Sokoine University of Agriculture

MSc Dissertation

Factors Influencing the Population Density and Distribution of Udzungwa Red Colobus Monkey (*Piliocolobus. gordonorum*) in Magombera Forest Reserve, Tanzania

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FACTORS INFLUENCING THE POPULATION DENSITY AND DISTRIBUTION OF UDZUNGWA RED COLOBUS MONKEY (*Piliocolobus. gordonorum*) IN MAGOMBERA FOREST RESERVE, TANZANIA

Dissertation submitted to Sokoine University of Agriculture in Fulfillment of the Requirements for the Degree of Master of Science in Wildlife Management and Conservation

By

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EXTENDED ABSTRACT

Primates perform essential roles in forest ecosystems such as enhancing seed dispersion which is important in the regeneration of fragmented forests and improving soil quality through defecation. Despite their important role in forest ecosystem, they are faced with a greater risk of extinction as a result of massive forest loss and degradation which are greatly influenced by anthropogenic activities such as logging, bush fires, agriculture and settlement expansion. Furthermore, forest loss may be attributed by natural changes such as climate change, droughts and tree die back which may result to changes in forest cover or tree species composition. As an outcome of all these, their population and distribution has been directly impacted, increasing their risk of becoming extinct. Kilombero cluster is one of the biodiversity hotspot areas as it comprises of several protected areas that harbors the vulnerable *P. gordonorum* such as Udzungwa National Park and the fragmented Magombera Forest Reserve (MFR). Therefore, this study was conducted within Kilombero cluster to identify the population density of *P. gordonorum* in MFR, identify factors influencing the population density of *P. gordonorum* in MFR and assess the impact of climate change on the current and future distribution of suitable habitats for *P. gordonorum* in Kilombero cluster. Systematic distance sampling technique using line transect was used to obtain data for estimating population density. Where a total of 15 transects were established in three habitat types. Along each transect information about primate sightings, occurrence locations, human disturbances and vegetation structure were collected. Furthermore, a combination of field surveys and data downloaded from Global Biodiversity Information Facility was used to identify the current and future distribution of *P. gordonorum* under the influence of climate change. Shannon Weiner index was used to compute tree species diversity, Allometric models was used for above ground biomass estimation, Generalized Linear Model with Gaussian error function was run to determine the influence of predictor variables on the density of *P. gordonorum* and non-parametric Kruskal Wallis test was used to test for significant differences in every predictor variable. The results from this study showed that the average density of *P. gordonorum* in MFR was (27.4±22.12) individuals per km^2 and it varied among the three habitat types namely semi-evergreen, semi-deciduous and wooded grassland with a density estimate of (44±11.3) individuals per km^2, (5.5±7.4) individuals per km^2 and (1±0.5) individuals per km^2 respectively. Vegetation structure, availability of preferred food tree species and human disturbances was seen to influence the density of *P. gordonorum*. Furthermore, findings from this study revealed that, currently, the distribution of suitable habitats for the Udzungwa red colobus monkey covers an area of 1 142 400 ha for highly suitable habitats and these areas will decline to 392 000 ha and to 96 000 ha in 2050 and 2070 respectively according to RCP 8.5. From the findings, isotherm and precipitation of the wettest month were seen to greatly influence the current and future potential distribution of suitable habitats for *P. gordonorum.* This study has provided sufficient information on the status of *P. gordonorum* population in MFR. And the impact of climate change on the distribution of *P. gordonorum*. Furthermore, the study has helped in the identification of high priority areas for conservation of the vulnerable *P. gordonorum*. Finally, the study recommends for strong management and conservation initiatives for those areas that *P. gordonorum* have been predicted to occur. Such initiatives should involve improved management capacity in the existing nature forest reserves and village owned forests, protection of the existing wildlife corridors to ensure habitat connectivity, the balance between socio-economic gains and conservation and national wise mitigation strategies such as the reduction of greenhouse gas emission. Thus, this study calls for further research on mapping the distribution of *P.gordonorum* with an account of climatic variables, vegetation variables such as Normalized Vegetation Index (NDVI), percentage tree cover, topographic variables, and proximity to human disturbances.

Key words: Anthropogenic activities, Climate change, Distribution, Population density, Vegetation structure

IKISIRI KUU

Nyani hutekeleza majukumu muhimu katika mifumo ikolojia ya misitu kama vile kuimarisha mtawanyiko wa mbegu ambao ni muhimu katika urejeshaji wa misitu iliyogawanyika na kuboresha ubora wa udongo kwa njia ya haja kubwa. Licha ya jukumu lao muhimu katika mfumo ikolojia wa misitu, wanakabiliwa na hatari kubwa ya kutoweka kutokana na upotevu mkubwa wa misitu na uharibifu unaochangiwa sana na shughuli za kibinadamu kama vile ukataji miti, uchomaji moto wa misitu, kilimo na upanuzi wa makazi. Zaidi ya hayo, upotevu wa misitu unaweza kuchangiwa na mabadiliko ya asili kama vile mabadiliko ya hali ya hewa, ukame na miti kufa ambayo inaweza kusababisha mabadiliko ya misitu au muundo wa miti. Kama matokeo ya haya yote, idadi ya nyani na usambaaji wao umeathiriwa moja kwa moja, na kuongeza hatari yao ya kutoweka. Nguzo ya Kilombero ni mojawapo ya maeneo yenye bayoanuwai kwani inajumuisha maeneo kadhaa ya hifadhi ambayo ni maeneo muhimu ya kolobus wekundu wa Udzungwa kama vile Hifadhi ya Taifa ya Udzungwa na Hifadhi ya Msitu wa Magombera. Kwa hiyo, utafiti huu ulifanywa ndani ya nguzo ya Kilombero ili kubaini idadi ya Kolobus mwekundu katika msitu wa Magombera na pia kubainisha mambo yanayoathiri idadi ya Mbega mwekundu katika msitu wa Magombera na kutathmini athari za mabadiliko ya hali ya hewa kwenye mgawanyo wa sasa na wa baadaye wa makazi yanayofaa kwa ajili ya Mbega wekundu katika nguzo ya Kilombero. Mbinu ya utaratibu ya sampuli za umbali kwa kutumia mpito wa mstari ilitumiwa kupata data ya kukadiria idadi ya Kolobus wekundu. Zaidi ya hayo, mseto wa tafiti za nyanjani na data iliyopakuliwa kutoka kwa Kituo cha Taarifa za Bioanuwai Ulimwenguni ilitumiwa kutambua usambaaji wa sasa na ujao wa Mbega wekundu chini ya ushawishi wa mabadiliko ya hali ya hewa. Faharasa ya Shannon Weiner, miundo ya Allometric ya ukadiriaji wa biomasi ya juu ya ardhi, Muundo wa Linear wa Jumla wenye hitilafu ya Gaussian na jaribio lisilo la kigezo la Kruskal Wallis zilitumika katika uchanganuzi. Matokeo ya utafiti huu yalionyesha kuwa wastani wa idadi ya Mbega wekundu katika msitu wa Magombera ulikuwa (27.4±22.12) kwa kila kilometa ya mraba na ulitofautiana kati ya aina tatu za misitu ambazo ni msitu wa kijani kibichi, msitu wa nusu-nyasi na msitu wa nyasi zenye miti yenye makadirio ya idadi ya (44±11.3), (5.5±7.4) na (1±0.5) kwa kila kilometa ya mraba mtawalia. Muundo wa mimea, upatikanaji wa chakula na shughuli za kibinadamu zilionekana kuathiri idadi ya Mbega wekundu katika msitu wa Magombera. Ingawa utajiri wa spishi za miti, urefu wa miti na kaboni ya miti juu ya ardhi ilikuwa juu katika msitu wa kijani kibichi kuliko misitu yenye miti midogo midogo na nyasi. Zaidi ya hayo, matokeo ya utafiti huu yalifichua kwamba, kwa sasa, maeneo yanayofaa zaidi kwa kolobus wekundu ni eneo la hekta 1 142 400 na maeneo haya yatapungua hadi hekta 392,000 na hadi 96,000 mwaka 2050 na 2070 mtawalia kulingana na RCP 8.5. Kutokana na matokeo hayo, joto na mvua ya mwezi ilionekana kuwa na ushawishi mkubwa kwa uwepo wa sasa na ujao wa makazi yanayofaa kwa Mbega wekundu. Utafiti huu umetoa taarifa juu ya idadi ya Mbega wekundu katika msitu wa Magombera. Na athari za mabadiliko ya hali ya hewa katika usambaaji wa Mbega wekundu. Zaidi ya hayo, utafiti umesaidia katika kubainisha maeneo ya kipaumbele cha juu kwa ajili ya uhifadhi wa Mbega wekundu walio katika mazingira magumu. Hatimaye, utafiti unapendekeza kuwepo kwa usimamizi thabiti na mipango ya uhifadhi kwa yale maeneo ambayo yametabiriwa kuwa ya muhimu kwa Mbega wekundu. Juhudi kama hizo zinapaswa kuhusisha uboreshaji wa uwezo wa usimamizi katika hifadhi zilizopo za misitu ya asili na misitu inayomilikiwa na vijiji, ulinzi wa shoroba zilizopo za wanyamapori ili kuhakikisha uhusiano wa makazi, uwiano kati ya mafanikio ya kijamii na kiuchumi na uhifadhi. Pamoja na mikakati ya kitaifa ya busara ya kukabiliana na hali kama vile kupunguza utoaji wa gesi chafuzi Kwa hivyo, utafiti huu unahitaji utafiti zaidi juu ya kuchora ramani ya usambaaji wa Mbega wekundu kwa kuzingatia vigezo vya hali ya hewa, vigezo vya mimea kama vile Kielezo cha Uoto wa Kawaida (NDVI), asilimia ya mifuniko ya miti, vigeu vya topografia, na ukaribu wa shughuli za kibinadamu.

Maneno muhimu: Mabadiliko ya hali ya hewa, Muundo wa mimea, Shughuli za kibinadamu, Takwimu ya Mbega wekundu, Usambaaji wa Mbega wekundu,

DECLARATION

I, Natasha Riverson Mamuya, do hereby declare to the Senate of Sokoine University of Agriculture, that this dissertation is my original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

______________________ ______________________

Natasha R. Mamuya Date

(MSc. Candidate)

The above declaration is confirmed by:

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Prof. Japhet J. Kashaigili Date

(Main Supervisor)

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Dr. Geofrey. Soka Date

(Co-Supervisor)

LIST OF PUBLISHED MANUSCRIPT

i. Submitted to Open Journal of Ecology titled: Factors influencing the population density of Udzungwa red colobus (*Procolobus gordonorum*) in Magombera Forest Reserve
ii. To be submitted to African Journal of Wildlife Research titled: Factors influencing the distribution of Udzungwa red colobus (*Procolobus gordonorum*) in Magombera Forest Reserve

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DEDICATION

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LIST OF ABBREVIATION AND ACRONYMS

DBH	Diameter at Breast Height
DEM	Digital Elevation Model
GBIF	Global Biodiversity Information Facility
GPS	Global Positioning System
HR	Hours
IUCN	International Union for Conservation of Nature
KGCA	Kilombero Game Controlled Area
KNR	Kilombero Nature Reserve
MFR	Magombera Forest Reserve
MNP	Mikumi National Park
NNP	Nyerere National Park
QGIS	Quantum Geographic Information System
RCP	Representative Concentration Pathway
REDD	Reducing Emissions from Deforestation and Forest Degradation
UNP	Udzungwa National Park
URT	United Republic of Tanzania

CHAPTER ONE

INTRODUCTION, JUSTIFICATION AND OBJECTIVES

1.1 General Introduction

Primates play an essential role in structuring ecosystems of tropical forests as seed dispersal. Furthermore, they add nutrients into the soil thus improving the quality of the soil through defecation (Chapman *et al.,* 2013)**.** Primates also play a key role in regenerating fragmented landscapes example Chimpanzees are seed dispersers between fragmented forests (Heymann, 2017).

