2021-12

Tree species diversity, composition, population structure and associated herbivore abundance in human-impacted and non-impacted areas of marang’ forest, northern Tanzania

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NM-AIST

https://doi.org/10.58694/20.500.12479/1503

TREE SPECIES DIVERSITY, COMPOSITION, POPULATION STRUCTURE AND ASSOCIATED HERBIVORE ABUNDANCE IN HUMAN-IMPACTED AND NON-IMPACTED AREAS OF MARANG' FOREST, NORTHERN TANZANIA

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A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Master's in Life Sciences of the Nelson Mandela African Institution of Science and Technology

Arusha, Tanzania

December, 2021

ABSTRACT

Forest resources are mainly conserved in protected areas under various management regimes. The present study aimed at understanding the impacts of changing the status of Marang' Forest (MF) in Northern Tanzania to a higher-ranked protection status on its tree-species diversity, composition, structure and mammalian-herbivores richness and abundance. Transects and concentric circular plots were used to identify tree species, count stems, measure tree diameter, assess indicators of disturbances and count the signs of large mammalian-herbivores in human-impacted and non-impacted areas. The results show that tree species richness and Shannon's diversity index were about one-third and 17% higher in impacted areas than in non-impacted areas (t = 5.03, p < 0.001; t = 4.98, p < 0.001), respectively. The average number of tree stems ha^{-1} in impacted areas was significantly higher than the non-impacted ones (t = 3.46, p = 0.01). The impacted areas mostly contained seedlings, saplings and sub-mature trees of pioneer tree species, while the non-impacted ones contained more mature tree stems (F = 16.8, p < 0.001), including endangered species *such as Prunus africana*. The human disturbances included wood extraction, mining, livestock grazing associated with trespassing. The signs of elephants and buffaloes were about 35% more frequent in impacted than in non-impacted areas. These findings reveal that lowering human disturbances by upgrading forests reserve to higher protection status that emphasize more on resource protection enhance forest recovery and improve tree species diversity, composition, and structure as well as the utilization of the forest by large mammalian-herbivores. Governmental and conservation agencies should deter human disturbances to a minimum level to secure forest resources, which are important for providing environmental services.

DECLARATION

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

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Nelson Mandela African Institution of Science and Technology a dissertation titled "*Tree Species Diversity, Composition, Population Structure and Associated Herbivore Abundance in Human-Impacted and Non-Impacted Areas of Marang' Forest, Northern Tanzania*" for the degree awards of Master's in Life Sciences of Nelson Mandela African Institution of Science and Technology, Arusha-Tanzania.

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ACKNOWLEDGMENTS

I thank the Almighty God for health without which I would not have finished my Master's studies. I am also obliged to thank my supervisors Prof. Anna C. Treydte and Dr. Francis Moyo for their guidance, passion, understanding, and assistance throughout, which have been invaluable at every stage of this work and my study period at NM-AIST. They delicately improved my intellectual thinking.

I also thank the management and staff of NM-AIST at large and the Tanzania National Park Authority for allowing me to conduct my study in their area of jurisdiction and the management of Lake Manyara National Park with special thanks to Rehema Kahitila, the park Ecologist and the park rangers for their generous support during my fieldwork.

I thank the Centre for Research, Agricultural advancement, Teaching Excellence and Sustainability in Food and Nutritional Security (CREATES) in a special way for the generous financial support they accorded me in my studies and the Forestry Training Institute (FTI) for the financial support during the fieldwork. Indeed, it would have been practically impossible for me to conduct my research without their support. I am also grateful to Dr. Canisus Kayombo for his assistance in the identification of trees in the field and Mr. Chamba Pamba for his substantial support throughout data collection.

Special thanks to Mr. Richard A. Giliba for his encouragement when the work seemed to be hard. I would also like to thank my friends Ms. Philipina Shayo and Mr. Massana G. Mwishawa, for their challenging ideas and constructive suggestions. Last but not least, I am grateful to my family for the moral support and courage they offered me throughout my studies. I am also indebted to the generous support and kind assistance of many dedicated individuals and not all of them can be mentioned. I offer my deep thankfulness to all. May the Almighty God bless them abundantly.

DEDICATION

To my beloved daughters; Esta, Glory, and Gianne

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LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	Analysis of Variance
AWF	African Wildlife Foundation
CBFM	Community-based forests management
CREATES	Centre for Research, Agricultural advancement, Teaching Excellence and Sustainability in Food and Nutritional Security
DBH	Diameter at breast height
GPS	Geographical positioning system
H’	Shannon Wiener diversity index
ID	Simpsons’ index of dominance
IUCN	International Union for Conservation of Nature
JFM	Joint Forest Management
LMNP	Lake Manyara National Park
MF	Marang’ Forest
NAFORMA	National Forestry Resource Monitoring and Assessment
NM-AIST	Nelson Mandela African Institution of Science and Technology
PFM	Participatory Forest Management
TANAPA	Tanzania National Parks
TAWA	Tanzania Wildlife Authority
TFS	Tanzania Forest Service Agency
UNEP-WCMC	United Nations Environment Programme -World Conservation Monitoring Centre
URT	United Republic of Tanzania

CHAPTER ONE

INTRODUCTION

1.1 Background of the problem

Protected forest reserves are important for biodiversity conservation (Riggio *et al.*, 2019; Rosa *et al.,* 2018; Saura *et al.,* 2018) since they minimize anthropogenic activities that are destructive to species and their habitats (Gizachew *et al.,* 2020; Mathur *et al.,* 2015). Protected forest reserves are often established for multiple purposes, including extractive utilization such as timber production and firewood collection (Pfeifer *et al.,* 2012; Riggio *et al.,* 2019; United Nations Environment Programme -World Conservation Monitoring Centre [UNEP-WCMC] & International Union for Conservation of Nature [IUCN], 2016). According to the Ministry for Natural Resources and Tourism (MNRT) (2006), protected forest reserves vary in terms of conservation purposes, landscape heterogeneity, and administrative authorities (Appendex 1). Studies reveal that protected forest reserves are more prone to anthropogenic threats than other categories of protected areas such as National Parks (Pfeifer *et al.*, 2012; Riggio *et al.*, 2019) and are, therefore, more likely to lose their biological diversity because of extractive utilization such as timber production and firewood collection (Pfeifer *et al.,* 2012; Riggio *et al.,* 2019; UNEP-WCMC & IUCN, 2016), while other protected areas such as National Parks are purely conservation areas.

Human disturbances caused by agricultural activities and other extractive utilization of forest resources are the major drivers of deforestation and degradation of forests in both protected and non-protected forests (Gizachew *et al.,* 2020). For instance, tree species distribution and diversity are highly affected by extractive utilization (Pereira *et al.,* 2007), and the gaps left after removal of preferred tree species are easily colonized by other fast-growing, often pioneer, or invasive tree species (Abdo *et al.,* 2017). Since protection status and management regimes can ensure effective protection of forest resources (Gizachew *et al.,* 2020), re-categorization and upgrading of protected forests reserves to higher-ranked conservation status such as national parks which put more restrictions on the access of resources are widely used by states and conservation agencies (Pfeifer *et al.,* 2012; Riggio *et al.,* 2019). According to Pringle (2017), the re-categorization and upgrading of protected forests to higher-ranked conservation status such as Nature reserves and National Parks have also recently become an important conservation tool for forest resources. Upgrading protected forest reserves can also be effective in protecting the habitats and species found within these protected forest reserves (Lindsey *et al.,* 2017; Pfeifer *et al.,* 2012; Pringle, 2017; Tranquilli *et al.,* 2014).

Tanzania is one of the Sub-Sahara African countries that code its protected areas based on International Union for Conservation of Nature (IUCN) categories (UNEP-WCMC & IUCN, 2016; URT, 2014) (Appendix 2). Most of the protected areas in Tanzania are ranked from category I to VI (UNEP-WCMC & IUCN, 2016; URT, 2010). These include National Parks, Ngorongoro conservation area, Marine Parks, Nature Reserves, Game Reserves, Marine Reserves, Forest Reserves, Game-controlled areas, and Wildlife Management Areas (Kideghesho & Msuya, 2012; URT, 2010; URT, 2014) (Appendix 2). However, the protected forests are excluded from a list of globally protected areas under the IUCN categories (Burgess *et al.,* 2017; IUCN, 2020). The IUCN categories set the level of access and exclusion of human activities to protect the resources depending on the importance of a particular area to global biodiversity. Most of the protected forest reserves in Tanzania and their management regimes are not well linked with the IUCN standards (Burgess *et al.,* 2005; Franks & Booker, 2015; MNRT, 2006). The protected forests are either managed as national forest reserves, nature reserves, catchment forests, districts local authority forests reserves, private forests, and village forest reserves whereby nature forest reserve is the highest protection status of the forests (Santos, 2017; URT; 2002, 2010).

In Tanzania, more than twenty forest reserves have been merged and upgraded into twelve nature reserves since the 1990s (Santos, 2017) (Appendix 3) and some of the protected forest reserves have been annexed into National Parks (Eastern Arc Mountains Conservation Endowment Fund [EAMCEF], 2013; Ministry of Natural Resources and Tourism [MNRT], 2006; Tanzania National Parks Authority [TANAPA], 2014). The country's forest management policy is also shifting toward a total paramilitary forest management regime (MNRT, 2020). The protected forest reserves upgraded to Nature Reserves are managed as wilderness areas and ranked in category 1b of the IUCN standards of protected area (Santos, 2017), which reinforces their protection from deforestation caused by rapid population growth and the rising demand for forest resources (Santos, 2017). However, the effects of stronger protection efforts on forest tree species diversity, structure, and composition have rarely been systematically quantified and documented, given the large size and number of protected forests present in Tanzania (Gizachew *et al.,* 2020).

The Marang' Forest (MF) was annexed to Lake Manyara National Park (LMNP) in 2009 (TANAPA, 2014) after being impacted by mining and other human activities. The inclusion of Marang' Forest is important to conserve tree species, protect crucial habitat for large herbivores, and to maintain watershed and catchment functions for Lake Manyara (TANAPA, 2014). However, there is little information about the forest's tree species diversity, composition, distribution, and population dynamics (United Republic of Tanzania [URT], 2014). Moreover, although human activities are still threatening the forest, these have never been systematically assessed and quantified. This lack of information is likely to hinder the conservation authorities from achieving their conservation objectives (UNEP-WCMC & IUCN, 2016), and monitor the impacts of upgrading the forest's protection status.

The present study assessed tree species diversity, composition, and structure as well as the richness and abundance of large mammalian-herbivores in human-impacted and non-impacted areas of MF, whereby areas with human disturbances and nearby areas with similar soil and vegetation as control sites were selected. The information and data obtained in this study are important as they provide invaluable information about the forest's resources, specifically on tree species diversity which is an essential attribute for forest biodiversity, as well as basic needs and habitat for other species including large mammalian-herbivores (Khaine *et al.,* 2017). Tree species diversity is an essential indicator of sustainable management practices (Khaine *et al.,* 2017). Tree species composition and structure are essential indicators of disturbances and for defining the status of forest recovery from previous disturbances (Zilliox & Gosselin, 2014).

