefore might necessitate soil treatment (P and N nourishment) efforts to be undertaken before re-introducing species in the proposed UDOM site.

Furthermore, P is known to have interaction with other nutrients in the soil such as N and Ca which affect productivity and/or leading to nutrient deficient disorders (Li, 2004; Guignard, 2017). The Ca:P ratio in the rewilding proposed site was relatively high (57:1) compared to pasture critical ratio (1:7) as suggested by Gao *et al.* (2017). This is attributed to low P in the rewilding proposed site. High Ca:P ratios have been linked to animal disorders such as milk fever, impaired feed conversion and poor breeding performance (Abaye *et al.,* 2009). No matter how high the elevated Ca concentration in pasture forages, Ca assimilation under low dietary P and/or a high Ca:P ratio may be reduced (Gizachew *et al.,* 2002). Low soil P in the rewilding proposed site can be improved through fertilization as suggested by Rogers *et al.* (2021).

(ii) Cation Exchange Capacity

The CEC offers a buffering effect to pH changes, controlling nutrients availability and calcium levels and change in soil structure (Hazelton & Murphy, 2007). The CEC of the soil in the rewilding proposed area ranged from13.08 to 26.35 cmol/kg with the mean value of 20.52 cmol/kg (Table 10). According to NSS (1990) soils with CEC of >12 cmol/kg are perfect for pasture productivity. This is a good indication that the vegetation restoration efforts at the rewilding proposed site would be a success.

(iii) Exchangeable Bases (Ca, Mg and K)

The rewilding proposed area soil had lower (0.01) K/ (Ca+ Mg) than critical value (2.2) as suggested by Kemp and Hart (1956). It is known that, in order for K to have a preventive effect on Mg absorption, the K/ (Ca + Mg) should exceed the critical value (Gizachew *et al.,* 2002). Parallel to this, K: Mg ratio of 0.01 in the proposed rewilding area was also lower than critical value of ≥1.5 (CCMA, 2016) suggesting that there is no interference in the ability of plants to absorb Mg which may lead to Mg deficiency (Gizachew *et al.,* 2002). All these results indicate that, there is low risk of grass tetany development to the expected herbivores in proposed rewilding site which would result as a consequence of low dietary Mg (hypomagnesaemia), a condition which not only lower productivity but also proved fatal to the animals (Lock *et al.,* 2002).

(iv) Available Cu, Fe, Mn and Zn

The soil of the rewilding proposed site was recognized to have Zn, Cu, and Mn deficiency (0.29, 0.02 and 138.06 mg/kg) but nonetheless very sufficient Fe (93.23 ppm) in relation to pasture critical levels (DiaryNZ, 2016). Low Mn, Zn and Cu to animals may lead to retarded growth and reduced reproductive performance of animals (Mirzaei, 2012; Horneck *et al.,* 2011). The low Zn, Cu and Mn in the study site soil might be attributed not only to the parent rock but also heavy cultivation of the area for several years without the application of fertilizer (Silver *et al.,* 2021). Nevertheless, micronutrient deficiency is not perturbing problem because even if the soil shows deficiency, the roots of the plant may still have as many times as the amount required by the plants; the major problem is bioavailability (Hooda, 2010). Similarly, Horneck *et al.* (2011) argues that, micronutrients deficiency should be observed in plant tissue and soil testing should help to determine remediation amount. In that regard, forage nutrient analysis should be performed before reintroduction of herbivore species so as to determine which of the available micronutrient is deficient.

Therefore, the soil results obtained from the current study will serve as the baseline for fertilization and inform other important measures to improve soil quality and fertility in the rewilding proposed area for animal health and high pasture productivity.

4.2.4 University of Dodoma Proposed Rewilding Site Soil Seedbank

Soil seed bank plays a vital role in vegetation succession and dynamics (Skoglund, 1992). Pot experiment revealed that the most dominant seeds in the rewilding proposed area were grasses (*Poaceae*). This is vital for the future of grazers as most *Poaceae* form their diet. Nine more species were observed which were not spotted in field survey indicating that when the condition is favorable, the plant species abundance, composition and diversity in the rewilding proposed area would increase remarkably. Relatively large soil seed bank has several advantages to an area under restoration. They reduce the cost of purchasing seeds as most seeds particularly grasses are relatively expensive. Equally, they reduce the time and the effort needed for reseeding while enhancing a quick vegetation recovery (Wang *et al.,* 2013). The information from seed bank pot experiment will inform on seed requirements for future restoration of vegetation in the rewilding proposed area.