Despite their key roles in the ecosystem, they are faced with massive extinction. Carvalho *et al*. (2019) reports that about a half of the entire primate species are endangered with extinction, whereby 62% have been categorized to be threatened and 5% to be nearly threatened. Primate populations, are faced with the problem of surviving with the dynamics so they are obliged to adapt to these changes so as to survive, failure to do so results to their extinction (Isabirye and Lwanga, 2008).

African continent harbours the greatest primate diversity of about 64 species to which 23 of them are categorized to be threatened and among these 6 species are of *P. gordonorum* (Chapman and Peres, 2001). In most developing countries there is a decline of primate population as a result of forest degradation that leads to their extinction (Ley-vela, 2005; Melle Ekane *et al.,* 2019).

Currently, conservation threats are from habitat loss and destruction whereas changes in forest habitat are due to major human-induced activities such as logging, forest fragmentation, exotic plant species introduction and deforestation. Furthermore, these changes may be attributed by natural changes such as climate change, droughts and tree die back which may result to changes in canopy cover of forests or tree species composition (Isabirye and Lwanga, 2008). It is estimated that an average of 128 million ha of global forested area in the tropics are undergoing loss from a period of 1990 to 2015 (Morales *et al*., 2015; Struhsaker, 2005).

This has led to destruction of several wildlife habitats in Africa, posing massive extinction risks to several species (Mahulu, 2016). The common impacts to all forest's types comprise loss of biodiversity, disappearance of wildlife habitats, and increased risk of bush fires, limited availability of forest products and ecosystem shift such as from forest to woodlands or woodlands to grasslands (Shayo, 2013).

Colobus monkeys are normally viewed as members of the subfamily Colobinae of the family Cercopithecoidea that are closely related to the olive colobus and the black-and-white colobus dispersed through equatorial East Africa (Oates and Ting, 2015). This primate family is poorly adapted to habitat degradation and their populations have been extirpated from several forests outside protected areas due to habitat degradation and loss (Colobus and Struhsaker, 2020; Struhsaker, 2005). Tanzania is a country with global conservation significance as it contains 29.6% of endemic primates at species level and 28.6% at species and subspecies level. Despite of the high endemism, primates are highly threatened with the expansion of human population, development and habitat fragmentation (Davenport *et al.,* 2014). In Tanzania the endangered *P. gordonorum* monkey is endemic to the Udzungwa Mountains and neighboring forests in the Kilombero Valley south-central of Tanzania (Struhsaker et al. 2004).

1.2 Problem Statement

Mittermeier (2009) reports that the current outcomes from the assessment done by IUCN shows that primates are among the vertebrates' groups that are highly endangered with up to 50% threat of extinction. This is due to habitat loss that is currently taking place everywhere in Tanzania, Magombera Forest Reserve not being an exception. Anthropogenic activities including deforestation, bush-meat hunting, and the exotic pet trade are a result of extensive habitat loss and the reduction of wild populations (Chapman *et al*., 2006). Climatic change will also need to be assessed as it adds more pressure on primates, resulting to increasing extinction risks for many species (Graham *et al.,* 2016).

Despite studies on ecology of primates (Araldi *et al*., 2014; Rovero *et al.,* 2012) the current status of the *P. gordonorum* after MFR annexation to a nature reserve in 2019 is yet to be studied. Therefore, this study aimed at providing baseline information on the population density and distribution of *P. gordonorum* in MFR.

1.3 Justification

This study is designed to provide baseline information on the population density and distribution of *P. gordonorum* in MFR. Thorough evidence on the population density and spatial distribution of species delivers evidence for conserving and managing species, specifically when it comes to endangered species. The findings of this study provide sufficient information on the influence vegetation structure and anthropogenic activities such as edge distance, climate change and other human disturbances on the population density and distribution of *P. gordonorum*. This information will be useful to management authorities and to Southern Agricultural Growth Corridor of Tanzania under the Development Corridor Partnership Project. As it provides information on how to strike a balance between development activities and the conservation of *P. gordonorum* by ensuring that natural resource management and utilization maximizes biodiversity. Furthermore, the use of species distribution models provided information about potential distribution of suitable habitats of *P. gordonorum* and that will enable managers to identify areas of great conservation consideration thus providing future conservation planning strategies.

1.4 Study Objectives

1.4.1 Main objective

To assess factors influencing population density and distribution of *P. gordonorum* in MFR, Tanzania.

1.4.2 Specific Objectives

The specific objectives of the study are:

i. To determine the population density of *P. gordonorum* in MFR
ii. To examine factors influencing the population density of *P. gordonorum* in MFR
iii. To assess the impact of climate change on the current and future distribution of *P. gordonorum* in MFR.

1.4.3 Research Questions

i. What is the current population density of *P. gordonorum* in MFR**?**
ii. Are there any factors influencing the population density of *P. gordonorum* in MFR?
iii. How does anthropogenic activities such as forest fires, pit sawing, deforestation and charcoal burning impact the population of *P. gordonorum* in MFR?
iv. How does vegetation structure such as food availability, tree species richness, and above ground biomass impact the population of *P. gordonorum* in MFR?
v. How do the current climate conditions affect the distribution of *P. gordonorum* in MFR?
vi. How do the future climate conditions affect the distribution of *P. gordonorum* in MFR?

1.5 Dissertation Structure

This dissertation has been written in publishable manuscript format including the extended abstract, general introduction, manuscript-based chapter, general discussion, general conclusions and recommendations and references. In addition to that, specific objective number one and two has been presented as manuscript chapter one and objective number two has been presented as manuscript chapter two. Each chapter therefore, has its own abstract, introduction, methods and materials, results, discussion and conclusion and references. The last chapter includes the general conclusion and recommendation of the whole dissertation.

Chapter one presents the general introduction of the study which include information about threats to primate's population and distribution globally, problem statement, justification, objectives of the study, research questions and limitation of the study

Chapter two presents the first manuscript, which is focusing on determining the population density of *P. gordonorum* in Magombera Forest Reserve and the influence of several anthropogenic and vegetation attributes to the population of *P. gordonorum.* This manuscript describes in detail the relationship between population density of *P. gordonorum* and various vegetation attributes such as food availability, tree species richness, above ground biomass and tree species diversity. Furthermore, the influence of anthropogenic activities such as forest fires to the population of *P. gordonorum* has been assessed.

Chapter three presents the second manuscript, which explain the current and future distribution of *P. gordonorum* and the impact of both environmental and climatic variables to the habitat suitability of *P. gordonorum* in Magombera Forest Reserve ecosystems. Maxent ecological niche modeling was used in predicting the current and future potential distribution of *P. gordonorum* in Kilombero flood plain and assessed the environmental variables that influence their distribution. *P. gordonorum* occurrence data were obtained from field surveys and GBIF data set. Environmental variables included 19 bioclimatic variables downloaded from Worldclim dataset and 4 topographic variables (slope, aspect, elevation) derived from DEM and land cover maps generated using QGIS. The highest scenario for Green House Gas emissions, RCP 8.5 was used to predict the future distribution of *P. gordonorum* for the period 2050 and 2070.

1.6 Limitation of the Study

a. The nature of the forest is a lowland forest which becomes inaccessible during the rainy season. So, this study was carried out during the dry season and it was not able to capture information on the effect of seasonality on the population status of *P. gordonorum*.
b. The presence of river Msolwa which is a border between Magombera Forest Reserve and Nyerere National Park hindered the length of some transect lines which may have resulted to insufficient data on primate’s population.

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CHAPTER TWO

Manuscript One

ASSESSMENT OF THE FACTORS INFLUENCING THE DENSITY OF UDZUNGWA RED COLOBUS MONKEY (*Procolobus gordonorum*) IN MAGOMBERA FOREST RESERVE, TANZANIA

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Abstract
Udzungwa red colobus (*Procolobus gordonorum)* population is at threat as a result to habitat degradation. This study aimed at assessing the population of *P. gordonorum* in Magombera Forest. Line transect distance sampling was used to assess the population of *P. gordonorum*. Primate census was done in three habitat types semi-evergreen, semi-deciduous and wooded grassland. In each habitat variables such as tree species richness, tree DBH, tree height and human disturbances were recorded. Also, above ground biomass was computed using allometric model. Tree species diversity was computed from Shannon-Weiner diversity index. Tree species richness was obtained by counting the number of tree species in each habitat. Food tree species density was derived by dividing the total number of individual foods tree species per hectare. Density was obtained following a method proposed by Sutherland. Generalized Linear Model with a Gaussian error function was run to determine the influence of predictor variables on the

density of *P. gordonorum*. Then Kruskal Wallis test was used to test for significant differences in every predictor variable. Results show that the average density estimate of *P. gordonorum* was 27.4±22.12 individuals per km^2 with an average group size of 24.29±9.25 individuals and there is a significant difference in density estimate of *P. gordonorum* among habitat types ($p < 0.05$). The density of *P. gordonorum* was high in the semi-evergreen forest (44 individuals per km^2) and low in wooded grassland (1 individual per km^2). Vegetation structure and human disturbances negatively influenced the density of *P. gordonorum*. Whereas, tree species richness, above ground biomass and fire had an explained deviance of 78.4%,76.3% and 44.1% respectively. And *Erythrophleum suaveolens, Albizia gummifera,* and *Ochna macrocalyx* were the most favorable food tree species for *P. gordonorum.* This study has shown that both anthropogenic disturbances and vegetation structure has a great influence to the population status of *P. gordonorum*. Therefore, this study calls for essential conservation initiatives measures to ensure that suitable habitats for *P. gordonorum* are conserved.

Key words: Anthropogenic activities, *P. gordonorum,* Population density, Vegetation structure

1.0 Introduction

Over the past two centuries the tropics have experienced massive forest loss of about 128 million ha as a result of habitat degradation (Struhsaker, 2005; Morales *et al*., 2015). Forests in tropical regions are subjected to illegitimate and legitimate anthropogenic activities which result to forest degradation and loss (Wambua, 2017). Degradation and loss of habitat are a result of logging, bush fires, tree debarking, clearance of forest for agriculture and settlement expansion (Ley-vela 2005; Mahulu, 2016). Natural forests have been altered mainly by logging for commercial purposes and clearance of forests for agriculture (Chapman and Lambert, 2000). Such activities pose serious threat to several wild flora and fauna species resulting to their extinction (Maxwell *et al.,* 2016).