Furthermore, such information on tree species and large mammalian-herbivores is also important as it provides an insight for detecting change and for forecasting future trends of forest resource stabilization. For example presence of some species such as *Croton macrostachyus, Macaranga capensis, Clausena anisata, Celtis africana, Dovyallis abyssinica, Albzia gummifera,* and *Neoboutonia macrocalyx* indicates stages of forest recovery and habitat suitability for other species such as large herbivores (Bracebridge *et al.,* 2012; Lindenmayer *et al.,* 2019; Mullah *et al.,* 2014). The study further unveils a possible explanation of the changes in forest ecological community as human disturbances can influence the distribution of species in space and time (Baumgartner *et al.,* 2015). The study generally contributes to the ongoing debate of finding better ways to manage forest resources in Tanzania and tropical montane forests at large by unveiling the potential of variations in tree species diversity, composition, and structure as well as the associated forest ecological communities.

1.2 Statement of the problem

Forest resources are largely protected by setting aside forested land which is managed by different authorities ranging from the local community to the central government. However, most protected forest reserves are managed for utilization of forest resources and do not conform to the IUCN protected areas establishment and management guidelines (Burgess *et al.,* 2005; Pfeifer *et al.,* 2012; Riggio *et al.,* 2019). Although the utilization of forest resources is regulated by laws and by-laws, protected forest reserves have ineffective management regimes and inefficient monitoring of their biodiversity (Romeiras *et al.,* 2014). This, coupled with the lack of documentation of systematically assessed biodiversity information (UNEP-WCMC, 2016), may impede the achievement of protection and management strategies and purposes (Gizachew *et al.,* 2020).

Most of the protected forest reserves established for extractive utilization are also important for providing refuge to threatened species of plants and animals (Burgess *et al.*, 2005; FAO, 2017). However, studies reveal that these reserves are more prone to anthropogenic threats than other categories of protected areas which are more linked with the IUCN standards such as National Parks (Linying *et al.,* 2006; Pfeifer *et al.,* 2012; Riggio *et al.,* 2019; Rosa *et al.,* 2018; Saura *et al.,* 2018; UNEP-WCMC, 2016). One of the vital steps in reducing the anthropogenic threats to the biodiversity within these protected forest reserves is to deploy effective conservation management regimes for existing tropical and montane protected forests which are located within the extensive network of protected areas. Effective management regimes are important for strengthening the protection of forest habitats and species as protected areas and its effective management regimes are vital for the protection and conservation of biodiversity (Pringle, 2017; Riggio *et al.,* 2019).

Marang' Forest (MF) was designated as a national forest reserve in 1938 (Lovett, 1993). Like other protected forests in the tropical and montane forests within the sub-Sahara region, it was threatened by encroachment and other human activities despite its protection status (Elikana *et al.,* 2020; Gizachew *et al.,* 2020; Riggio *et al.,* 2019; URT, 2014). The MF was degraded and encroached by human activities that led to a reduction of its forested area by 35% from its original size of 350 km² to 230 km² (Kiwango, 2013). Human activities that encompass mining, taking off the tree resources for fuelwood, building materials, and timber, clear-felling, and grazing of domestic animals (African Wildlife Foundation [AWF], 2003) continued to contribute to the degradation of MF (Kiwango, 2013). In 2009, the government of Tanzania upgraded the protection status of MF to National Park that put more access restrictions to the forest resources by annexing the forest to the LMNP (TANAPA, 2014). The integration of MF into LMNP was important for the survival and sustainability of the park and justified on: (a) conservation of forest resources, (b) protection of crucial habitat for large herbivores and corridors that connect the national park and other protected areas, and (c) protection of watershed and catchment function for Lake Manyara (TANAPA, 2014). However, there is an inadequacy of systematically-assessed and documented information about the forest's trees diversity, species composition, and structure as well the associated large mammalian-herbivores, and the existing ones need to be reviewed. Further, human activities are still threatening the forest, but these human disturbances have never been assessed and quantified. Scientific studies conducted in LMNP have generally explained its vegetation (Greenway & Vesey-Fitzgerald, 1969), fluctuations of large mammals population (Mwalyosi, 1977), ecological changes (Mwalyosi, 1981), and the dynamic ecology of *Acacia tortilis* in the national park (Mwalyosi, 1990). These studies have, however, not fully explored or systematically assessed and documented the tree species diversity as well as richness and abundance of large mammalian-herbivores in MF. This inadequate availability of information is likely to impede conservation authorities from achieving conservation objectives (UNEP-WCMC, 2016), and the attempt to monitor the impacts of upgrading the protection status of the forests to the higher ranks of conservation status.

The present study was designed to assess the tree species diversity, composition, and structure as well as the richness and abundance of large mammalian herbivores in human impacted areas and non-impacted areas in upgraded MF. This is an attempt to contribute to the knowledge on finding better ways to manage forest resources in Tanzania and tropical montane forests at large. The understanding of tree species attributes such as their frequency of occurrence, diameter sizes, and regeneration patterns can explain the possible causes of variations in the tree species diversity, composition and structure, and the assemblage of associated large mammalian-herbivores in forests with high-ranked conservation status.

1.3 Rationale of the study

Findings from this study bridge the information gap about tree species diversity, composition, and structure as well as richness and abundance of large mammalian-herbivores in MF. The study also shows the impact of upgrading the protection status of protected forest reserves on the forest resources and the associated biodiversity. This information is useful for guiding state actors on forest management decision making processes.

1.4 Research objectives

1.4.1 General objective

The main objective of this study was to assess the tree species diversity, composition, structure, and the distribution of associated large mammalian-herbivores across human-impacted and non-impacted areas in upgraded Marang' Forest (MF) in northern Tanzania.

1.4.2 Specific objectives

(i) To assess tree species diversity in the human-impacted and non-impacted areas in the MF.

(ii) To determine tree species composition and structure in human-impacted and non-impacted areas within MF.

(iii) To assess the human disturbances in MF and quantify their severity

(iv) To determine the species richness and relative abundance of large mammalian-herbivores in the human-impacted and non-impacted areas of MF.

1.5 Research questions

(i) Does tree species diversity differ between impacted and non-impacted areas in MF?

(ii) What is the composition and structure of the tree species in the human-impacted and non-impacted areas of MF?

(iii) What is the severity of the human disturbances within MF?

(iv) Is there any difference in species richness and distribution of large mammalian-herbivores in the human-impacted and non-impacted areas within MF?

1.6 Significance of the study

The findings from this study add to the information on the tree species diversity as well as larger mammalian-herbivores species present in MF. The information is also important for enlightening the management on setting appropriate conservation strategies and strengthen the enforcement of forest conservation laws (Khaine *et al.*, 2017). Not only are tree species diversity, composition, and structure are indicators of prevailing disturbances (Zilliox & Gosselin, 2014), but these can also show whether a forest can recover and stabilize from previous disturbances (Lindenmayer *et al.*, 2019). The presence of some tree species can also indicate habitat suitability to other forest-dependent species such as large mammalian-herbivores (Bracebridge *et al.*, 2012; Lindenmayer *et al.*, 2019; Mullah *et al.*, 2014). The findings of this study can generally contribute to the basis for forming recommendations on the plan for the utilization of the forest by both wildlife and tourism.

1.7 Delineation of the study

The present study is limited to tree species and did not assess other plant species such as shrubs, herbs, lianas, climbers, and grasses. The study also included only a few wild animals within the forest with a focus on large mammalian-herbivores including elephants and buffaloes.

CHAPTER TWO

LITERATURE REVIEW

2.1 Importance of tree species assessment within protected forest reserves

The effective management of forest resources depends on the availability of data and documentation of the information on the forest biodiversity where information on tree species is key (UNEP-WCMC & IUCN, 2016). Information on tree species is important because they are an important attribute of the forest ecosystem (Hossain *et al.,* 2019; Kacholi, 2019). The determination of tree species also enables the quantification of the spatial and temporal heterogeneity of vegetation communities within the forest ecosystem (Zilliox & Gosselin, 2014). Moreover, the tree species present in protected forests not only provide critical and diverse services and values to the human society but also act as habitat for a wide range of wild animal species and support biodiversity maintenance and conservation (Heino *et al.,* 2015).

Systematically assessed and quantified tree species information is important because it indicates the existing forest resources, their sustainable management and determines the survival of other forest-depended species such as large mammalian-herbivores (Gebeyehu *et al.,* 2019; Zilliox & Gosselin, 2014). The inadequate and unavailability of up to date data on tree species diversity within many protected forests in sub-Saharan Africa is the hindrance in setting the protection and conservation priorities on the forest resources (Girma & Maryo, 2018; Magurran, 2004).

Tropical and Afromontane forests are among the most studied in efforts of understanding the forest biodiversity changes over time and space (Basha & Rao, 2017; Elikana *et al.,* 2020). The knowledge generated from the tree species assessment form the basis for understanding the forest resources and enables the protection of the threatened species of plants, trees of economic and ecological values, wildlife species, and their habitats (Burgess *et al.,* 2005; Girma & Maryo, 2018; Manral *et al.,* 2017). Apart from generating knowledge about specific forest resources, the information enables comparison among forests in terms of forests with lower or higher diversity. The diversity comparison among the forests gives insights into different potential management approaches, and tracks changes in diversity over time (Brandt *et al.,* 2018; Dutta & Devi, 2013; Zilliox & Gosselin, 2014).

The systematic assessment of tree species to obtain information needed for the description and quantification of forest resources in both protected or unprotected forests is acquired through sampling and botanical inventories (Vesa *et al.,* 2010). The assessment of changes in forest tree species is mostly performed by measuring tree attributes such as their occurrence, abundance, diameter, height, ground vegetation cover, and extent of regeneration after disturbance (Brandt *et al.,* 2018; Vesa *et al.,* 2010). The assessed tree species attributes used in quantification of richness, diversity, composition, structure, and ascertain the assemblage of the forest associated communities such as herbivores. The information from tree species attributes is used to compute different indices (Buckland *et al.,* 2012) which are more important in forests with a history of human activities impact, because it enables the understanding of the trend of forest recovery and stabilization (Chaudhary *et al.,* 2016; Chowdhury *et al.,* 2019; Manral *et al.,* 2017). The assessment of tree species composition and structure is not only important when describing the recovery of such forests but also enable conservation institution to strategize on conservation actions (Malik *et al.,* 2014).

The evaluation of forest ecosystems and quantification of the floristic diversity in them including tree species diversity is done through the computation of different indices (Buckland *et al.,* 2012; Risser & Rice, 1971; Whittaker, 1972) including species richness, Shannon's diversity index, Simpson's diversity index, and index of dominance. Some of the utmost frequently used indices are the Shannon Weiner diversity index and Simpson's dominance index (Mligo, 2018; Thukral *et al.,* 2019) as outlined in subsections 2.1.1 and 2.1.2.

2.1.1 Diversity and dominance indices

Among the attempts to generate multiple indices that combine measures of richness and abundance are Shannon's diversity index (H') and Simpson's index of dominance (ID) (Thukral *et al.,* 2019). Several scholars like Magurran (2004), Buckland *et al.* (2012), Mligo (2018), and Yuan *et al.* (2016) propound that biodiversity is one of the key issues of ecologists, but quantifying the species diversity of particular ecological communities is complicated, as their statistical computation is subjective in nature of delineating an ecological community (Mligo, 2018; Thukral *et al.,* 2019; Yuan *et al.,* 2016). The diversity indices are either computed using the number of species present (species richness), or their relative abundances (dominance) (Yuan *et al.,* 2016). The obtained diversity indices values are used to extrapolate the healthiness and sustainability of ecological communities (Thukral *et al.,* 2019), in this study are referred to the sustainability of the tree species and large mammalian- herbivores within the protected forests**.** Thus, the computation of diversity and dominance indices is important when evaluating the performance and sustainability of forest ecosystems (Mligo, 2018; Thukral *et al.*, 2019).