4.2.5 Temperature and Rainfall Pattern at the Proposed Rewilding Site

Mean temperature and rainfall pattern in the study area varied significantly from one year to another possibly due to climate change. This is the same as the study by Sangeda and Malole (2014) which revealed the variation of rainfall and temperature in most rangelands of Tanzania as a consequence of climate change. Climate change is known to impact the restoration efforts all over the world (Harris *et al.,* 2006). For example, climate change hampered restoration of Salmon in western USA by interfering with stream flow and temperature fluctuation (Beechie *et al.,* 2013). Likewise, in Three-Rivers Headwaters in Alpine zone, climate change led to decrease in restored vegetation (Guo *et al.,* 2022). Additionally, climate change is known to shift the baseline and therefore complicate the rewilding and restoration efforts (World Bank, 2019). Kangaroo grass (*Themeda triandra*) and bermuda grass (*Cynodon dactylon*) abundances for-instance have been reduced tremendously in the rewilding proposed area which calls for the need to restore these two important species as part of rewilding and restoration initiative.

Rainfall and temperature are known to influence germination (Ribeiro & Borghetti, 2014), affect vegetation growth (Guo *et al.,* 2022) and determine the availability of both quality and quantity forage (Boschma *et al.,* 2017; Pandey & Singh, 1992). Even though the rewilding proposed area experience variation of temperature and rainfall, the restoration of the proposed species is expected to be successful. This is due to the fact that *Cynodon dactylon* has varieties that can tolerate drought and water stress (Kumar, 2017; Shi *et al.,* 2012) while *Themeda triandra* can be reseeded during optimum condition (temperature of about 30°C and moisture approaching field capacity) for its germination (Cole & Lunt, 2005). This condition occurs in the rewilding proposed area between March and May (Appendix 1 and 2). Despite the fact that temperature and rainfall fluctuation might delay the recovery, *Themeda triandra* and *Cynodon dactylon* reintroduction is inevitable for survival of both existing and to be re-introduced grazers. Irrigation schemes must be put in place at the rewilding proposed area as a backup in case of excessive drought.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study highlighted the important information about the historical and present vegetation and mammal distribution in central Tanzania first by providing a novel synthesis of the various vegetation cover and composition that existed in the region and the way anthropogenic drivers, including LULCC, have driven these to local extinction. Furthermore, the study explored the soil, rainfall and temperature variation, as they are known to influence both vegetation and herbivore distributions. Additionally, the study described the role of reintroduction and rewilding as extinction reversal strategies by highlighting potential large mammal species that can be reintroduced in the UDOM area as socioecological opportunity not only for the UDOM campus but also for regional-scale restoration and large herbivore rewilding strategies. The study revealed that the UDOM proposed large herbivore re-introduction site was once supported by the remarkable populations of large mammals that included elephants, impala, buffaloes, hippopotamus, wildebeest, lions, leopards and wild dogs among many others inhabiting savanna woodland. The study further indicated moderate soil fertility with relatively high seed bank. Besides, the weather of the rewilding proposed area was found to vary significantly from one year to another. The results suggest that rewilding and restoration can be successful with some manipulation of the area for instance improving of soil quality and restoration of important vegetation species. Therefore, this study has provided evidence-based information necessary to inform re-introduction at UDOM and adjacent area. These results would guide both the current and near-future re-wilding and restoration opportunities for not only UDOM proposed rewilding and re-introduction site but also elsewhere.

5.2 Recommendations

(i) Since the study established that the large herbivore that occupied the area in the past included but not limited to an array of grazers and browsers such as impala, wildebeest, zebra, greater kudu and giraffe, then these should be the candidates to be selected in the rewilding process.