Several studies highlighted the negative consequences of forest loss and degradation on terrestrial mammals (Brodie *et al.,*2015; Galán-Acedo *et al.,* 2019; Buchmann *et al.,* 2013), reptiles (Theisinger and Ratianarivo, 2015; Quesnelle *et al.,* 2013), birds (Mortelliti *et al.,* 2010; Morante-filho *et al.,* 2015; Korfanta *et al*., 2012). Many primate species density and richness are also declining as an outcome of habitat loss and degradation (Wiederholt and Post, 2010; Almeida-Rocha *et al.,* 2017; Bowers-sword, 2020).

A variety of primate species exist including baboons, bushbabies and even humans (Wambua, 2017). But this study mainly focused on one primate specie the Udzungwa red colobus *(P. gordonorum)* which has a vulnerability status as a result of increased human disturbances such as subsistence hunting, small scale logging, timber harvesting, expansion of settlements, livestock farming and expansion of land for agriculture which has greatly influenced a decline in their population (Linder *et al.,* 2021).

Udzungwa red colobus monkey are a member of the sub-family colobinae which comprises of at least 30 species distributed in the African tropical forests (Oates, 1994; Bruner, 2006). Other primate species closely related to this primate group are the Zanzibar red colobus, Tana River red colobus and the Western red colobus which are all at threat as a result of habitat loss and fragmentation (Rovero *et al.,* 2009).

Nevertheless, primates respond differently to habitat degradation depending on the type of species and habitat requirements. For instance, Preston (2011) reported that the density of black and white colobus monkey increased with disturbance in Usambara Mountains while it decreased with disturbance in the Udzungwa mountains. Another studies by Almeida-Rocha *et al.,* (2017); Kamilar and Beaudrot, (2018) have indicated that habitat fragmentation in the Tana River led to the shift of red colobus monkeys to more suitable forest patches, as they are very sensitive to habitat degradation and they depend on forests for their survival. Hunting and fragmentation due to expansion of land for agriculture and settlements, development of infrastructure, timber and charcoal production are among the major threats to primate (Linder *et al.,* 2021).

Kilombero district in Morogoro region is composed of several protected areas including national parks (e.g. Nyerere National Park (NNP), Udzungwa National Park (UNP) and Mikumi National Park (MNP)) nature forest reserves (Magombera Forest Reserve (MFR) and Kilombero Nature Reserve (KNR)) and Game Controlled Areas (Kilombero Game Controlled Area (KGCA)) (Starkey, 2020). Some of these protected areas such as the UNP and MFR harbor a number of endangered and endemic primate species such as Sanje Mangabeys (*Cercocebus galeritus sanjei*) and Kipunji (*Rungwecebus kipunji*) (URT, 2013; Davenport *et al.,* 2014). Other primate species including Udzungwa Red colobus (*P. gordonorum*) are vulnerable and endemic primate species in the Udzungwa Mountains and nearby fragmented forest forests such as MFR (Araldi *et al.,* 2014; Anon, 2020).

Magombera Forest Reserve being a small forest patch located to the south eastern part of the cluster, it is the only nature forest reserve which harbors *P. gordonorum* monkey at a higher density (URT., 2013). Colobine monkeys are individuals that are few in number, with limited distribution range and less status of protection than the rest of the taxa, therefore their survival is compromised an alarming rate of habitat degradation and loss as an outcome of human activities (Marshall, 2007; Araldi *et al.,* 2014).

Despite its greatest importance in the conservation of this vulnerable primate species just like the rest of the forest patches areas in the tropics, MFR is highly impacted by anthropogenic activities such as conversion of forests for agriculture, human settlements and pastoralism (Dinesen, 2016). Forest disturbance of any kind can distort primate's habitat, affecting their population and habitat requirements (Araldi *et al.,* 2014). Therefore, an understanding of the population status and how anthropogenic activities impacts tropical rainforest ecosystem is crucial for the conservation of *P.goronorum* as they are crucial habitats for this specie and are currently experiencing deterioration (Ruiz-lopez *et al.,* 2016). Moreover, estimation of primate density is essential in conservation as it helps to determine the current status for effective management (Ley-vela, 2005). The population status of *P. gordonorum* in MFR have been studied from 2002-2012 (Rovero *et al*., 2015) before Magombera forest was annexed to nature forest reserve with an improved management capacity. It is therefore the interest of this study to understand the population status of *P. gordonorum* in MFR, after annexation of MFR to a nature forest reserve in 2019. This is important for the conservation of *P. gordonorum* as it will provide reliable information on the effectiveness of existing conservation strategies and habitat management interventions.

2.0 Materials and Methods

2.1 Description of the Study area

The study was conducted in Magombera Forest Reserve (Fig. 2.1) one of the forest reserves located in the Southern Agricultural Growth Corridor of Tanzania in Kilombero cluster known as Morogoro region, Tanzania. The cluster is a home to the largest Ramsar site in Eastern Africa, covering an area of about 260 km long and 52km wide (SAGCOT, 2023). The cluster also harbors several protected areas such as Village Forest Reserves, Nature Forest Reserves (Magombera, Kilombero), Game reserve (Selous), Game Controlled Areas (Kilombero Game Controlled Area) and National parks (Mikumi, Nyerere and Udzungwa). Harboring a large number of animal and plants species making it a biodiversity potential area (Dinesen, 2016). The area is also surrounded by farms and miombo woodlands (URT, 2013). Magombera Forest Reserve is located at about 8^{0} 40’0’’S and 36 10’ 0’’ E. The area experiences variations of climate in the elevated areas and low areas, with an average annual precipitation range of (1,100 mm - 2,100 mm), an average temperature of 26^{0} C and seasonal flooding (Wilbard and Samora, 2013).

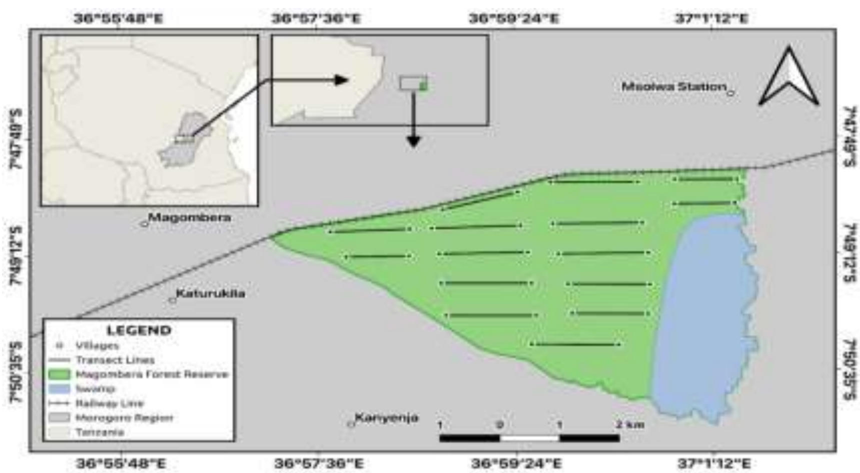

Figure 2.1: Map of Magombera Forest Reserve in Tanzania showing the position of line transect

2.2 Vegetation

Magombera Forest Reserve is characterized by saplings, herbs and grasses of closed and open canopy of semi-evergreen and semi-deciduous forest and wooded grassland forest (Mahulu, 2016); with its habitat similar to lowland and montane forests close to the Udzungwa Mountains and the coastline forests of Kenya and Tanzania (Marshall, 2008).

Semi-evergreen forest is the one which retains their leaves throughout the year (Chapman *et al.,*1990). Common tree species include *Parinari excelsa* (Chrysobalanaceae), *Macaranga* spp. (Euphorbiaceae), *Erythrophloeum suaveolens* (Leguminosae), *Synsepalum cerasiferum* (Sapotaceae), *Sorindeia madagascariensis* (Anacardiaceae), and *Parkia filicoidea* (Leguminosae) (Rovero *et al.,* 2006).

Semi-deciduous forest is a forest which 50-75% of its species shade their leaves during the dry season (Hartter *et al.,* 2008). It is in a transition zone between deciduous and evergreen which is a moderate to old growth forest dominated by Sorindeia*, madagascariensis* (Anacardiaceae), *Combretum* spp. (Combretaceae) *Ricinodendron heudelotii* (Euphorbiaceae), *Ficus* spp (Moraceae), and *Trema orientalis.*

Wooded grassland is the one which is composed of scattered woody plants, palm trees, dwarf trees, shrubs, grasses and other herbs covering almost 10 to 40 percent on the ground. Common tree species include *Combretum molle, Kigelia Africana*, *Vitex doniana* and *Tamarindus indica* (Kindt *et al.,* 2011).

The habitat is also characterized by upper canopy trees such as *Isoberlinia scheffleri, Lettowianthus stellatus, Erythrophleum suaveolens, Xylopia longipetala*, *Tapura fischeri, Ochna holstii, Pseudobersama mossambicensis, Sorindeia madagascariensis, Diospyros mespiliformis, Vitex doniana* (Marshall, 2008).

2.3 Research Design

This study was carried out during dry season (February to March 2021) where most habitats are easily reached. In this study, line transect method using systematic distance sampling techniques was used following Buckland and Plumptre (2010). Line transect sampling has been used widely to estimate primates population density (Araldi *et al.,* 2014; Yager, 2018; Hansen *et al.,* 2019).

According to Buckland and Plumptre (2010) the key assumptions of this method are: groups should be detected at their initial location, groups very close to the line are detected with certainty, measurements from the group center to the line are measured accurately, there is enough sample of randomly placed lines and there is an accurate record of group size.

A reconnaissance survey was carried out in Magombera Forest Reserve to gain knowledge of the study site. During field surveys 5 new transects of 1.5 km long and 1 km apart with a distance of 100m from the forest boundary were laid down in each of the three habitat types (semi-evergreen, semi-deciduous and wooded grassland) with minimum vegetation destruction so as to account for edge effect. Establishment of new transects increase accessibility and increases the chances of observing more forest disturbances (Preston , 2011).

2.3.1 *P. gordonorum* population density

During the surveys, four observers walked along transects silently at an average speed of 1km/hr., scanning and listening for primates and recording evidence of their presence. Primates census was conducted early in the morning between 0700HR and 1100HR when primates are mostly active (Mammides *et al.,* 2009).When a group of primates was encountered, the following details were recorded, the time and date of detection, number of individuals within a group, sign of detection, observer-animal distance, the sighting angle, tree species in which the group was initially detected and the position within the transect line which was estimated using the numbered tags after every 50m along the transect line and a Global Positioning System (GPS).Observer animal distance and the sighting angle were recorded by the use of a LEICA Range-master range finder with an accuracy of 1meter and compass respectively. A pair of binoculars was used to correctly identify the species and observe them for 10 minutes. A group was considered to differ from another when encountered at a distance of more than 200m as proposed by (Davenport *et al.,* 2007; Kitegile *al.,*2021). After every 300m of walking, a 10 minutes pause was taken so as to increase the probability of detecting animals. At the beginning of each transect the name of transect, coordinates, weather, time and date of observation were recorded.