(i) Diversity index

The diversity index of different species in a given ecosystem is measured as the number of individuals in that ecosystem and their relative frequencies (Buckland *et al.,* 2012; Thukral, 2017), and in this study refers to individuals of tree species and large mammalian-herbivores. In the present study, the species richness (S) and Shannon diversity index (H') were employed to quantify tree species diversity and the large mammalian-herbivores. The use of H' is useful because it takes into consideration both species richness and evenness within the sample (Mligo, 2018). The value of H' within the diverse forest ecosystem ranges from 1.5 to 3.5 and rarely exceeds 3.5 (Zilliox & Gosselin, 2014). The index values of diversity are useful in providing information about the tree species population and the status of the forest concerning the human disturbance severity or other environmental factors (Chowdhury *et al.,* 2019). However, the interpretation of the index values is done by referring to other studies conducted in the same forest or elsewhere, which can be confusing (Chowdhury *et al.*, 2019). For example, in the study of floristic diversity, some scholars consider all plants from herbs to trees but others consider trees only, whether the study conducted in the same forest site or different site, under such situation the differences in diversity indices is obvious. This is because the one who takes into consideration of all the plants species will report higher diversity indices than the ones considers only tree species (Chowdhury *et al.*, 2019). Thus, care must be taken when interpreting the diversity indices to have meaningful information about the ecological community under study.

Studies conducted in several protected forests that underwent diverse management regimes with a history of human disturbance in the Eastern Arc montane forests and the Great Rift Valley of East Africa have revealed differing ranges of diversity indices. For instance, Shannon diversity indices ranged from 1.9 to 2.9 was reported for Eastern Arc Nature Reserve Forests in Tanzania (EAMCEF, 2013), 2 to 3.7 for Ngumburuni Forest Reserve in Tanzania (Kimaro & Lulandala, 2013), 2.2 for Kizee Village Forest Reserve in Tanzania (Maguzu *et al.*, 2017) and 2.8 for Ades protected forest in Ethiopia (Reshad *et al.,* 2019), 1.9 to 3.4 for Chebere Churcura National Park in Ethiopia (Girma & Maryo, 2018), and 1.1 to 2.8 for Taita Hills montane forests in Kenya (Omoro *et al.*, 2010; Wekesa *et al.,* 2019). For re-categorized and upgraded forests such as MF and most of the protected forests in the Eastern Arc Mountains, Tanzania, tree diversity should be evaluated after halting extractive utilization such as logging, mining, and collection of non-timber products (Gizachew *et al.*, 2020; Mathur *et al.*, 2015).

Most studies conducted in forests with a history of human disturbance have shown that tree species richness and diversity indices tend to be high in disturbed areas (Bhuyan *et al.*, 2003; Sahoo *et al.*, 2020). However, the high intensity and severe disturbance lower species abundance and diversity, thus, only minimum disturbance can promote tree species diversity while taking into consideration the kind of tree species occurring within disturbed areas (Gogoi & Sahoo, 2018). This is probably because the diversity in forests with minimum disturbance is enhanced by invasive, pioneers, and/ or opportunistic species, which can at a times be detrimental to the functioning of the forest ecosystems (Gogoi & Sahoo, 2018; Wekesa *et al.*, 2016, 2019).

(ii) Dominance index

The tree species dominance index (ID) is an aggregated metric that represents the unique share of the individual tree species to the whole possible tree species based on the spatial area (Thukral *et al.*, 2019). This index is an important tool for assessing plant diversity as it provides information on the composition of tree types available in a given forest (Chowdhury *et al.*, 2019). The use of ID has been employed by many studies to assess the dominance of different species in ecosystems (Gogoi & Sahoo, 2018). Studies by Gogoi and Sahoo (2018), Kimaro and Lundalala (2013), Hossain *et al.* (2019), Kacholi (2019), and Obemio *et al.* (2016). These studies have shown that the use of this index is useful in determining, linking, and assessing the variation of tree species and forest conditions within different management regimes and varying human disturbances. The disturbances in forest ecosystems cause tree species with high frequencies and biomass to dominate (Sahoo *et al.*, 2020). Simpson's index of dominance measures the distribution of individuals among species in the community and its value ranges from 0 to 1 whereby the greater this value, the lower the diversity while the smaller it is, the higher the diversity (Kayombo, 2016). A high dominance index is obtained when a few individuals dominate an area but when several species contribute equally to the community, the dominance index becomes smaller (Mligo, 2018; Thukral *et al.*, 2019; Whittaker, 1972).

2.1.2 Tree species composition and population structure

Tree species composition refers to the relative contribution of a particular tree species individuals in the tree population and is expressed in terms of percentage (Gebeyehu *et al.*, 2019). Its assessment is important because trees are among the essential component of forest ecosystems (Ayalew, 2020). Tree species composition and structure tend to vary in place and time in forests with similar or different conditions (John, 2015). Such variations are either a result of natural factors such as the succession process or are induced by human disturbances such as selective wood extraction, mining, and agricultural activities (Ayalew, 2020).

Stem density and basal areas are some of the parameters used in describing forest tree species composition and population structures (Gebeyehu *et al.,* 2019). Stem density refers to the number of stems per given unit of area, usually expressed in hectares (ha), and indicates how many trees occupy a fixed area (Zilliox & Gosselin, 2014). On the other hand, basal area refers to the cross-section area of the tree at the diameter at breast height (DBH), normally measured at 1.3 m above ground level and expressed in $m^2\ ha^{-1}$ (Ayalew, 2020).

Stem density is a good measure of species composition in forests because it describes the distribution of stems per given unit of area (Ayalew, 2020). According to Gebeyehu *et al.* (2019), the estimation of stem density is commonly used in determining the composition and structure when evaluating changes in forest conditions following the presence of human disturbances. The variation of stem densities within species and within diameter size can help ascertain the successfulness of forest recovery following different conservation efforts on halting the human disturbances (Brandt *et al.,* 2018; Girma & Maryo, 2018; Hossain *et al.,* 2019; Manral *et al.,* 2017). Though the variety of tree species composition and structure is obvious as reported by different scholars (Girma & Maryo, 2018; Mwakosya & Mligo, 2014; Sahoo *et al.,* 2020), many protected forests lack reliable data and up to date systematically assessed information for management and monitoring the forest resources (Hossain *et al.,* 2019; Wekesa *et al.,* 2019). This may impede conservation and management targets since some tree species may fail to regenerate (Brandt *et al.,* 2018; Wekesa *et al.,* 2016, 2019), or withstand the competition from the fast-growing species (Mwakosya & Mligo, 2014). In other cases, some species of herbs, shrubs, or invasive species can dominate in forests (Gogoi & Sahoo, 2018) following the deterration of human disturbances (Mwakosya & Mligo, 2014).

Studies conducted in different protected forests with a history of human disturbances in the Eastern Arc Mountain forests have all shown that the number of tree stems can be high in areas affected by human activities, but mostly with small diameters due to the effects of extraction of tree species. These studies include those by Ndangalasi *et al.* (2014) in Ihang'ana Forest Reserve, Kikoti and Mligo (2015) and Rutten *et al.* (2015) in the montane forest of Mount

Kilimanjaro, Sassen and Sheil (2013) in protected montane forests in Uganda, Kacholi (2013) in Kimboza Forest Reserve, Kayombo and Ndangalassi (2020) in Image Forest Reserve, Kimaro and Lulandala (2013) in Ngumburuni Forest Reserve within the Eastern Arc Mountain Forests, Omoro *et al.* (2010) in Taita hills montane forests, Brandt *et al.* (2018) and Hitimana *et al.* (2009) in Montane forests of Kenya, Girma and Maryo (2018) in Chebera Churcura National Park, Gebeyehu *et al.* (2019) and Ayalew (2020) Gatira in Gorgers montane forest, in Ethiopia. This high density is attributed to the regeneration and colonization of fast-growing tree species within the created gaps (Ayalew, 2020; Kacholi, 2013, 2019; Madoffle *et al.*, 2006). High stem densities have also been reported by Mwakosya and Mligo (2014) in Rungwe Forest Reserve (417 ha^{-1}) and Rutten *et al*. (2015) in Kilimanjaro montane forest (620.8 ha^{-1}) in human impacted areas but many tree species were pioneer and opportunistic ones. These ascertain the effects of human disturbance on tree species composition and structure in forests.

Most forests where extractive utilization of tree species is allowed tend to have more stems of lower diameter but the reverse is true in forests with no extractive utilization of trees (Chowdhury *et al.*, 2019). In forests with human disturbances, the high stem density only exists in moderately disturbed areas and not in severely disturbed ones since severe disturbances affect the regeneration process (Rutten *et al.*, 2015; Seta *et al.*, 2019). It is necessary to assess tree species stand parameters in different protected forests to assertion their composition and structure as indicators of sustainable management of forest resources under varying forest conditions and management regimes (Ayalew, 2020). The importance of assessing the tree species composition and structure in the protected forest reserves was also pointed out by other scholars such as Pharm *et al.* (2020), Riggio *et al.* (2019), Gizachew *et al.* (2020), Lindsey *et al.* (2017), and Chowdhury *et al.* (2019) since most protected forests are still facing human disturbance threats regardless of their protection status.

2.2 Forest management regimes

Forested land at the global level is set aside for different purposes such as biodiversity conservation and/or extractive utilization (Burgess *et al.*, 2005; Gizachew *et al.*, 2020; Riggio *et al.*, 2019; UNEP-WCMC & IUCN, 2016). The protected forests are placed under a certain form of a management regime that has a mandate over the forest resources (Akida & Blomley, 2006; Green & Lund, 2015; Heino *et al.,* 2015). For example, can be mandated to the state, community, or private managers. Forests are governed by various laws and policies and mandated to different management regimes because they fulfill different purposes and functions (Akida & Blomley, 2006; Green & Lund, 2015; Heino *et al.,* 2015; UNEP-WCMC & IUCN, 2016). Some forests need full protection, but others entail only a sustainable management practice (Burgess *et al.,* 2005; Tanzania Forest Service agency [TFS], 2016). The management regimes regulate access to forest resources and control anthropogenic activities (Gizachew *et al.,* 2020).

In East African countries, numerous institutions are involved in forest resource management. For example, in Kenya, the Kenya Forest Service (KFS) and Kenya Wildlife Service (KWS) are mandated to manage the forest resources while in Uganda, the Ugandan National Forestry Authority and Uganda Wildlife Authority are in charge of forest resources (Mwangi *et al.,* 2018). On the other hand, the Tanzania Forest Service agency (TFS), TANAPA, Tanzania Wildlife Authority (TAWA), and local governments have the mandate to manage most of the forest resources in Tanzania (Elikana *et al.,* 2020; Gizachew *et al.,* 2020; Mwangi *et al.,* 2018). Generally, in Tanzania, most of the forest resources are managed by the central government and local government (Elikana *et al.,* 2020; Gizachew *et al.,* 2020).