(ii) Species that were historically not available in the area, for instance *Thomson gazelle,* should not be introduced as free-ranging animals.

(iii) The most preferred plant species for grazers such as *Themeda triandra* and *Cynodon dactylon* should be restored, as their abundance is currently relatively low.

(iv) Human-wildlife conflicts must be considered before reintroducing wildlife by not only fencing the area but also through outreach programmes to raise awareness to the surrounding community.

(v) Post release monitoring and evaluation systems and programmes must be put in place for the reintroduced herbivore species to thrive.

(vi) Further study to assess biomass and carrying capacity should be undertaken before reintroduction of wild animal species.

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APPENDICES

Appendix 1: Temperature data for the past seven (7) years in Dodoma municipality

	Temperature (℃)													
	2015		**2016**		**2017**		**2018**		**2019**		**2020**		**2021**	
	Max	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**
January	28.8	19.3	29.4	20.0	31.7	20.3	27.7	19.0	29.9	19.9	28.7	19.9	28.4	19.2
February	31.8	19.8	29.4	19.7	30.0	19.5	30.9	19.5	31.2	20.3	29.6	19.9	28.9	19.3
March	30.4	19.5	32.0	20.5	29.3	19.4	27.8	19.1	30.9	19.7	28.5	19.6	29.2	19.0
April	30.3	19.4	28.5	19.2	28.3	19.1	27.8	19.1	30.0	19.8	28.0	19.1	29.1	18.9
May	28.3	17.9	28.0	16.4	27.9	17.7	27.8	17.4	27.8	18.3	27.7	17.4	28.5	17.3
June	28.2	16.0	27.0	15.2	27.8	16.8	27.4	15.1	27.9	15.7	27.7	15.5	26.7	15.6
July	27.3	15.6	26.7	14.2	27.4	15.4	26.1	14.8	27.5	15.1	26.1	14.7	25.9	14.8
August	28.1	15.6	27.6	14.8	28.1	16.3	27.7	15.4	28.3	16.0	28.2	15.9	27.9	16.1
September	29.4	16.0	28.7	15.3	29.6	16.6	29.6	16.6	30.0	17.2	29.5	16.7	28.9	16.9
October	31.5	18.2	31.0	17.9	31.8	18.9	30.6	18.1	30.3	18.5	31.5	18.4	31.1	18.1
November	31.7	19.3	31.9	19.3	31.9	19.4	32.5	19.5	31.3	19.5	30.7	19.6	32.8	19.6
December	31.1	20.1	32.4	20.2	32.3	20.5	30.4	19.7	29.0	19.6	30.3	19.8	31.7	20.0

Appendix 2: Rainfall data for the past seven (7) years in Dodoma municipality

	Rainfall (mm)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**TOTAL**
2015	64.2	46.0	10.9	46.9	30.1	0.0	0.0	0.0	0.0	0.0	66.9	187.2	**452.2**
2016	179.5	135.7	108.8	110.2	0.0	0.0	0.0	0.0	0.0	0.0	2.5	8.5	**545.2**
2017	73.9	202.0	112.2	9.4	1.9	0.0	0.0	0.0	0.0	0.0	12.9	31.6	**443.9**
2018	320.7	31.7	177.1	24.2	2.9	0.0	0.0	0.0	0.0	0.0	11.3	150.1	**718.0**
2019	123.5	146.1	128.8	28.1	1.5	0.0	0.0	0.0	0.0	4.6	28.0	309.9	**770.5**
2020	220.5	197.4	268.2	154.5	0.2	0.0	4.8	0.0	0.0	8.5	144.4	127	**1117.0**
2021	205.3	178.1	171.9	19.9	0.0	0.0	0.0	0.0	0.0	10.5	0.0	12.4	**598.1**

RESEARCH OUTPUTS

(i) Publication

Athumani, P. C., Munishi, L. K., & Ngondya, I. B. (2023). Reconstructing Historical Distribution of Large Mammals and their Habitat to Inform Rewilding and Restoration in Central Tanzania. *Tropical Conservation Science*, *6, 1–15*

(ii) Poster Presentation