2.3.2 Vegetation survey

Vegetation parameters such as tree height, tree DBH, number of tree stems and tree species were sampled from the plots of 25m×25m which were laid along the transect line simultaneously to *P. gordonorum* sightings. This is because *P. gordonorum* prefer and utilize trees with a tree Diameter at Breast Height (DBH ≥ 10) cm. In each plot, all living tree species with a tree Diameter at Breast Height (DBH ≥ 10) cm were measured at 1.3m height. A tape measure and a laser range finder were used to measure tree DBH and tree height respectively. The number of stems of all trees including edible tree species which were identified through literature review were observed, counted and recorded. According to Steel, (2012) edible tree species are those species of trees that produce more than one species-specific component consumed by *P. gordonorum* and contains at least 2% of their diet for a period of at least one monthly sample.

2.3.3 Habitat disturbance

Anthropogenic disturbances were assessed through direct observation within each plot surveyed. The number of signs of snares, charcoal burning sites, pit sawing sites, presence of forest fires and freshly cut tree stumps identified through presence of wood chips and vegetation disturbance were recorded. A point scale was used to assess the degree of disturbance in every plot as proposed by Anderson and Currier (1973) where a six-point scale of 0-5 was used which 0 stand for no disturbance, 1 stand for 0-20% of the plot is disturbed, 2 stands for 21-40% of the plot is disturbed, 3 stands for 41-60% of the plot is disturbed, 4 stands for 61-80% of the plot is disturbed and 5 stands for 81-100% of the plot is disturbed.

2.4 Data Analysis

2.4.1 Density Estimate

Analysis of density estimate employed the method proposed by Sutherland (2006),whose assumption is a negative exponential detectability function and density estimate within a line transect can be computed as

$$D = \{(n1 + n2)\ loge\ [(n1 + n2)/\ n2]\}/\ (2LZ)$$

n1= is the number of primates detected within the first zone

n2= is the number of primates detected within the second zone

Z= is the observer animal distance to which most sightings were frequent

L= Total length of the transect

The distance from the line transect to unit Z on both sides of the transect is known as the first zone while that extending beyond Z to infinity is known as the second zone.

2.4.2 Vegetation structure

Variations among the three habitat types were assessed by observing the differences in tree species richness, tree DBH and tree height.

2.4.2.1 Above Ground Biomass

Allometric model by Chave *et al. (*2014) using total tree height (H) (cm), wood specific gravity (P) (gcm^3) which was retrieved from the global wood density database developed by Zanne *et al.* (2009) and tree diameter (D) in cm as the independent variables was used to compute for above ground biomass(AGB) (t/ha) using:

$$AGB = 0.0673 \times \ (PD2H)\ 0.976$$

2.4.2.2 Tree species diversity

Tree species diversity was computed using Shannon-wiener diversity index (H) by (Magurran, 2003):

$$H' = \ -\sum pi\ ln\ (pi)$$

were
H′ = Shannon-Wiener index,
Pi = proportional abundance of the ith tree species in each habitat type,
ln = natural logarithm

2.4.2.3 Tree species Richness

Tree species richness was obtained by counting the number of tree species in each habitat type.

2.4.2.4 Food tree species density

The density of edible tree species was computed by dividing the total number of individual tree species per ha.

2.4.3 Determination of the influence of predictor variables on the density

Generalized linear models (GLM) with a Gaussian error function were used to determine the influence of predictor variables on the density of *P. gordonorum* in Magombera Forest Reserve. Before running the GLMs, predictor variables were explored for any intercorrelation. The intercorrelated variables were reduced using Pearson correlation (r) and Variance Inflation Factors (VIF). When there was high correlation between two or more variables i.e. VIF > 8 (Zuur *et al*., 2010), and Pearson correlation (r) > 0.7 (Dormann *et al.,* 2013), predictor variables with less influence to the response variable were eliminated. Results from the regression analysis showed that tree DBH and tree height were highly correlated (r^2=0.73). Therefore, we computed above ground biomass since tree

DBH and tree height were highly correlated. Furthermore, tree species diversity and richness were also highly correlated (r^2=0.77). Therefore, tree species richness was selected to be used in the model due to its influence on *P. gordonorum's* population.

Backward–forward stepwise selection and the Akaike Information Criterion were used to obtain the reduced model that explained better the variation of the response variable (Murtaugh, 2009; Zuur *et al*., 2009). Models were fitted to investigate the predictor variables with high influence on the density *P. gordonorum* in Magombera Forest Reserve. Final models were validated by observing the spread of residual patterns and trend lines were visualized in R (Breheny and Burchett, 2017; Zuur and Ieno, 2016).

To determine the influence of edible tree species on the population density of *P. gordonorum* a GLM was run between each independent variables and the dependent variable using Univariate analysis of Variance in SPSS. To which the dependent variable was *P. gordonorum* density estimate and the independent variables were the edible tree species by *P. gordonorum*.

2.4.4 Non-parametric test

Wilcoxon's signed rank test and graphical observation were used to check for normality of the data. When results showed that data did not fall under normal distribution, a non-parametric Kruskal-Walli's test was used to test if there was any significant difference in tree species richness, tree above ground biomass, tree height, tree DBH and density estimate of *P. gordonorum* among the three habitat types using R software version 4.0.2.

2.5 Results

2.5.1 Density estimate of *P. gordonorum*

In this study, the average density estimate of *P. gordonorum* was 27.4±22.12 individuals per km^2 with an average group size of 24.29±9.25 individuals. Furthermore, there was a significant difference in density estimate of *P. gordonorum* among the three habitat types with (H (2) =24.444, $p < 0.05$). Pairwise Wilcoxon's *post-hoc* test showed a significant difference in density estimate of *P. gordonorum* between semi-evergreen and semi-deciduous habitat, semi-evergreen and wooded grassland (p-value< 0.05).

However, there was no significance difference in density estimate between semi-deciduous and wooded grassland habitats (p-value> 0.05). Whereas the highest density estimate was observed in semi-evergreen forest with a mean of 44±11.3 individuals per km^2 followed by semi-deciduous forest with a mean of 5.5±7.4 individuals per km^2 and wooded grassland had the least density estimate with a mean of 1±0.6 individual per km^2 (Fig. 2.2)

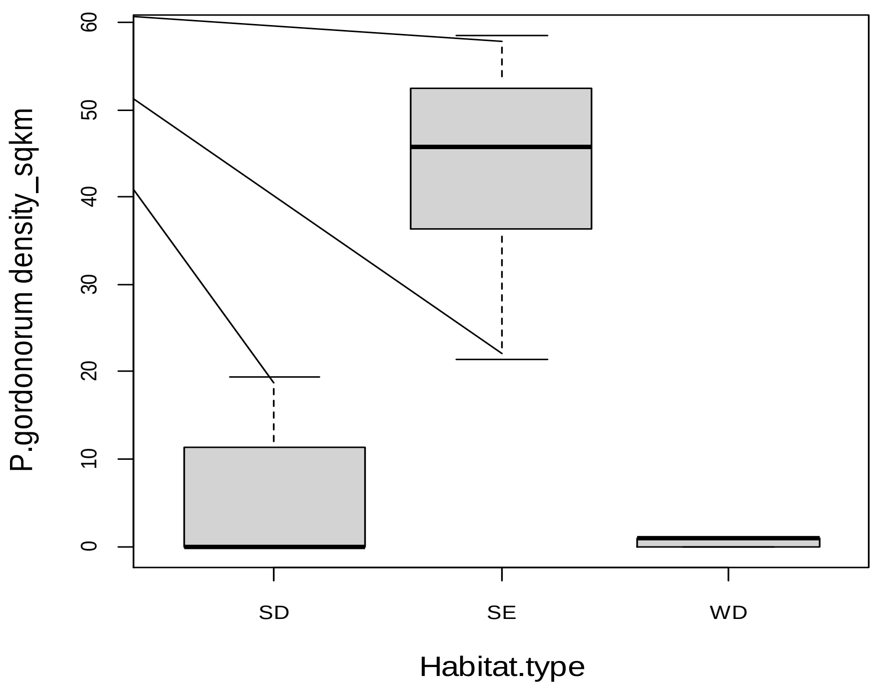

Figure 2.2: The density of *P. gordonorum* in different habitat types in MFR

Whereas SE= Semi-evergreen; SD= Semi-deciduous; WD= Wooded grassland.

2.5.2 Vegetation structure

2.5.2.1 Tree species richness

In this study, it was found that the semi-evergreen habitat had the highest tree species richness compared to semi-deciduous and wooded grassland habitats (Fig. 2.3a). Pairwise Wilcoxon's *post-hoc* test showed a significant difference in tree species richness between semi-evergreen and semi-deciduous habitat, semi-evergreen and wooded grassland and semi-deciduous and wooded grassland habitat with (*H'* (2) =27.21, p< 0.05).

2.5.2.2 Above ground biomass

Semi-evergreen habitat had the highest tree above ground biomass (66.48±15.47t/ha) compared to semi-deciduous (25.3±9.01 t/ha) and wooded grassland (2.27±1.94 t/ha) (Fig. 2.3b). Pairwise Wilcoxon's post-hoc test showed a significant difference in above ground biomass among the habitat types (*H'* (2) =27.121, p < 0.05).

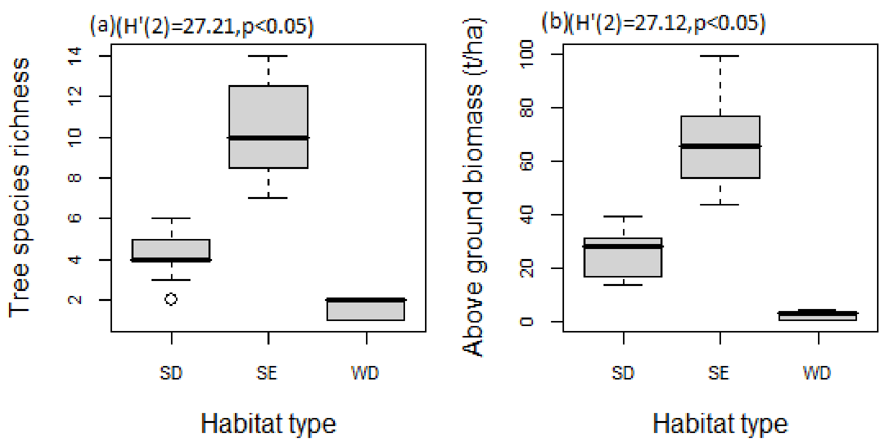

Figure 2.3: Tree species richness and above ground biomass in in different habitat types in MFR

Whereas SE= Semi-evergreen; SD= Semi-deciduous; WD= Wooded grassland.

2.5.2.3 Edible tree species by P. gordonorum

The most common food tree species for *P. gordonorum* were *Erythrophleum suaveolens, Albizia gummifera, Ochna macrocalyx, Pteleopsis myrtifolia*, and *Xylopia parviflora* as illustrated in (Fig. 2.4) below.