Despite some positive results of the rule of law in forest management and the existence of various institutional frameworks mandated to forest resource management, the depletion of forest tree species and other forest resources remains a challenge in many forest-rich countries (Elikana *et al.,* 2020; Gizachew *et al.,* 2020; Heino *et al.,* 2015; Pham *et al.,* 2020; Riggio *et al.,* 2019). In attempts to control the threats, different forest managements have passed through different management regimes and scenarios. For example, in the last four decades, countries including Indonesia, India, Nepal, Kenya, Uganda, and Tanzania have adopted participatory approaches that engage local communities in the management of forest resources (Bwagalilo *et al.,* 2019; Chaudhary *et al.,* 2016; Islam *et al.,* 2020; Persha & Blomley, 2009). In such approaches, there is the devolution of forest resource management from the central government to local communities (Berkes, 2010; Bwagalilo *et al.,* 2019) while the governments regulate the use of forest resources (Kweka *et al.,* 2015). Under this form of forest management called participatory forest management (PFM), the forest resources are extracted for consumptive purposes, local community income generation, and as sources of raw materials. Under PFM the part of the local communities in decision making and planning depends on the management regime framework (Bwagalilo *et al.,* 2019; Kweka *et al.,* 2015).

Despite the efforts to protect the forest resources, there is high demand and pressure on forest resources due to poverty and increasing population, leading to illegal and uncontrollable off-take of forest resources (Islam *et al.,* 2020; Pham *et al.,* 2020). Furthermore, though the utilization of the resources within protected forests is regulated by laws across the globe, the effectiveness varies greatly in reducing the threats to biodiversity (Gizachew *et al.*, 2020) because they are managed for the provision of timber and non-timber products (Heino *et al.*, 2015). Consequently, forests under most of the management regimes are faced with high rates of deforestation, degradation, encroachment, and resource depletion (Gizachew *et al.,* 2020; Islam *et al.,* 2020; Mukul *et al.,* 2017; Riggio *et al.,* 2019). This necessitates governments to review the management regimes of most forests to safeguard the habitats and species within them (Akida & Blomley, 2006; Bwagalilo *et al.,* 2019; Chowdhury *et al.,* 2019; Riggio *et al.,* 2019). The review of the forest's management regimes is also important because these forests play a crucial role in the conservation of biodiversity despite having been established for multiple purposes including extractive utilization (Akida & Blomley, 2006; Chaudhary *et al.,* 2016; Green & Lund, 2015; UNEP-WCMC & IUCN, 2016).

2.3 An overview of forests management and protection in Tanzania

Designating protected forests in Tanzania is very practical since the country is among those in the eastern African block with large land covered by forests (FAO, 2017; URT, 2015). Tanzania has about 48.1 million ha covered by forests and woodlands (MNRT, 2015) which is about 55% of the total land surface of the country (88.6 million ha) (URT, 2014, 2015). According to TFS (2016), about 90% of this forested area is woodland, and the remaining part comprises other forest types such as montane, mangrove, acacia, and coastal woodland forests.

Setting aside forested land for different purposes in Tanzania dates back to the colonial times when forests were managed mostly for extractive utilization even though a few forests such as the montane ones, served mainly as water catchment zones (Burgess *et al.*, 2005; Bwagalilo *et al.,* 2019). The local communities were prohibited from accessing the resources within these protected forests through strong law enforcement and punishments (Bwagalilo *et al.,* 2019; Persha & Blomley, 2009; Russell *et al.*, 2017). This form of forest management and protection was reviewed after independence in the mid -1980s to include the local community in forest management efforts (Burgess *et al.*, 2005; Bwagalilo *et al.*, 2019; Russell *et al.,* 2017) where forest management rights and responsibilities were decentralized and delegated to local communities (Bwagalilo *et al.*, 2019; Kweka *et al.*, 2015).

The involvement of local communities in the management and protection of forests occurs in the form of participatory forest management (PFM). The PFM is either in the form of joint forest management (JFM) where the local communities co-manage national forest reserves or in form of community-based forests management (CBFM) where communities manage village land forest reserves (Akida & Blomley, 2006; Burgess *et al.*, 2005; Bwagalilo *et al.*, 2019; URT, 2002). Furthermore, about 52% (25 million ha) of the protected forests are under PFM where they are managed through CBFM regimes or JFM regimes by governments and communities. The management of forests in the country also involves private stakeholders whereby about 7% are privately owned and managed by individuals or non-governmental organizations (TFS, 2016) and the rest is within the public and general lands (TFS, 2016; URT, 2014). The sustainable utilization of forest resources under PMF regimes was regulated by issuing permits and fees. Nevertheless, the state-owned forests and those under JFM are often faced with destructive activities such as encroachment for farming and settlement, mining, illegal logging, and livestock grazing which are practiced within the reserved forests (Franks & Booker, 2015).

The natural forests in Tanzania are presently mainly managed by the central government and local government and a few of them are managed by private stakeholders (TFS, 2016; URT, 2002, 2018). The central government manages the protected forests through TFS that has a mandate on national forest reserves and nature reserves, TANAPA that has mandated on forests falling within areas gazetted as national parks, and TAWA with a mandate on all forests that fall in game reserves, game controlled areas and wildlife management areas (URT, 2018). Approximately 40% (16.8 million ha) of various forest types including national forest reserves and nature reserves are managed by the central government under TFS, while about 5% (2.4 million ha) are under TANAPA and TAWA.

The local government manages forest resources through District council authorities which have a mandate on forest reserves under district authority or village governments which have a mandate on village land forest reserves and community forest reserves (TFS, 2016; URT, 2018). The forest resources under the jurisdiction of local government are either utilized for the production of timber and other extractive utilization or managed for water catchment functions (Akida & Blomley, 2006; Gizachew *et al.*, 2020; TFS, 2016). Forests that do not fall under the management of central government or local government are managed by private organizations or individuals as private forest reserves and others are found on public village lands and general lands where they are poorly managed (Elikana *et al.*, 2020; Gizachew *et al.*, 2020; Kweka *et al.*, 2015; TFS, 2016).

Despite the numerous institutions with different management regimes and the existing forest protection and management legal framework authorities that implement forest management and protection policies and laws in Tanzania, there is still high deforestation and degradation of the forests in the country (FAO, 2017; Kweka *et al.,* 2015; URT, 2014). This can be attributed to weak management, poor enforcement of laws, and tenure security in open access land (Kweka *et al.,* 2015). Deforestation is also accelerated by financial constraints for implementing forest laws coupled with understaffed institutions, weak coordination among stakeholders, conflicting policies between sectors that favor forest conversion, corruption, and political interferences (URT, 2014).

To minimize the rapid depletion of forest resources, including tree species, Tanzania has entered into sector restructuring by forming the forestry agency; TFS to strengthen the implementation of forest management and enforcement of laws. The related contradicting policies and laws from other sectors such as agriculture, mining, livestock, land, and settlement (URT, 2014) also have been reviewed. The TFS takes over the management of all national forest reserves and nature reserves which were under the Forestry and Beekeeping Division. The process of reviewing the forest policy is also ongoing (URT, 2014) aiming towards a paramilitary way of carrying out forest resource management and protection (MNRT, 2020). The protected forest reserves which are critical for biodiversity conservation are further re-categorized to high-ranked conservation status such as national parks or upgraded to nature reserves to strengthening the management and protection of the forest resources (Santos, 2017), and to align them with the IUCN protected areas standards.

The protected forests in Tanzania are less harmonized with the IUCN standards because forests were mainly established for watershed protection and resource extractions and are less focused on biodiversity conservation which weakens their protection (Heino *et al.,* 2015; MNRT, 2006). Recently, the government of Tanzania reviewed the management regimes of most forests, and forest policy is shifting towards total paramilitary practices (MNRT, 2020). These changes reveal the importance of forests to biodiversity conservation. Most national forest reserves under the central government have been recognized for their international and national importance for biodiversity conservation and as biodiversity hotspots (URT, 2014). In these re-categorized and upgraded forests, extractive utilization is banned and access to resources restricted by laws, enforcement of laws is stronger and resource management adheres to IUCN standards of protected areas (Santos, 2017).

2.4 Tree species diversity, composition, and structure in protected forests

Most tropical forests and tropical montane forests are covered by the network of protected forests which are managed as state forests, PFM, CBFM, or privately (Franks & Booker, 2015). However, the level of protecting tree species from threats emanating from human disturbances varies depending on the management regimes that are mandated to manage the forest resources (Burgess *et al.,* 2005; Franks & Booker, 2015).

Tree species in most protected forests in tropical forests are often threatened by human disturbances and their diversity varies significantly from place to place depending on the modifications caused by the disturbances (Seta *et al.,* 2019). The differences in tree species diversity in disturbed areas can be small or large-scale depending on the effects of the prevailing human disturbances (Seta *et al.,* 2019). Different scholars have reported the differences in tree diversity in various protected forests of tropical and montane forests with a history of human disturbances. Studies by Kimaro and Lulandala (2013) showed significant differences in tree diversity between disturbed and undisturbed strata at Ngumburuni Forest Reserve where the diversity index values ranged from 2.0 and 3.7 in the undisturbed and disturbed strata respectively. Asefa *et al.* (2015) also reported higher tree species diversity in areas with human disturbance compared to the intact ones in Bale Mountains montane forests. Recent studies by Seta *et al.* (2019) have also reported a significant variation in tree species diversity in Biteyu Forest Reserve in Ethiopia and Reshad *et al.* (2019) recently established that the disturbed areas within Ades Afromontane in Ethiopia had higher tree species diversity compared to undisturbed areas with an average H' of 2.8. Mohammed *et al.* (2019) have also established a significant variation in tree species diversity in Jello-Muktar participatory forest reserve in Ethiopia, but the reported tree species variation did not concur with the hypothesis of intermediate disturbance whereby the highest tree species diversity was reported in the mature stage and the lowest diversity reported in the initial stage of the forest recovery. Tree species diversity variations reported in other studies (Asefa *et al.,* 2015; Kimaro & Lulandala, 2013; Maguzu *et al.,* 2017; Reshad *et al.,* 2019) have concurred with the intermediate disturbance hypothesis whereby the areas with moderate human disturbances had higher tree species diversity than intact undisturbed forest strata.

Human disturbances in protected forests can also affect tree species structure and composition. A study conducted in the West Usambara montane forest within the Eastern Arc Mountains found that tree species stem densities differed between the human-disturbed and intact areas of the forest (Huang *et al.,* 2003). While the intact parts of the forest contained more stems of mature trees, the disturbed areas had most stems belonging to relatively small to medium size trees of 20 - 30 cm DBH but the comparison of the diversity, structure, and composition of various forest conditions was limited by data unavailability.

Human disturbances affect tree population structure in both protected and unprotected forests (Rutten *et al.,* 2015). However, the effects depend on the type of disturbance and severity on the individual tree species and the existence of disturbance in space and time (Mwakosya & Mligo, 2014). In protected forests with a history of human disturbances, the tree population structure is reflected by differences in tree species growth patterns in terms of regeneration, and DBH while taking into consideration of their population and composition of individual tree species.

According to Mwakosya and Mligo (2014) and Kikoti and Mligo (2015), the structure of tree populations in disturbed forests display hampered regeneration due to selective wood extraction associated with poor recruitment of the harvested tree species. Different tree species tend to respond differently even to small-scale environmental variations caused by human disturbances (Seta *et al.,* 2019). The most effective sign of human disturbances to tree species population structure among those reported by different studies in tropical and tropical montane protected forests is the existence of many seedlings and a large number of small-sized trees with an average DBH of 10 cm to 40 cm in disturbed areas which seldomly contain large trees exceeding 80 cm DBH (Asefa *et al.*, 2015; Fleury *et al.*, 2015; Kacholi, 2013; Kikoti & Mligo, 2015; Mwakosya & Mligo, 2014; Persha & Blomley, 2009; Rutten *et al.*, 2015; Seta *et al.*, 2019).