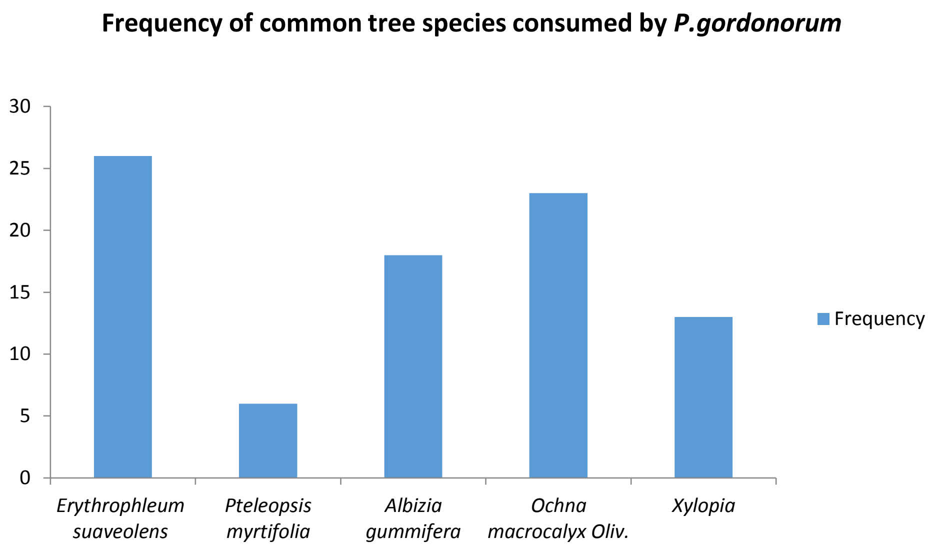

Figure 2.4: Frequency of common food tree species fed by *P. gordonorum*

2.5.3 Influence of vegetation structure and anthropogenic disturbance on the density of *P. gordonorum*

2.5.3.1 Above Ground Biomass

In this study, it was observed that the above ground biomass significantly influenced the density of *P. gordonorum* with an explained deviance of 76.3%. This suggests that as above ground biomass increases there is also an increase in the density of *P. gordonorum* as shown in (Fig. 2.5). Furthermore, tree DBH and tree height showed a significant contribution in the density of *P. gordonorum* in MFR with an explained deviance of 36% and 35% respectively.

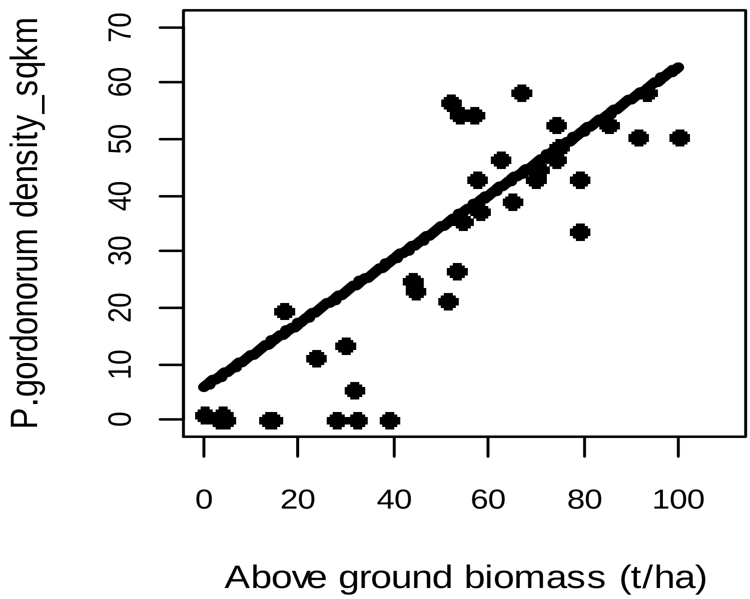

Figure 2.5: Relationship between above ground biomass and the density of *P. gordonorum* in MFR2.5.3.2 Tree species richness

In this study, it was revealed that tree species richness had a great influence on the density of *P. gordonorum* in MFR with an explained deviance of 78.4%. Furthermore, it was observed that areas with higher tree species richness experience higher density of *P. gordonorum* while low species richness resulted in low density of *P. gordonorum* (Fig. 2.6).

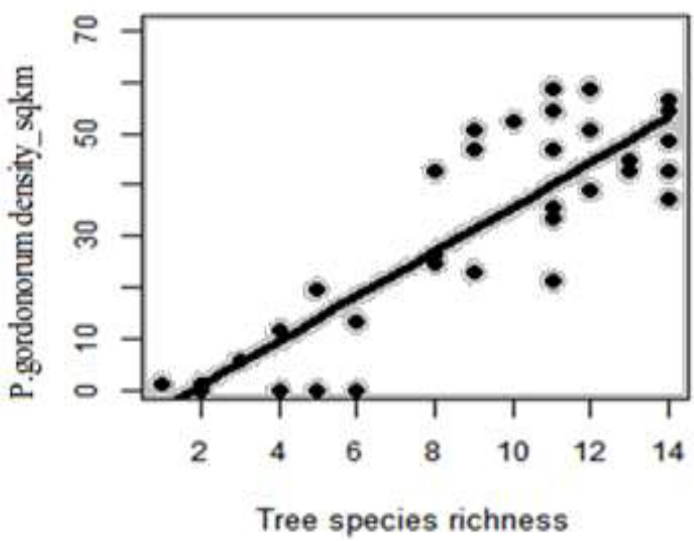

Figure 2.6: Relationship between *P. gordonorum* density and tree species richness in MFR

2.5.3.3 Fire

The results from this study also showed that fire was the only anthropogenic disturbance that greatly influenced the density of *P. gordonorum* with an explained deviance of 44.1%. It has been observed that areas with higher fire occurrence experience low density of *P. gordonorum* while those with low fire experience had higher density (Fig. 2.7).

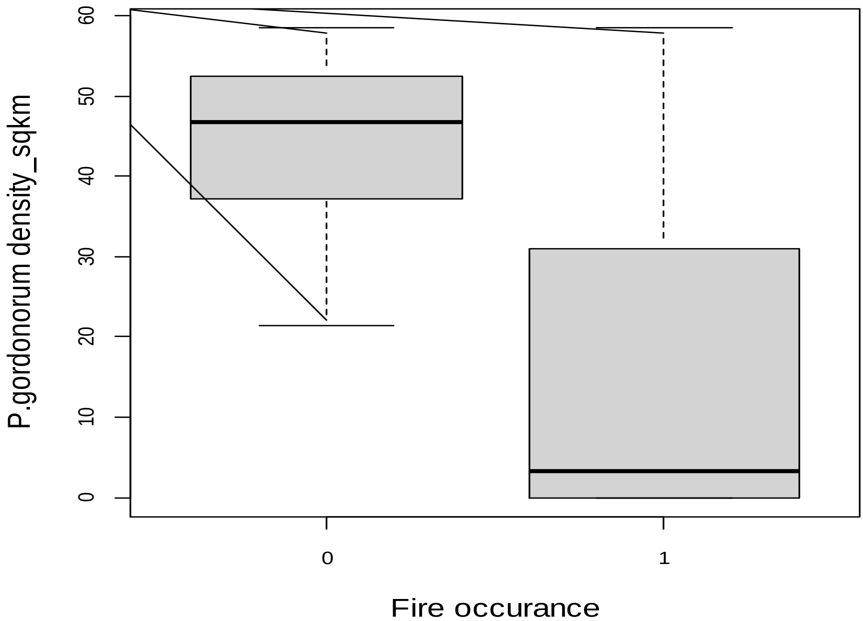

Figure 2.7: Influence of forest fires on the density of *P. gordonorum* in MFR

2.5.4 Influence of edible tree species on the density of *P. gordonorum*

There was main effect of *Erythrophleum suaveolens, Albizia gummifera,* and *Ochna macrocalyx* on the density of *P. gordonorum*. It was observed that sites where *Erythrophleum suaveolens, Albizia gummifera,* and *Ochna macrocalyx. P. gordonorum* were abundant (F (1, 32) =33.24, p = 0.000), (F (1, 32) =14.80, p=0.001) and (F (1, 32) =7.63, p=0.009) had high abundance of *P. gordonorum*. However, there was no main effect of *Pteleopsis myrtifolia,* and *Xylopia parviflora* on the density of *P. gordonorum* (F (1, 32) = 0.019, p = 0.890) and (F (1, 32) = 0.934, p = 0.341) respectively.

2.6 Discussion

Araldi *et al.* (2014) reported a decade ago that the mean density of *P. gordonorum* was 81.5 individuals per km^2. The findings from this study show that the overall density estimate of *P. gordonorum* is low compared to that reported a decade ago. These results align with the findings from Marshall (2008) that in the upcoming years, the population of *P. gordonorum* should be expected to decline due to instability of their population which is greatly influenced by the reduction of the forest as a consequence of anthropogenic disturbances. Also, the average group size from this study is within the range with the findings reported by (Marshal, 2008) which reported an average group size of (22.6 ±5.5). These results are also in the range to that of other degraded forest like Kalunga reported by (Struhsaker *et al.,* 2004). This is an implication that the forest is still under the threat of anthropogenic activities.

The higher density of *P. gordonorum* in the semi-evergreen habitat than in the rest of the habitats is greatly attributed by the richness of tree species which allows the presence of a variety of food tree species consumed by *P. gordonorum.* Availability of favorable tree species consumed by *P. gordonorum* such as *Ochna macrocalyx,* and *Erythrophleum suaveolens* influences their population density (Marshall, 2008). Steel *et al.* (2012) also reported that *Erythrophleum suaveolens* is the most favorable tree species for food by *P. gordonorum* as it is frequently ingested and has a great contribution to their diet due to their fruit, leaves and bud palatability.

Furthermore, high above ground biomass in semi-evergreen forest due to the presence of large and tall trees explains their high density in this part of the forest as they comprise most of their food tree species. Similar findings have been observed by Salunkhe *et al.* (2018); Baul *et al.* (2021) that there is a significant relationship among above ground biomass, tree DBH and tree height. Similar findings have been reported by Rovero and Struhsaker (2007) that red colobus monkeys prefer semi-evergreen habitats due to the presence of large and tall trees as they comprise most of their food tree species. The density of *P. gordonorum* is greatly influenced by the structure of vegetation and its composition (Marshall, 2007).

Additionally, less disturbance in vegetation structure in semi-evergreen habitat than the rest of the habitat types enables it to support primate species in terms of habitat requirement. Similar findings have been reported by (Yager, 2018; Wekesa *et al.,* 2016) that most of the tree species were found to cluster in forests with minimal disturbances than in the disturbed forests. Day *et al*. (2014) also reported that forest disturbance as a result of human activities greatly impacts forest standing biomass. Highly frequently occurring forest fires can extremely change the composition and structure of aboveground biomass (Chaiyo *et al.,* 2011). The impact of anthropogenic activities such as forest fires affects availability of food tree species for *P. gordonorum*. These fires are greatly attributed by agricultural practices that involve slash and burning in the sugarcane farms adjacent to the forest reserve which further extends to the forest. Every year forest fires spread from adjacent farms into the forest causing a serious threat for the regeneration of understory plants. It exacerbates the fast colonization of invasive species hindering the growth of regenerating tree species (Marshall, 2008).

The presence of forest fires degrades forest structure at a large extent removing all the habitat requirements that favors the presence of *P. gordonorum*. Similar results have been reported by Ellis *et al.* (2017); Spaan *et al. (*2020) who reported that the density of primates was negatively influenced by the presence of forest fires whereas approximately 57 746 ha of forest cover is lost as a result of fire in Yucatan Peninsula. Frequent forest fires destroy the structure of the forest by reducing biomass stocks as an outcome of tree cover loss which leads to a more fragmented forest (Hanan *et al.,* 2008; Smit *et al.,* 2010). Yearly, forest fires diminish the population of *P. gordonorum* (Marshall and Rovero, 2017).

Therefore, it has been observed that both vegetation structure and anthropogenic activities (fire) influence density estimate of *P. gordonorum*. Variation in tree species richness, above ground biomass and forest disturbances such as forest fires has resulted to variation in density estimates among the three habitat types, that negatively affects the density estimates of *P. gordonorum*.

2.7 Conclusion and Recommendation

This study has provided sufficient information on the status of *P. gordonorum* population in MFR. It has been revealed that there has been a decline in population density estimate *P. gordonorum* even after its annexation to a nature forest reserve. It has also been observed that vegetation structure and forest fires greatly influence their population and that urgent conservation initiatives should be taken into account so as to ensure effective protection of their habitats from anthropogenic threats.

Further studies should be conducted to assess the population status of other primate species in Magombera Forest Reserve after its annexation into a nature forest reserve so as to provide information on the effectiveness of the forest management towards conservation of biodiversity. Also, other studies should focus on the involvement of the community in conservation of primate species so as to assess their contribution in biodiversity conservation at a broad scale.

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CHAPTER THREE

MANUSCRIPT TWO

FACTORS INFLUENCING THE DISTRIBUTION OF UDZUNGWA RED COLOBUS (*Piliocolobus gordonorum*) MONKEY IN KILOMBERO DISTRICT, TANZANIA

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Abstract
Udzungwa red colobus monkey (*P. gordonorum*) is vulnerable primate specie which is endemic to the Udzungwa Mountains and some few fragmented forests such as Magombera Forest Reserve. This study used Maxent ecological niche modeling in predicting the current and future potential distribution of *P. gordonorum* in Kilombero flood plain and assessed the environmental variables that influence their distribution. *P. gordonorum* occurrence data were obtained from field surveys and GBIF data set. Environmental variables included 19 bioclimatic variables downloaded from Worldclim dataset and 4 topographic variables (slope, aspect, elevation) derived from DEM and land cover maps generated using QGIS. The highest scenario for Green House Gas emissions, RCP 8.5 was used to predict the future distribution of *P. gordonorum* for the period 2050 and 2070. Results show that the potential distribution of *P. gordonorum* is beyond the known distribution range which was in Udzungwa Mountains National Park and the small

fragmented forest in Kilombero valley floodplain. Furthermore, results show that currently, the distribution of Udzungwa red colobus monkey covers an area of 1 142 400 ha for highly suitable habitats and these areas will decline to 392 000 ha and to 96 000ha in 2050 and 2070 respectively, this is according to RCP 8.5. Results show that isotherm, mean annual temperature range and mean annual temperature of the coldest quarter were detected to greatly influence the current and future potential distribution for *P. gordonorum*. Therefore, climate change has been proven to influence the current and future potential distribution of *P. gordonorum* in terms of their feeding behavior and physiological response and that conservation initiatives for climate change mitigation and adaptation should be focused in those areas where highly suitable habitats for *P. gordonorum* have been predicted to occur.

Keywords: Climate change, habitat suitability, maximum entropy, *P. gordonorum*

3.1 Introduction

Udzungwa red colobus monkey (*P. gordonorum*) is a vulnerable primate specie that is endemic to the Udzungwa Mountains and nearby fragmented forests. They are mostly found in Magombera Forest Reserve, which is located in east of Udzungwa National Park in Kilombero District with 1000 individuals in every 10km^2 (Marshall *et al.,* 2005; Struhsaker *et al.,* 2000; Rovero *et al.,* 2009). They are related closely to olive, black and white colobus monkey which are dispersed through equatorial East Africa (Oates and Ting, 2015). Despite their population being reported to be high, a future decline is expected to occur as a result of habitat degradation which is accelerated by the increase in human demand for farming and settlements area (Marshall, 2008; Araldi *et al.,* 2014). Marshall *et al*. (2005), reports that the population of Udzungwa red colobus has been greatly affected by human activities such as hunting, tree cutting and forest fires. On the other hand, climate change affects primates than the rest of the mammalian orders due to the fact that primates are tropical order per-se. Due to this, their geographic distribution is limited as an outcome of habitat shift and degradation (Korstjens and Hillyer, 2016; Kamilar and Beaudrot, 2018;). Additionally, Korstjens and Hillyer (2016) reports that as an outcome of climate change, habitat suitability of primates may increase, decrease or get fragmented.

It is reported that species that are endemic to certain areas are at a greater risk of becoming extinct due to limitation of suitable migratory areas as a response to climate change (Williams *et al.,* 2003; Malcolm *et al.,* 2006; Ohlemüller *et al.,* 2006). Thus, climate change will result in extreme changes in forest structure, that will have a direct impact on the survival of species with narrow range and diet limitations that might result to their extinction or migration to other distant places (Kaeslin *et al.,* 2012).

P. gordonorum being among primate species with narrow range and vulnerable, there is a need to alleviate the impact of climate change on forest ecosystems using strategies such as modelling their distribution so as to identify places where they occupy currently and in the future. Anand and Oinam, (2021), reported that the impact of climate change on terrestrial species is vast thus information on their spatial distribution is crucial in ensuring their survival. Thus, information on the essential requirements for distribution of every specie and their habitats is of great concern for management plans. Therefore, this study used maximum entropy algorithm ecological niche modelling to identify suitable habitats and the pattern of species distribution.

Maxent is used to model the distribution of species using presence only data because they are easily available in herbaria and natural history museums unlike to absence data (Phillips *et al.,* 2006). It requires input variables such as species occurrence data and environmental parameters such as temperature and precipitation so as to insert the probability of species occurrence in every cell within the grid (Thinh *et al.,* 2018).

Several other studies have been done on the distribution pattern of primate species such as Qin *et al.* (2017), Thinh *et al.* (2018) and Moraes *et al.* (2020), but the distribution pattern of the vulnerable *P. gordonorum* monkey is yet to be assessed. Therefore, the aim of this study was to (1) map and predict the current and future distribution of *P. gordonorum* in the Kilombero valley, (2) To identify bioclimatic and environmental variables that significantly influence the distribution of *P. gordonorum*.

3.2 Materials and Methods

3.2.1 Description of the study area

The study was conducted in Kilombero district in the clustres to which Southern Agriculture Growth Corridor of Tanzania (SAGCOT) operates(Fig.8), found in Morogoro region southeastern part of Tanzania. The region is situated between a latitude 5° 58’ and 10’ south of the equator and between longitude 35° 25’ and 38° 30’ East Greenwich (Salehe & Hassan, 2012). The area covers a total of 5500 square miles. The land use/ land cover is mixed of forest, woodland, and agriculture land. The cluster consists of several protected areas which are found in some part or wholly, these areas include; Village Forest reserves, National Forest reserve, Nature reserve such as Magombera Forest Reserve, Game reserve (Selous), Kilombero game-controlled area and National parks (Mikumi National Park and Udzungwa National Park). In lowland area the average rainfall is 500mm while in highland areas the average rainfall is 2200mm (Kirimi *et al.*, 2018a). And an average temperature of 24℃, where in lowlands is 30°C, 18° C in highland (Wilson *et al.*, 2015). The type of soil is silty loamy in large part of area. Most of people practice agriculture, other economic activities practiced are charcoal production, beekeeping, fishing in the floodplain, hunting and forest product utilization (Dinesen, 2016; Kirimi *et al.*, 2018b).

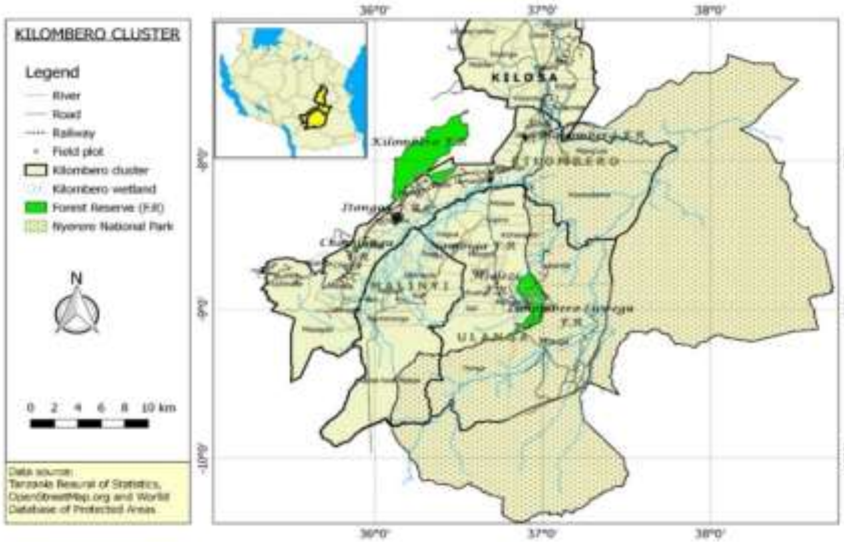

Figure 3.1: A map representing Kilombero district

3.2.2 Data collection

3.2.2.1 *P. gordonorum* occurrence data

The locations of occurrence of *P. gordonorum* were recorded across the nature forest reserve and downloaded from Global Biodiversity Facility (http://www.gbif.org/). Georeferenced positions based on direct observations and auditory cue of detection were recorded.

3.2.2.2 Environmental variables

A total of 19 bioclimatic variables which included 11 temperature variables and 8 precipitation variables were downloaded from worldclim dataset (https://biodiversityinformatics.amnh.org/open_source/maxent/). Three biophysical features (aspect, slope and land use cover) derived from the Digital Elevation Model (DEM) were used in this study. Before running the models, a Pearson correlation test was conducted in R software to assess for multicollinearity in the variables. Those variables with high collinearity ($r \geq 0.85$) were omitted for further modelling (Qin *et al.,* 2017; Thinh *et al.,* 2018), so as to obtain variables with the greatest biological significant for model performance. Due to the omission of the variables with the highest multicollinearity, only 7 out of 23 variables were used for the final model performance (Table 3.1). All the predictor variables were preprocessed in QGIS version 3.12 and later converted to ASCII format so as they can match the compatibility of maxent.