Human disturbances such as selective wood extraction and mining have significant effects on tree species population structures as they selectively remove some species with known economic values and leave behind those whose economic values are unknown (Asefa *et al.,* 2015; Kacholi, 2013; Mwakosya & Mligo, 2014; Seta *et al.,* 2019). For instance, having established the presence of tree species such as *Ficus sur* and *Sygyzium guineense* with large diameters in the highly-disturbed sites of Rungwe montane forest, Mwakosya and Mligo (2014), concluded that their economic values were unknown to the local community. Similarly, Rutten *et al.* (2015) established that in the montane forest of Mount Kilimanjaro that was previously subjected to logging, there was a small number of the most valuable tree species such as *Ocotea usamabrensis* although their regeneration was not limited and most tree species individuals had low mean diameter sizes. These findings are contrary to those by Kleinschroth *et al.* (2013) in the forests within the slopes of Mount Kenya which reported poor recruitment of timber targeted tree species including *O. usamabrensis*.

Sometimes human disturbances cause the tree species population structure to be unstable, and if the targeted extracted tree species are slow-growing and intolerant to disturbance, they might end up failing to withstand the effects of the prevailing disturbances (Seta *et al.*, 2019). This is because the gaps created by disturbances are quickly colonized by pioneers and opportunistic species which add up to the highest stem densities in the disturbed areas of forests as opposed to the intact ones. Furthermore, the disturbed areas are dominated by shrubs and tree species favored by the disturbance which increases the competition.

On the other hand, human disturbances emanating from livestock grazing in montane forests have been reported to affect the tree species population structure and composition by increasing the population of shrubs and herbs in the forest community (Kikoti & Mligo, 2015; Seta *et al.*, 2019). Other effects of human disturbance on tree population structure in both protected forests and nonprotected forests emanate from non-timber forest product collection, firewood collection medicinal plant collection, and traditional honey collection (Rutten *et al.*, 2015).

The studies conducted in different protected forests within the Eastern Arc Mountains around East Africa with a history of human disturbance and intervention of management regimes established a limited number of individual tree species in areas with selective logging, mining, and livestock grazing effects (Kikoti & Mligo, 2015; Rutten *et al.*, 2015; Seta *et al.*, 2019). Most individuals tree species affected by selective logging were confined either into seedlings or a lower mean stem diameter depending on the severity of disturbance that prevailed in a forest and period since management intervention took over.

2.5 Human disturbances in protected forests

Human disturbances in protected forests mainly emanate from human activities such as agriculture, logging, mining, fuelwood collection, raw materials collection for construction, and herbal medicine (Kikoti & Mligo, 2015; Pham *et al.*, 2020; Rutten *et al.*, 2015; Seta *et al.*, 2019). Agriculture, logging, and mining open up intact forests since they are clear-felled, the wood extracted for timber and other wood products and eventual cultivation, exposing the forests to more threats and making them vulnerable to fires and invasion (Kweka *et al.*, 2015; Pham *et al.*, 2020). Mining activities expose forest resources to other illegal users through access roads and trail construction during the mining process (Kiwango, 2013). The increasing demand for wood fuel, food, and settlement due to the increasing population leads to encroachment of protected forests. All aforementioned human activities contribute to high deforestation and forest degradation in Tanzania and if these activities are not halted, most protected forests in the country will be lost by the year 2070 (FAO, 2017; Kweka *et al.,* 2015; URT, 2015).

Despite different forest management regimes mandated to protect forest resources, human disturbances continue to persist (Gizachew *et al.,* 2020; Pham *et al.,* 2020). This is probably because most of these forests have weak management regimes which lead to the failure of the mandated institutions to implement and enforce the forest laws effectively and efficiently (Riggio *et al.,* 2019). Consequently, the encroachment of forests for expansion of both subsistence and commercial farms, illegal wood extraction, wildfires, illegal livestock grazing, and mining all had an impact on trees species diversity, composition, and structure, as well as the associated forest communities such as large mammalian-herbivores (Heino *et al.,* 2015; Pham *et al.,* 2020; Riggio *et al.,* 2019). For instance, the intrusion of the Kilimanjaro Mountain montane forests in Tanzania by grazing/browsing livestock and logging (Kikoti & Mligo, 2015; Rutten *et al.,* 2015), and Biteyu montane forest in Ethiopia by wood extraction (Seta et al., 2019) were established to adversely affect the tree species diversity, structure, and composition.

According to Tranquilli *et al.* (2014), the threats caused by human disturbances on the biodiversity of most protected forests around the globe are expected to continue due to the increasing demand for forest resources such as timber which take off the tree species. Thus, there is a need to review the management regimes of protected forests and undertake interventions towards reducing the threats to tree species which are mostly affected by extractive utilization (Burgess *et al.,* 2005; Gizachew *et al.,* 2020), and to safeguard the species and habitat for other forest-dependent species such as large mammalian herbivores.

2.6 Marang' Forest as an example of forests under varying management regimes

Marang' Forest is one of the important forests in Tanzania as it plays a critical catchment function to Lake Manyara and refuge areas for large mammalian-herbivores such as elephants and buffalo. From 1938s to 2004, MF was managed as a national forest reserve and catchment forest by Forestry and Beekeeping Division under MNRT (Kiwango, 2013). In 1938, MF was designated as a national forest reserve and later on, in 1957, its protection status was upgraded to a catchment forest (TANAPA, 2014). Despite management regimes, different human activities continue to threaten the forest (Ndembwike, 2010). The mining activities in the forest date back to the 1970s (Ndembwike, 2010), and were legal until 2004 when the process of annexing the forest to LMNP commenced (AWF, 2003). Apart from mining, the forest is also threatened by other human activities such as firewood collection, cutting trees for building materials, domestic animal grazing, and collection of non-timber products (AWF, 2003).

The forest is greatly encroached and the forested area has been reduced by about 35% from 350 km^2 of its original area to 230 km^2 (Kiwango, 2013). Human activities have greatly affected tree species diversity (Santos, 2017) as well as the composition, and structure of the forest community (Baumgartner *et al.*, 2015). In 2009, the protection status of MF was upgraded and it became part of LMNP due to its importance to the conservation of forest resources, its catchment function to Lake Manyara, and its role in biodiversity conservation as it connects LMNP to other protected areas (TANAPA, 2014).

The upgrading of the protection status of MF concurred after recommendations by Burgess *et al.* (2005) who pointed out that the upgrading of the conservation status of key forest reserves is an efficient way of enhancing the protection and conservation of threatened plant species in tropical and montane forests. However, according to Kiwango (2013), even though the MF is under the management of LMNP, there are still illegal human activities in the forest that might threaten its biodiversity and impede the intended objectives of upgrading its protection status. Though the forest is threatened by human activities the systematic assessment and documentation of the biodiversity information have rarely been locally assessed and quantified particularly for the tree species and large mammalian-herbivores which have often been affected by human activities operated into the forests.

2.7 The importance of upgrading protected forests to higher-ranked conservation status

Protected forests are important for minimizing anthropogenic threats to species and habitats. However, tree species, which is the main attribute of the forest’s ecosystem, are still affected by human activities undertaken either legally or illegally within protected forests (Pham *et al.*, 2020). This is because trees are the main source of timber and fuelwood and raw materials for construction and herb medicine. Furthermore, the habitats in these forests are also threatened by encroachment from agriculture and other land-use forms such as mining, and in other cases, they are degazetted and converted into other forms of land uses (Heino *et al.*, 2015). The increasing demand for forest resources at the local and international levels puts more pressure on tree species within protected forests as well as efforts to safeguard the tree species and associated forest ecological community (Pham *et al.*, 2020).

Regardless of the importance of the protected forest reserves to biodiversity conservation most forest management regimes and associated policies are implemented to achieve the intended purpose of a particular established protected forest (UNEP-WCMC, 2016). Cognizant of this, upgrading the protection status and reviewing the management regimes from lower to higher-ranked status can safeguard the forest tree species and the associated forest ecological community (Burgess *et al.,* 2005; Santos, 2017; URT, 2010).

Gizachew *et al.* (2020) and Pfeifer *et al.* (2012) assert that the management regimes of most protected forests are ineffective at preventing the threats facing the resources within them. Consequently, most forest resources are overexploited and forest habitats are destroyed by human activities and some are converted into other land use forms (Pringle, 2017). The human activities that degrade the forest resources and biodiversity within the protected forests can be halted and the degraded forests habitats can be secured and allowed to recover from the disturbances either by re-categorization and/or upgrading them to the higher-ranked conservation statuses (Pringle, 2017; Santos, 2017), to enhance the protection of forest resources and align them with the IUCN standards of protected areas (Santos, 2017).

In recognition of the importance of protected forests in the protection of species and their habitats regardless of their conservation status, since the 1990s, the government of Tanzania merged and upgraded more than twenty protected forests from forest reserves into twelve nature reserves (Appendix 1) (Santos, 2017). Some of the forests have been annexed into national parks (Santos, 2017; TANAPA, 2014). The upgraded forest reserves are managed as wilderness areas and ranked in category 1b of the IUCN (Santos, 2017). This is done to protect forest reserves from extensive tree species losses due to illegal logging, mining, and deforestation caused by increasing population and the rising demand for forest resources (Santos, 2017).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The present study was conducted in Marang' Forest (MF), with an area of 230 km^2, currently comprising one-third of LMNP after having been annexed in 2009 (Fig. 1). Lake Manyara National Park is located within longitudes 35º 44' and 35º 51' E and latitudes 03º 21' and 03º 34' S in northern Tanzania (TANAPA, 2014). The park was commissioned as a National Park in 1960 with an area of 330 km^2 and in 1980 declared as a man and biosphere Reserve by United Nations Educational, Scientific and Cultural Organization (UNESCO) (TANAPA, 2014). The area of the park was increased to 648 km^2 through the incorporation of other potential areas including 88 km^2 of farm numbers 1 and 3 and 230 km^2 of the MF after annexing in 2009 (Kiffner *et al.*, 2017; TANAPA, 2014).

3.2 Study site

The greater part of MF lies between 1500 and 2000 meters above sea level (Schipper & Burgess, 2020). The forest lies in the Great Rift Valley covering the plateau and escarpment on the western side of Lake Manyara. The area experiences a bimodal rainfall pattern, with rains between November - December, and March-May, with an average annual rainfall of 1200 – 1500 mm (AWF, 2003). The average temperature for the warmest months reaches 19ºC in March and drops to about 15ºC in July in the coolest months (Kiffner *et al.,* 2017; Weather Atlas, 2020). The MF is a montane forest dominated by *Casearia battiscombei, Cassipourea malosana, E. capensis, Tabernaemontana ventricosa, and Teclea nobilis* tree species (Elikana *et al.,* 2020). The large mammalian-herbivores within the forest include African elephants (*Loxodonta africana)* and buffaloes (*Cyncerus caffer*), which utilize the area during the dry season (TANAPA, 2014).