Table 3.1: Environmental variables for modeling species distribution

Variable	Description	Source of data
Bio 1	Annual mean temperature	Wordclim dataset
Bio 2	Diurnal mean temperature range ($T_{max} – T_{min}$)	
Bio 3	Isothermally (Temperature variability)	
Bio 4	Temperature seasonality	
Bio 5	Maximum temperature of the warmest month	
Bio 6	Minimum temperature of the coldest month	
Bio 7	Annual temperature range (T_{max} of warmest month –T_{min} of the coldest month)	
Bio 8	Mean temperature of the wettest quarter	
Bio 9	Mean temperature of the driest quarter	
Bio 10	Mean temperature of the warmest quarter	
Bio 11	Mean temperature of the coldest quarter	
Bio 12	Annual precipitation	
Bio 13	Precipitation of wettest month	
Bio 14	Precipitation of the driest moth	
Bio 15	Precipitation seasonality	
Bio 16	Precipitation of the wettest quarter	
Bio 17	Precipitation of driest quarter	
Bio 18	Precipitation of warmest quarter	
Bio 19	Precipitation of coldest quarter	
LULC	Land Use and Land Cover	USGS Earth Resources Observation and Science Center (EROS
ASP	Aspect	Digital Elevation Model
SL	Slope	Digital Elevation Model
ELE	Elevation	Digital Elevation Model

3.2.2.3 Land use/ land cover mapping

Landsat images were downloaded from USGS Earth Resources Observation and Science Center (EROS) relative to our study area. Pre-processing of the image was done in QGIS (version 3.2) so as to prepare the images for classification. Landsat bands were then downloaded separately and later on stacked together. Satellite imageries falling in the past 30 years (1990-2000, 2000-2010, and 2010-2020 images) were superimposed to detect the available land cover using QGIS software. A topographical map with the scale of 1:50,000 was used during the whole process of geo-referencing the Landsat scenes. Images acquired during the dry season over the past 30 years were used to minimize seasonality and clouds effects (Kashaigili, 2006). All files were combined together through mosaicking and thereafter clipped to produce a full extent of the study area. Image classification was done by using supervised image classification using maximum likelihood algorithm (MAXLIKE). The image classification resulted to 8 classes with nomenclature as per MNRT (2015), which include: (1) Agriculture; (2) Forest; (3) Woodland; (4) Shrub; (5) Grassland; (6) Wetland; (7) Settlements and (8) Water.

3.2.2.4 Climate change scenario

For prediction of the future distribution of *P. gordonorum*, climate change scenarios from worldclim were used. One Representative Concentration Pathway RCP 8.5 was used to map the future habitat suitability for *P. gordonorum* for 2050s (2041-2060) and 2070s (2061-2080).

3.2.3 Modeling species distribution

Maximum entropy algorithm ecological niche modelling using Maxent software was used to model species distribution (Phillips *et al.,* 2006).Maxent shows the relationship between species occurrence data and environmental variables within a defined landscape (Elith *et al*., 2011). By using the maximum entropy theory, the model requires data for species presence only so as to provide an estimate of the probability of species distribution occurrence in the presence of environmental variables. For this study, maximum number of background points, maximum iterations, convergence threshold, regularization multiplier and random sample test percentage were 10,000, 1000, 0.0001, 0.2 and 20% respectively. And the suitability of the model was determined using area under the response curve (AUC) with the application of Receiver Operator Characteristic (ROC) (Phillips *et al.,* 2006). AUC values ranges between 0 to1, whereas, a value of < 0.5 shows a poor model fitting, while that of >0.75 shows a good model fitting (Hosni *et al.,* 2020a). In this study, 75% of occurrence records was chosen as training data for the model while 25% of the data was retained for testing the model. Also, jackknife analysis was performed so as to know the contribution of every environmental variable in the model producing results in percentage and the habitat suitability curves for each environmental variables were produced (Li *et al.,* 2018).

From Maxent, a projection in ASCII format was produced showing habitat suitability of *P. gordonorum* range of values from 0 to 1 for every pixel. These results were then converted in raster format by using GIS. The final output of potential species distribution map had values ranging from 1 to 0 and were reclassified into 3 groups, highly suitable > 0.7; moderate suitable (0.4-0.7) and least suitable < 0.4 (Yang *et al.,* 2013).

3.3 Results

3.3.1 Current and future potential distribution of *P. gordonorum* under climate change scenario RCP 8.5

Results show that in the current period (2021), the area covered by high suitable habitat is 1 142 400 ha and that of low suitability covers an area 9 947 200 ha. Whereas, for the future periods of 2050 and 2070, the area covered by highly suitable habitat is 392 000 ha and 96 000ha respectively. While that of low suitability covers an area of 11 848 000 ha and 12 480 000 ha respectively as shown in (Fig. 3.2) and (Fig.3.3). Also results show that the north-eastern and north-western part of the study area harbors the high suitable habitat for *P. gordonorum.*

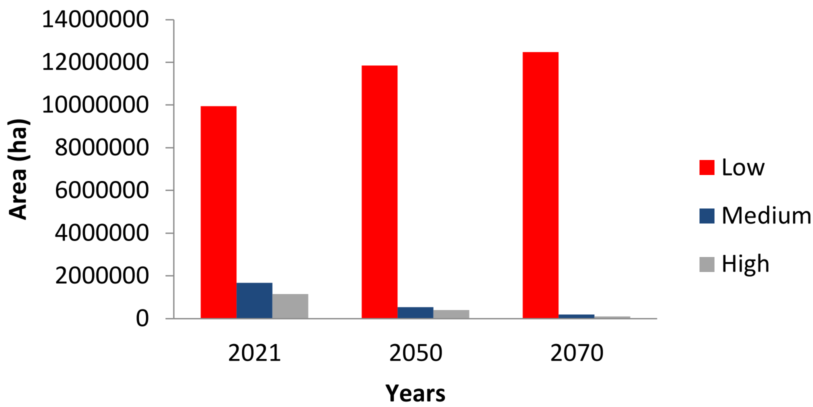

Figure 3.2: Current and future area of suitable habitats for *P. gordonorum* in Kilombero **cluster**

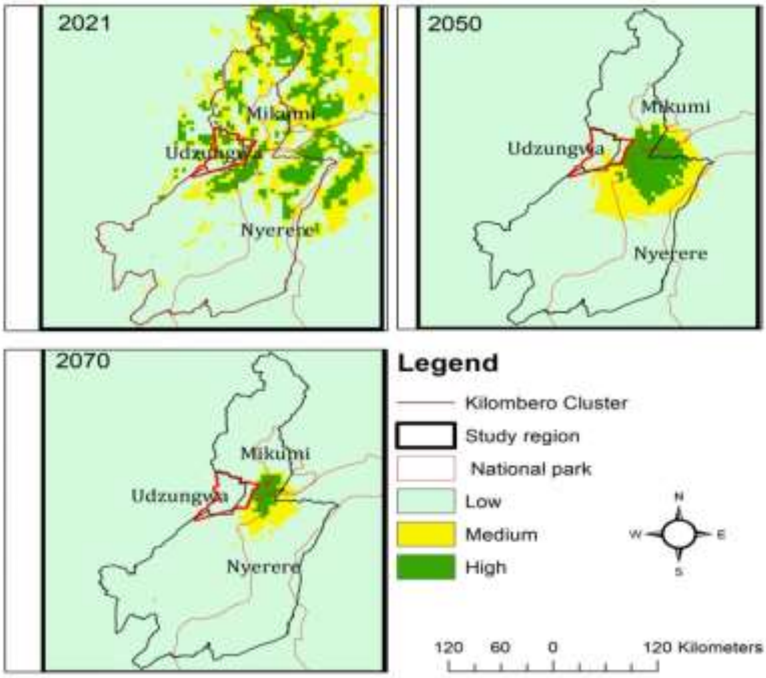

Figure 3.3: Map showing the predicted current and future distribution of *P. gordonorum*

3.3.2 Changes in habitat suitability between the current period (2021) and future periods of 2050 and 2070

Fig. 3.4 shows the relative change in percentage for *P. gordonorum* habitat suitability in the current and future periods 2021-2050, 2021-2070, 2050-2070. Results show that there is a decreasing trend in area (ha) of high suitable habitats from the current period to the future period while that of low suitable habitats keeps increasing.

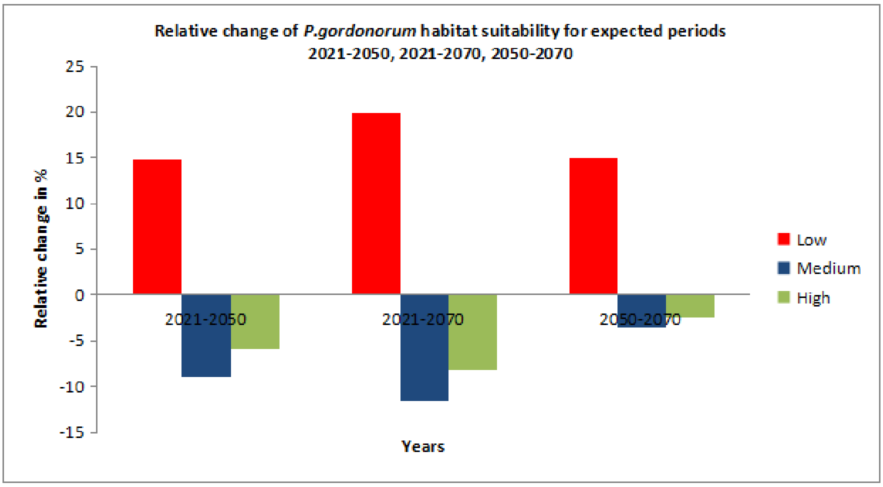

Figure 3.4: Relative change of *P. gordonorum's* habitat suitability for expected periods 2021-2050; 2021-2070, 2050-2070

3.3.3 Contribution of environmental variables on the distribution of *P. gordonorum*

The results using jackknife test reveals that isotherm, annual temperature range of the warmest month and the mean temperatures of the coldest quarter had the greatest contribution in the distribution of *P. gordonorum*. Isotherm had a contribution of 61.7% followed by annual temperature range of the warmest month with a percentage contribution of 16.8% then mean temperature of the coldest quarter with a percentage contribution of 13.7%. While temperature seasonality, maximum temperature of the warmest month and land use/ land cover change (LULC) had the least contribution in the distribution of *P. gordonorum* with a percentage contribution of 4%, 3.4% and 0.6% respectively (Fig. 3.12).