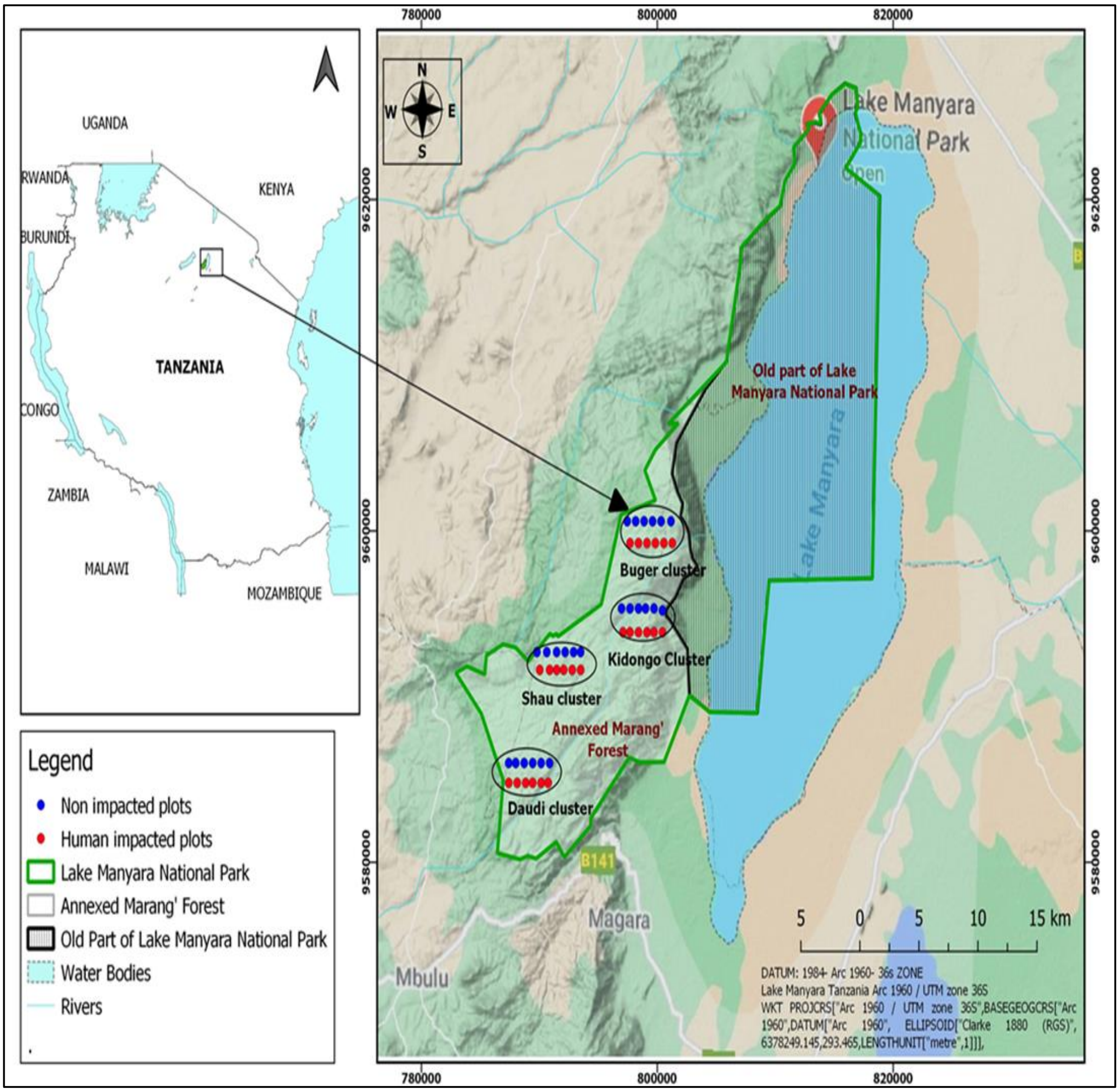

Figure 1: The map of Lake Manyara National Park including the annexed MF showing sampling plots across human-impacted (red dots) and non-impacted (blue dots) areas (TANAPA GIS department)

3.3 Methods

3.3.1 Sampling design

Stratified cluster sampling was employed based on the history of the occurrence of human disturbances within the forest (Mandllaz, 2008; Tomppo *et al.,* 2014). The allocation of the cluster was purposively applied to capture the impact of human disturbances that prevailed within the forest. The concentric circular plot was used whereby the plot was divided into two sub-plots with a radius of 2 m and 15 m (Fig. 2). The concentric circular plots were laid linearly in a transect line. The use of a concentric circular plot is appropriate for conducting tree species assessment in tropical forests as it gives chance to each individual to be included in the sample and avoid edge effects (Tomppo *et al.*, 2014; Vesa *et al.*, 2010).

3.3.2 Data collection

The actual data collection was done from June to July 2019, preceded by a reconnaissance survey whereby tree species were randomly selected from different points in the forest. The data collected from point sampling during the reconnaissance survey was used to determine standard deviations and means which thereafter were used to compute the sample size (number of plots) (Vesa *et al.*, 2010).

$$n = \frac{t^2 CV^2}{E^2} \quad (1)$$

where n = number of plots, CV = coefficient of variation which is equal to standard deviation divided by the mean, t = the value of t obtained from the student's distribution table at n-1 degree of freedom of the pilot study plots at 5% probability.

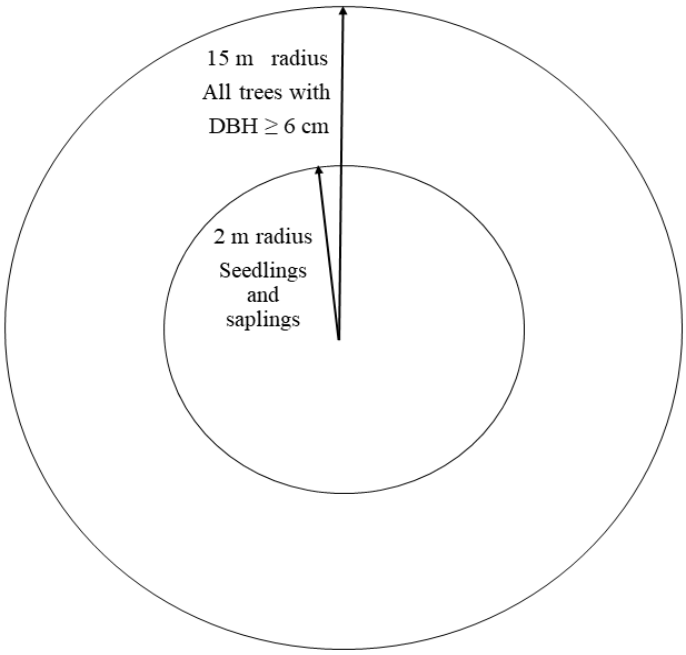

Figure 2: Layout, shape, and size of the concentric circular plot used for the collection of tree species parameters, human disturbance indicators, and signs of larger mammalian-herbivores in MF (Vesa *et al.*, 2010)

Based on Cochran (1977) (Equation 1), 24 plots were established in the human-impacted areas and replicated in control areas, the non-impacted areas, with similar soil and vegetation features (Fig.1). Systematic random sampling was used to establish plots within the clusters whereby the first plot was laid randomly at a distance of at least 50 m from the edge of the disturbed area and the subsequent plots were established systematically at intervals of 100 m along a line transect. The distance between the plots was calculated following (Kashaigili *et al.*, 2013) (Equation 2).

$$PI = \sqrt{\frac{TA}{n}} \qquad (2)$$

Where PI is plot interval, *TA* = total area of the forest, and *n* = number of plots.

Concentric circular plots, modified from the National Forestry Resource Monitoring and Assessment approach (Vesa *et al.*, 2010), with subplots of 2 m and 15 m radius were established (Fig. 2). Within the 2 m radius, all seedlings (trees with a diameter of < 2 cm) and saplings (2 – 5 cm diameter) were counted and identified while the stems of all trees with a DBH $\geq 5-20$ cm (sub-mature) and ≥ 20 cm (mature tree) (Lejju, 2004; Luoga *et al.*, 2004) were measured using caliper and diameter tape measure as illustrated in Plate 1 and identified within the 15 m radius using the Flora of Tropical East Africa Kokwaro (1986) and the Checklist of Tanzanian species version 1 of 2012 (John, 2015), and with the help of an experienced botanist.

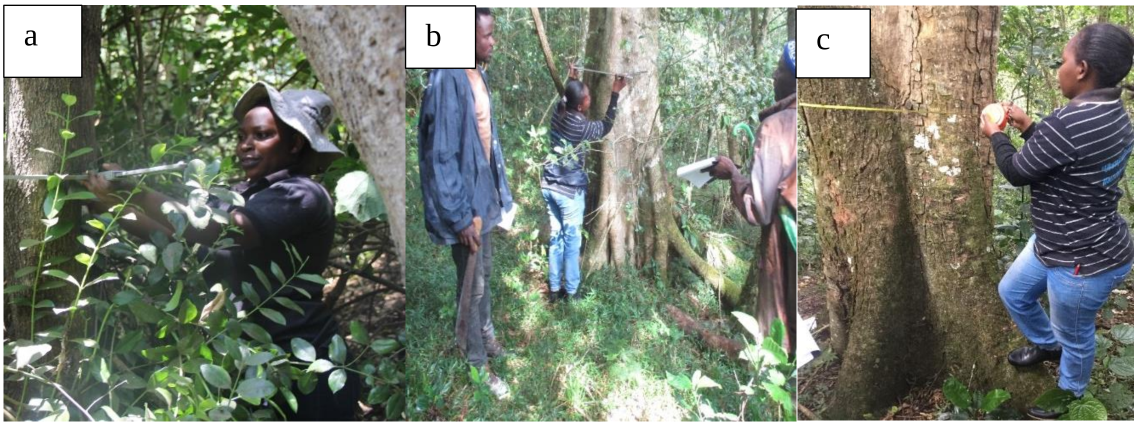

Plate 1: Measurement of tree diameter in Marang' Forest in June and July 2019. Measurement of tree DBH using a caliper (a & b), and diameter tape measure (c)

Human disturbance indicators such as livestock dung, grazing signs, tree stumps, tree debarking, cleared and excavated areas, soil heaps, and footpath trespassing were recorded along the transect lines and in each plot. The oldness of stumps was estimated (< 1, < 3, < 5 < 8 and > 8 years old),) with the help of a field expert, based on the color and grade of decay on the cut surface (Lund *et al.*, 2015). Similarly, mined holes and cleared excavated areas with soil heap were estimated (< 1, < 3, < 5 < 8 and > 8 years old) based on the freshness and bareness of the mined area. The oldness of livestock grazing disturbances was estimated in days because they tended to disappear within a short period, and was graded as < 1 day and < 7 days old based on the level of dryness, decay, and disintegration of the dungs and clearness of the footprints (Rivas *et al.,* 2015). The estimation of the oldness of the human disturbance indicators was used to drive clues on the prevalence of wood extraction, mining and livestock grazing disturbances within the forest since the management intervention from 2009 (Lund *et al.,* 2015). The severity of human disturbance was visually estimated and quantified using the Likert scale of 0 to 4, where; 0 = absence of disturbance, 1 = low disturbance, 2 = moderate disturbance, 3 = high disturbance, and 4 = severe disturbance (Makero & Kashaigili, 2016) (Table 1).