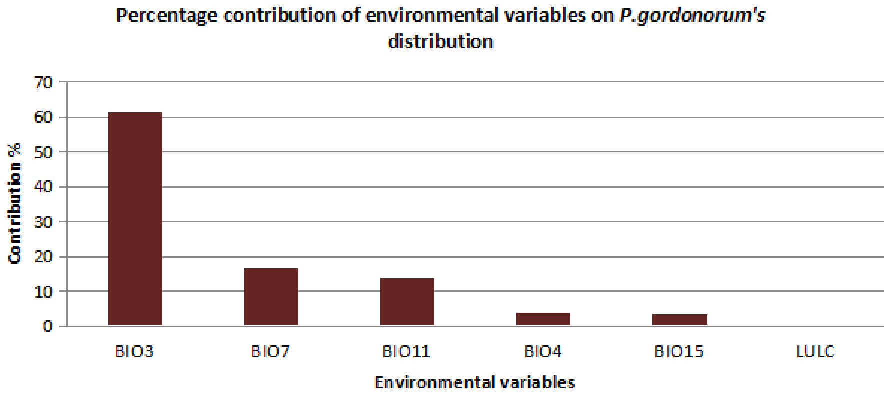

Figure 3.5: Percentage contribution of environmental variables used in Maxent to model the current and future potential distribution of *P. gordonorum*

Whereas;
BIO 3 stands for Isotherm Temperature variability
BIO7 stands for annual temperature range (warmest month-coldest month)
BIO 11 stands for mean temperature of the coldest quarter
BIO 4 stands for temperature seasonality
BIO 15 stands for precipitation seasonality
LULC stands for Land Use Land Cover

3.4 Discussion

From the findings of this study, it has been observed that there is a relative decline of highly suitable habitats by 6% and 9% for the periods 2021-2050 and 2021- 2070 respectively and a decline of moderate suitable habitats by 9% and 12% respectively for the periods 2021-2050 and 2021-2070. For the low suitable habitats there was a relative increase by 15% and 20% for the periods 2021-2050 and 2021- 2070 respectively. Similar findings were reported by Thinh *et al.* (2018), that the future distribution for narrow ranged species such as *P. gordonorum* will decrease drastically than that of species with wider range of distribution.

However, in the future, the model predicts a decrease in suitable habitats for *P. gordonorum* and a shrink in their distribution range towards the center of the study area. Whereas for highly suitable habitats and moderate suitable habitats there will be a relative decrease by 2% and 3.5% for period of 2050-2070, while, low suitability habitats will have a relative increase of 15% for the period of 2050-2070. These results align with the findings by Korstjens (1918) who report that Colobus monkey will lose a large area of their suitable habitats by the period of 2070. This shows how a small change in habitat suitability can lead to *P. gordonorum* extinction as their distribution range will be confined to very few areas as a response of climate change.

Additionally, the study found out that, climatic variables highly influence the distribution of *P. gordonorum* whereas isotherm (bio3), mean annual temperature range (bio7) and mean annual temperature range of the coldest quarter (bio11) shows the greatest contribution. The use of climatic variables in modeling distribution of *P. gordonorum* is a good approach. However, every predictor variable contributes differently to the habitat suitability of each specie (Serio-silva *et al.,* 2011). For other species, climatic variables influences the diversity and abundance of vegetation which defines their ecological niche (*viz*). But for primates, climatic variables not only affect the availability of plant species for food but also their behavior and physiological response for thermoregulation. Several other studies suggests that temperature has a significant impact in the distribution of primates (Korstjens, 2018; Serio-silva *et al.,* 2011; Hosni *et al.,* 2020b). Results from the model aligns with these findings. Whereas, isotherm, annual temperature range of the warmest month and mean temperature of the coldest quarter have shown the greatest contribution in the distribution of *P. gordonorum* than the rest of the variables. Similar findings have been reported by (Anand & Oinam, 2021). This is because as temperature increases, the minimum resting time for folivores species such as *P. gordonorum* is affected as they will spend more time resting than performing other activities such as foraging (Mcfarland *et al.,* 2014; Korstjens *et al.,* 2010). Furthermore, increase in temperature reduces leaves consumption of *P. gordonorum* as they become less palatable due to the increase of fiber and secondary compounds during hotter and drier periods (Korstjens, 2010; Arseneau-robar & Changasi, 2021).

Therefore, results from this study show that a larger area of most suitable habitats for *P. gordonorum* will be lost as a result of the future climatic conditions. Regardless of the loss, still a small stretch of most suitable habitats will remain at the central part of the study area that requires maximum conservation attention so as to ensure the future protection of the endangered *P. gordonorum*.

3.5 Conclusion and Recommendation

From the study, climate change has proven to influence the distribution of *P. gordonorum*. Expanding the current distribution of *P. gordonorum* to other suitable areas that were not known to exist. With an area of 1 142 400 ha, for highly suitable habitats and 9 947 200 ha for low suitable habitats. Furthermore, it has been predicted that the distribution of *P. gordonorum* will decrease drastically under the influence of future climatic conditions such as isotherm, annual mean temperature range and mean temperature range of the coldest quarter. Despite the loss of suitable habitats in the future, few suitable habitats will still exist in the center of the current distribution range making the area to be among the areas with the most biodiversity importance when it comes to primate's conservation most especially the vulnerable *P. gordonorum*.

Therefore, this study provides baseline information to the government, Southern Agriculture Growth Corridor of Tanzania (SAGCOT) and other conservation institutions such as Tanzania Forest Reserve (TFS) and Tanzania National Parks Authority (TANAPA) on the response of *P. gordonorum* to climate change and other landscape alterations. Furthermore, the study has helped in the identification of highly priority areas for conservation of the endangered *P. gordonorum*. Finally, the study recommends for management and conservation initiatives for those areas that *P. gordonorum* have been predicted to occur. Such initiatives should involve improved management capacity in the existing nature forest reserves and village owned forests, protection of the existing wildlife corridors to ensure habitat connectivity, the balance between socio-economic gains and conservation and national-wide mitigation strategies such as the reduction of greenhouse gas emission.

Thus, this study calls for further research on mapping the distribution of *P. gordonorum* with an account of climatic variables, vegetation variables such as Normalized Vegetation Index (NDVI), percentage tree cover, topographic variables, and proximity to human disturbances so as to increase the model accuracy.

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CHAPTER FOUR

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATION

4.1 General Discussion

The findings from this study show that the overall density estimate of *P. gordonorum* is low compared to that reported a decade ago. These results align with the findings from Marshall (2008) that in the upcoming years, the population of *P. gordonorum* should be expected to decline due to instability of their population which is greatly influenced by the reduction of the forest as a consequence of anthropogenic disturbances. Also, the average group size from this study is within the range with the findings reported by (Marshal, 2008) which reported an average group size of (22.6 ±5.5). These results are also in the range to that of other degraded forest like Kalunga reported by (Struhsaker *et al.,* 2004). This is an implication that the forest is still under the threat of anthropogenic activities. The higher density of *P. gordonorum* in the semi-evergreen habitat than in the rest of the habitats is greatly attributed by the richness of tree species, availability of favorable tree species consumed by *P. gordonorum* such as *Ochna macrocalyx,* and *Erythrophleum suaveolens* influences their population density (Marshall, 2008). Steel *et al.* (2012) also reported that *Erythrophleum suaveolens* is the most favorable tree species for food by *P. gordonorum* as it is frequently ingested and has a great contribution to their diet due to their fruit, leaves and bud palatability.

Furthermore, high above ground biomass in semi-evergreen forest due to the presence of large and tall trees explains their high density in this part of the forest as they comprise most of their food tree species. Similar findings have been observed by Salunkhe *et al.* (2018); Baul *et al.* (2021) that there is a significant relationship among above ground biomass, tree DBH and tree height. Similar findings have been reported by Rovero and Struhsaker (2007) that red colobus monkeys prefer semi-evergreen habitats due to the presence of large and tall trees as they comprise most of their food tree species. The density of *P. gordonorum* is greatly influenced by the structure of vegetation and its composition (Marshall, 2007). Additionally, less disturbance in vegetation structure in semi-evergreen habitat than the rest of the habitat types enables it to support primate species in terms of habitat requirement. Similar findings have been reported by (Yager, 2018; Wekesa *et al.,* 2016) that most of the tree species were found to cluster in forests with minimal disturbances than in the disturbed forest. The impact of anthropogenic activities such as forest fires affects availability of food tree species for *P. gordonorum*. These fires are greatly attributed by agricultural practices that involve slash and burning in the sugarcane farms adjacent to the forest reserve which further extends to the forest. Every year forest fires spread from adjacent farms into the forest causing a serious threat for the regeneration of understory plants. It exacerbates the fast colonization of invasive species hindering the growth of regenerating tree species (Marshall, 2008).

Also, the findings of this study have observed that there is a relative decline of highly suitable habitats by 6% and 9% for the periods 2021-2050 and 2021- 2070 respectively and a decline of moderate suitable habitats by 9% and 12% respectively for the periods 2021-2050 and 2021-2070. For the low suitable habitats there was a relative increase by 15% and 20% for the periods 2021-2050 and 2021- 2070 respectively. Similar findings were reported by Thinh *et al.* (2018), that the future distribution for narrow ranged species such as *P. gordonorum* will decrease drastically than that of species with wider range of distribution.

However, in the future, the model predicts a decrease in suitable habitats for *P. gordonorum* and a shrink in their distribution range towards the center of the study area. Whereas for highly suitable habitats and moderate suitable habitats there will be a relative decrease by 2% and 3.5% for period of 2050-2070, while, low suitability habitats will have a relative increase of 15% for the period of 2050-2070. These results align with the findings by Korstjens (1918) who report that Colobus monkey will lose a large area of their suitable habitats by the period of 2070. This shows how a small change in habitat suitability can lead to *P. gordonorum* extinction as their distribution range will be confined to very few areas as a response of climate change.

Additionally, the study found out that, climatic variables highly influence the distribution of *P. gordonorum* whereas isotherm (bio3), mean annual temperature range (bio7) and mean annual temperature range of the coldest quarter (bio11) shows the greatest contribution. The use of climatic variables in modeling distribution of *P. gordonorum* is a good approach. For other species, climatic variables influences the diversity and abundance of vegetation which defines their ecological niche (Serio-silva *et al.,* 2011). But for primates, climatic variables not only affect the availability of plant species for food but also their behavior and physiological response for thermoregulation. Several other studies suggests that temperature has a significant impact in the distribution of primates (Korstjens, 2018; Serio-silva *et al.,* 2011; Hosni *et al.,* 2020b). Results from the model aligns with these findings. Whereas, isotherm, annual temperature range of the warmest month and mean temperature of the coldest quarter have shown the greatest contribution in the distribution of *P. gordonorum* than the rest of the variables. This is because as temperature increases, the minimum resting time for folivores species such as *P. gordonorum* is affected as they will spend more time resting than performing other activities such as foraging (Mcfarland *et al.,* 2014; Korstjens *et al.,* 2010). Furthermore, increase in temperature reduces leaves consumption of *P. gordonorum* as they become less palatable due to the increase of fiber and secondary compounds during hotter and drier periods (Korstjens, 2010; Arseneau-robar and Changasi, 2021).

Therefore, results from this study show that a larger area of most suitable habitats for *P. gordonorum* will be lost as a result of the future climatic conditions. Regardless of the loss, still a small stretch of most suitable habitats will remain at the central part of the study area that requires maximum conservation attention so as to ensure the future protection of the endangered *P. gordonorum*.

4.2 General Conclusion

This study has provided information that the population and distribution of *P. gordonorum* is currently affected by anthropogenic activities such as poor agricultural practices and vegetation structure. Furthermore, climate change has been observed to further impact their distribution through the presence and absence of suitable habitats both in the present and in the future**.**

4.3 General Recommendation

Further studies should focus on identifying and mapping factors influencing the population status and distribution of other primate species respectively taking into consideration aspects such as climate change, proximity to human settlements and Normalized Vegetation Index (NDVI)

4.4 References

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