Table 1: Semi-quantitative indicators of human disturbance and their severity indices in Marang' Forest based on Linkert scale

Severity description	Portion of the plot affected by disturbance	Likert scale
Absent	0%	0
Low	25%	1
Moderate	50%	2
High	75%	3
Severe	100%	4

Makero & Kashaigili (2016)
Disturbance = % of plot covered by a disturbance (based on visual estimates)

An assessment of large mammalian-herbivore abundance was done along each transect which was about 700 m long and within plots that were established for sampling trees. The transects and plots were walked in the morning and evening hours to count and identify any large mammalian-herbivores that were detected within the areas. Any large mammalian-herbivore that was found within a distance of 25 m on the right and left side of the transect were also counted and identified. Further, the habitat type (impacted and non-impacted) where the animals were found was recorded. Indirect observation for any potential signs of the large mammalian herbivores was assessed in each plot and 1 m away from the plot to the right and the left side of the transect. In this study, the potential large mammalian-herbivores signs were dung piles, feeding damages, footpaths, footprints, wallowing and resting sites. Identification of the large mammalian herbivores signs was done by using African mammals' field guide book (Kingdon, 2015). The observation of large mammalian-herbivores was not done in the late evening's hours (beyond 1530 hours) due to poor visibility and safety reasons since the forest is very dense. Throughout the data collection period the data collection team was escorted by two armed rangers who ensures the safety while in the forest.

3.3.3 Data analysis

Tree species attributes such as diversity, composition and structure were obtained, whereby tree species diversity was expressed through species richness and diversity indices. The tree species richness was expressed as the number of species (S) within the sampled plots. Shannon Weiner diversity index (H') (Kent & Coker, 1992) and Simpson's index of dominance (ID) (Simpson, 1949) were applied to compute tree species diversity indices as shown in Equations 3 and 4 respectively:

$$H' = -(\sum_{i=1}^{s} P_i \ln P_i) \quad (3)$$

Where; pi is the proportion of individuals of a particular species in the sample, n_i is the number of individual stems for a particular tree species in a given plot, and N is the total number of stems of all tree species in the sampled plots.

$$ID = (\sum \left(\frac{n_i}{N}\right)^2) \quad (4)$$

The composition and structure of the tree species within the forest were expressed in terms of stem density (ha^{-1}) and within different growth stages based on their diameter size (DBH). The tree stem density was computed using Equation 5:

$$\text{Tree density} = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{n_i}{A}\right) \quad (5)$$

Where tree density is in terms of the number of stems ha^{-1} in a given growth stage, n_i is the number of stems in a given growth stage at a given plot, n is the number of plots, and A is the plot area.

The frequency of occurrence of each human disturbance indicator in the surveyed areas was analyzed and expressed as a percentage and the severity of each disturbance was calculated using Equation 6 as proposed by Makero and Kashaigili (2016).

$$\text{Severity} = \frac{\sum \text{occurrence of individual human disturbance}}{\text{Total severity scaled in sample plots}} \quad (6)$$

The abundance of the large herbivores was expressed as a relative abundance computed from the frequency of which the species occurs in all samples and their richness was accounted as the number of species (S) within the sampled plots. Inferential statistics were performed in the Jamovi computer program software (V. 1.1.9.0), and the data were tested for normality using the QQ plot test and Shapiro-Wilk test. The student's t-test was used to establish if the average tree species diversity indices, composition, and structure, as well as the richness and abundance of large mammalian herbivores, were statistically different between human-impacted and non-impacted areas (Jayaraman, 2000). The Chi-square tests were used to establish whether human disturbance differed significantly within the surveyed area (Makero & Kashaigili, 2016).

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Results

4.1.1 Tree species diversity in Marang' Forest

In total, 58 tree species encompassing 32 families were found across the human-impacted and non-impacted areas of MF. Among those, 34 tree species occurred in both areas, while 15 and 9 tree species were observed only in impacted areas and non-impacted areas respectively. The unique tree species that occurred in the impacted areas and contributed to the high diversity were *Nuxia congesta, Senna didymobotrya, Solanicio mannii, Vernonia auriculifolia, Brucea antidysentrica, Canthium oligocarpum, C. anisate, Ehretia cymosa* and *Abutilon longicuspe* (Appendix 4).

The tree species richness was about one-third higher in impacted areas ($t = 5.03$, $df = 34$, $p < 0.001$) than in the non-impacted areas (Fig. 3a). A similar pattern was observed for H' that was by about 17% higher in human-impacted areas than the non-impacted areas ($t = 4.98$, $df = 34$, $p < 0.001$) (Fig. 3b).

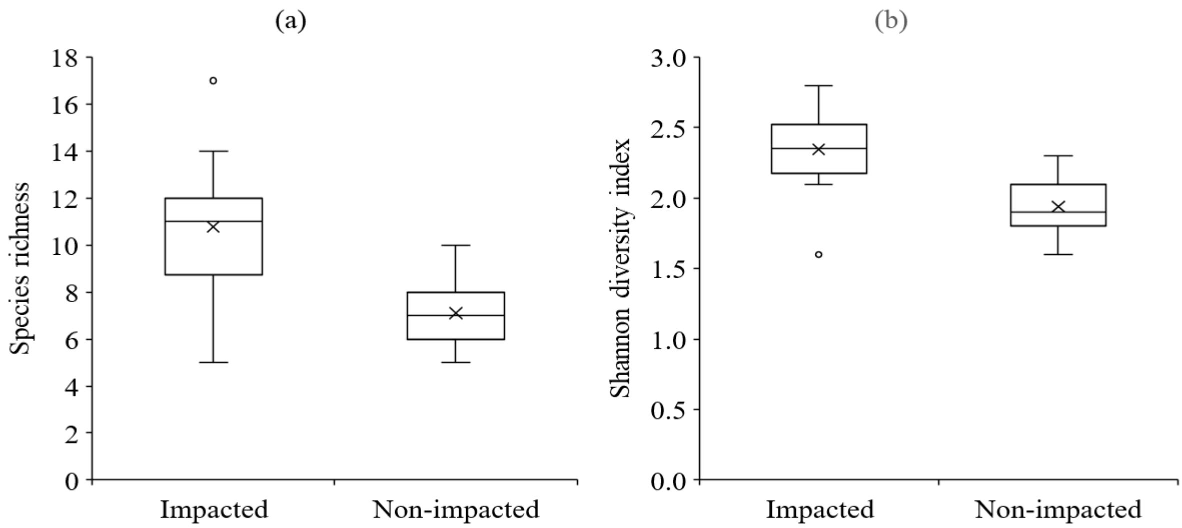

Figure 3: Tree species richness and diversity indices in the impacted and non-impacted areas of Marang' Forest. (a) Tree species richness, (b) Shannon's index. The boxes represent the inter-quartile range, circles represent outliers, the median represented is by a line, and the whiskers represent the variation range

The index of dominance (ID) was also higher in impacted areas than in non-impacted areas by about 2% ($t = 4.54$, $df = 34$, $p < 0.001$). The ID was generally lower among tree species, reflecting the small number of stems per individual tree species, which differed slightly but not significantly between the human-impacted (ID = 0.10 ± 0.01) and non-impacted areas (ID = 0.15 ± 0.00), suggesting that there was a little variation among tree species but there was a significant difference between the impacted and non-impacted. The complete list of tree species index of dominance in the human-impacted and non-impacted areas of MF is provided in Appendix 5. Even though some tree species occupied only a small portion of the forest with a small dominance index value, still they occurred regularly in the forest and contributed to the diversity and richness of the forest (Appendix 5).

4.1.2 Tree species composition and their structure in Marang' Forest

The most dominant tree species in the non-impacted areas were *Xymalos monosphora, T. ventricosa, C. battiscombei, Vepris simplicifolia, T. nobilis, B. abyssinica, O. capensis,* and *P. africana*. *Tabernaemontana ventricosa* and *Xymalos monosphora*, were the two most dominant tree species across both impacted and non-impacted areas, occurring at about 8% and 11%, respectively in the impacted areas, and 6% and 7%, respectively in the non-impacted areas. Additionally, these two tree species had the highest number of stems ha^{-1} and appeared to have more stems ha^{-1} in the impacted areas than the non-impacted ones (Fig. 4).

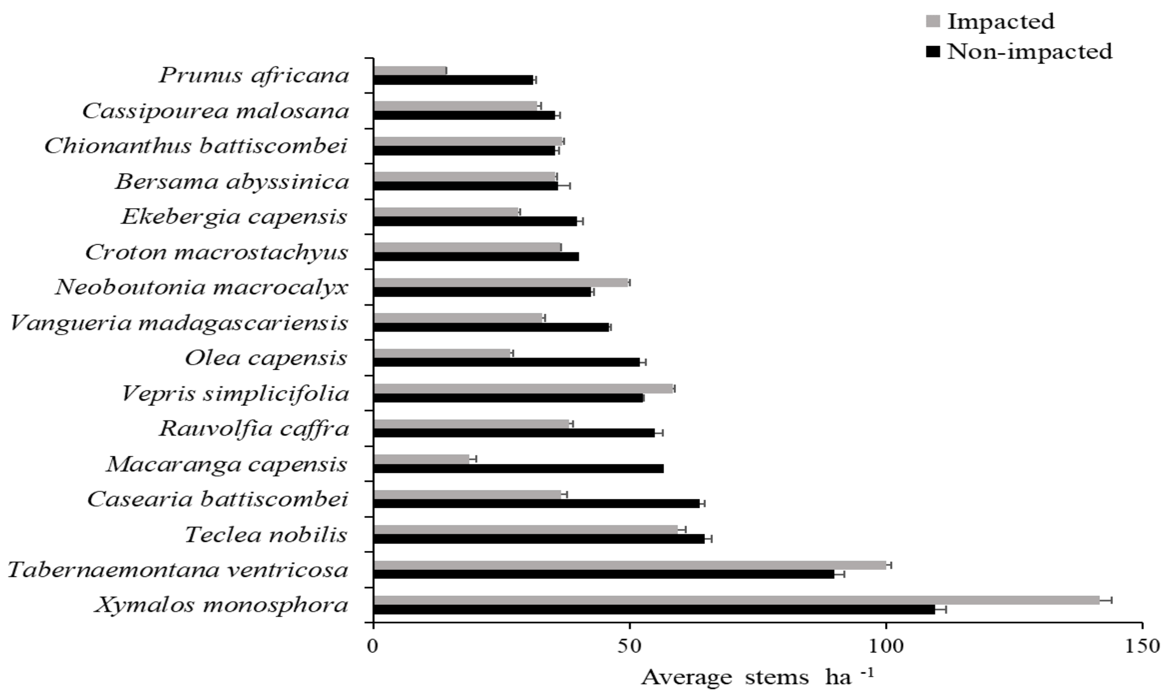

Figure 4: The most abundant occurring tree species in the impacted and non-impacted areas of Marang' Forest. The total number of tree species (n = 58) recorded in MF in June to July 2019

Most of the tree stem in the impacted areas had an average diameter of 10-20 cm while only a few species namely *Ekebergia capensis, Albezia gummifera,* and *Ficus thonningii* had stems with diameter size > 50 cm mostly pioneers and opportunistic species. In contrast, the non-impacted areas had more stems of tree species with larger diameters (> 50 cm), mostly species which are intolerant to diatubances including the endangered tree species *P. africana* (Fig. 5).

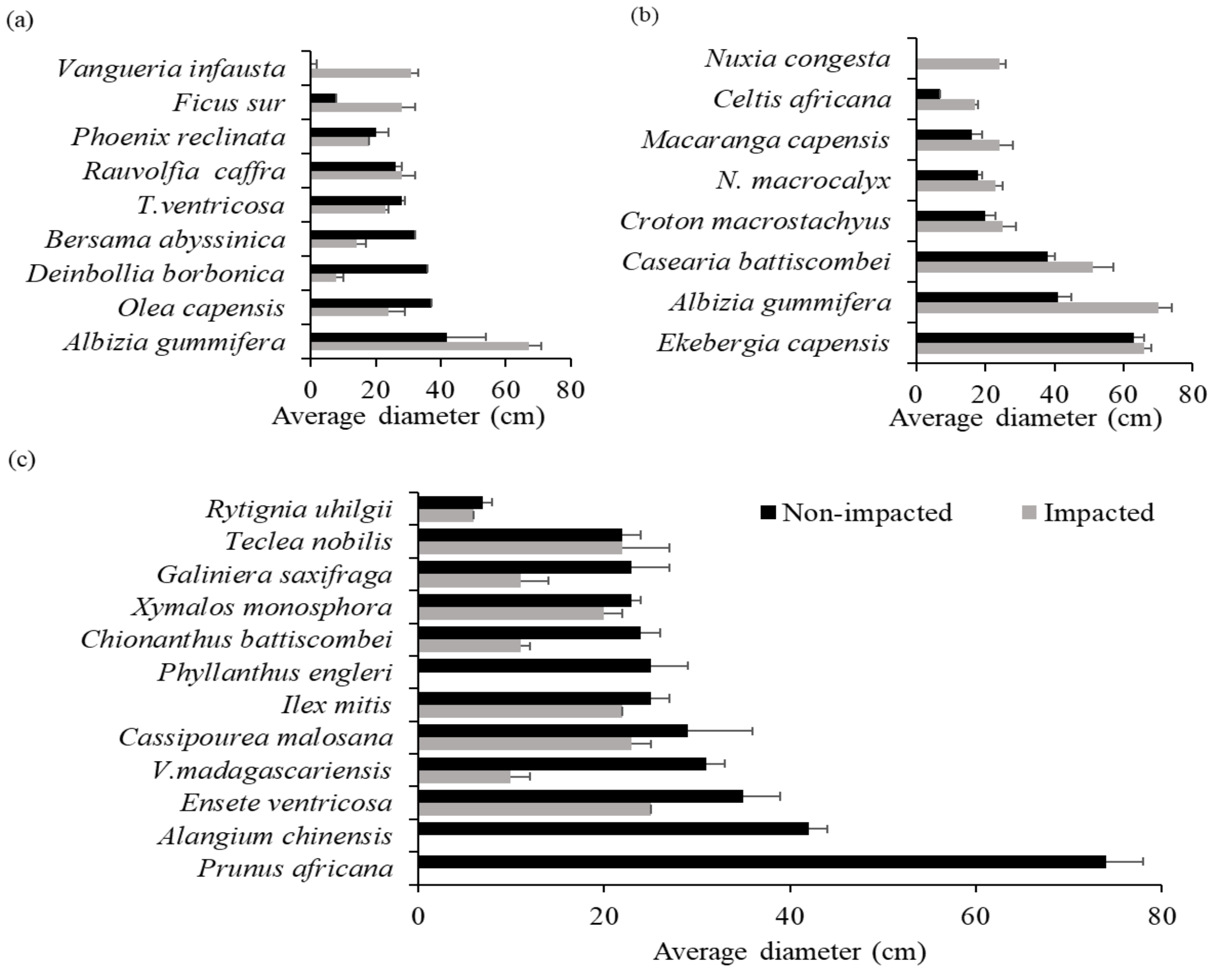

Figure 5: Average stem diameter of the mature tree species in impacted and non-impacted area within Marang' Forest

4.1.3 Tree population structure in Marang' Forest

The average number of tree stems ha^{-1} was by about 10% significantly higher in the human-impacted areas than the non-impacted areas (t = 3.46, df = 34, p = 0.01). The high stem density in the human-impacted areas was largely contributed by seedlings and saplings which were higher in these areas than in non-impacted areas by about 62% and 38% respectively (t = 7.21, p < 0.001 and t = 10.56, p < 0.001, respectively). Similar patterns were observed for the density of sub-mature tree stems which was also by about 26% higher in the impacted areas than in non-impacted areas (t = 5.18, p < 0.001) (Fig. 6).

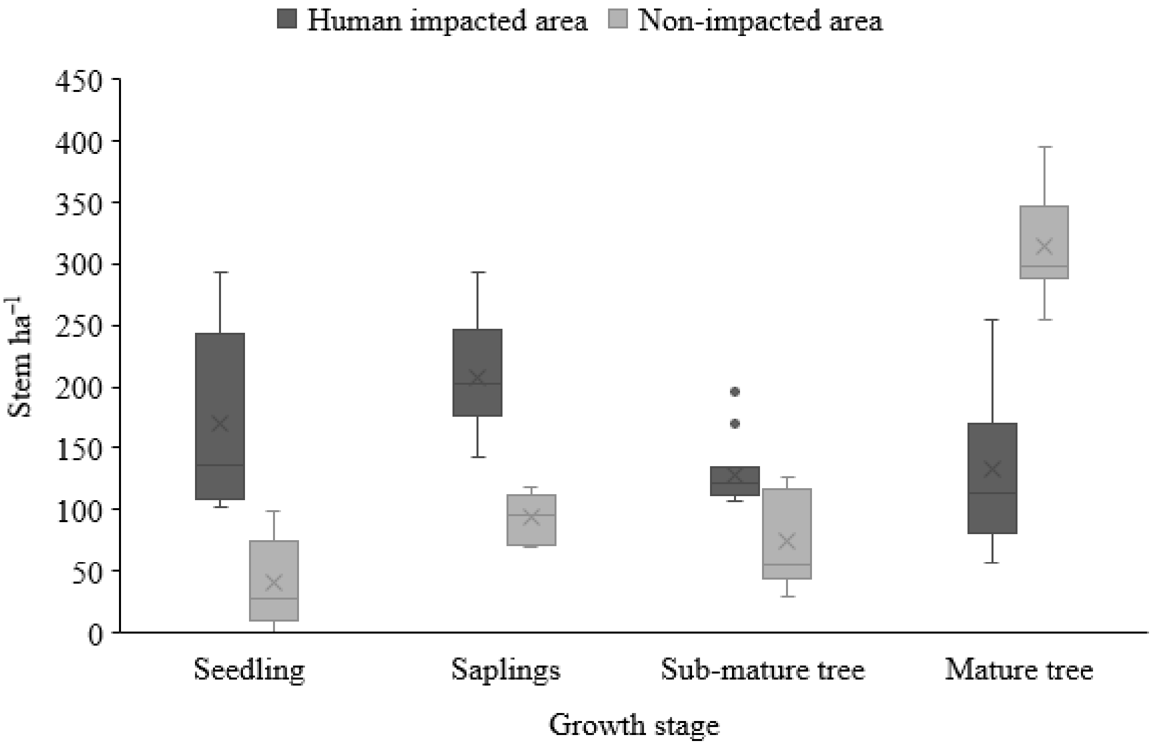

Figure 6: The number of tree stems ha^{-1} within different growth stages in impacted and non-impacted areas across Marang' Forest. The boxes represent the inter-quartile range, mean represented by x, circle represent outliers, median represented by a line, and whiskers represent the variation range

In contrast, the density of mature tree stems was about 40% higher in non-impacted areas than impacted areas (t = 10.37, p < 0.001) (Fig. 6). Besides, the tree stem density differed significantly among growth stages, with seedlings and saplings being more abundant than sub-mature and mature trees (F= 16.8, df = 3, p <0.001).

Nevertheless, out of the 58 tree species identified in MF, only 36 tree species had seedlings. Most of the observed seedlings and saplings were dominated by species of *S. didymobotrya, C. anisate, C. macrostachyus,* and *A. longicuspe*. The presence of some seedlings and saplings of the endangered tree species such as *P. africana* was also noted in the impacted areas of the forest (Appendix 4). Other tree species such as *Ensete ventricosa, Galiniera saxifrage, Ritchiea albersii,* and *Rothmania fischeri* showed no seedlings and were only recorded in sub-mature and mature stages in both impacted and non-impacted areas (Appendix 4). An illustration of the observed tree seedlings and saplings is shown in Plate 2 exhibits tree regeneration observed in impacted areas of the forest.

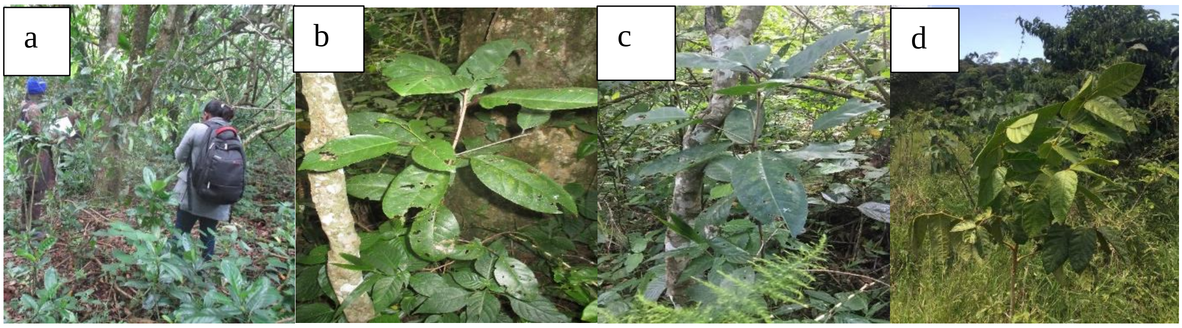

Plate 2: Tree seedlings and saplings regeneration in the human-impacted areas of Marang' Forest. *Psychotria riparia* seedling (a), *Prunus africana* seedling (b), *Prunus africana* sapling (c), and *Brucea antidysenterica* sapling (d)

4.1.4 Human disturbances and their severity in the Marang' Forest

(i) Human disturbances in human-impacted areas within Marang' Forest

The identified human disturbance differed significantly in their frequencies. About one-third of the signs of human disturbance were mining, followed by wood extraction and livestock grazing, associated with trespassing ($\chi^2 = 9.24$, df = 3, $p = 0.026$) (Table 2). The percentage of human disturbances calculated as the total frequency of the indicators for each disturbance over the total frequency of all indicators across all sampled plots revealed that mining and wood extraction were the most prevalent forms of human disturbances in the forest (Table 2).

These disturbances in MF were revealed by assessing different human disturbance indicators in the forest. For instance, wood extraction disturbances were denoted by a full harvested tree, uprooted tree, cutting mark on the trees, debarking, sawing platforms, and stumps. On the other hand, livestock grazing was represented by the presence of cow dung, trespass footpaths, present of livestock, browsing signs and their footprints while mining disturbances were represented by the presence of mining holes, siltation on river banks, sand and soil heaps, and cleared excavated areas within the forest (Table 2). The most observed indicators of human disturbance in the forest were stumps, cleared excavated areas with soil heap and pits, footpaths, and cow dung piles (Table 2). Some of these indicators were observed to be fresh in the surveyed areas signifying that the related human activities are regularly illegally conducted within the forest (Plate 3).

Table 2: The frequency of human disturbance signs observed in Marang' Forest

Observed indicator	Wood extraction	Grazing	Trespassing	Mining	Total	Percent (%)
Stump	38	0	0	5	**43**	**31.6**
Sawing platform	1	0	0	0	**1**	**0.7**
Log beehive	1	0	0	0	**1**	**0.7**
Excavated area	0	0	0	24	**24**	**17.8**
Siltation	0	0	0	7	**7**	**5.1**
Uprooted tree	1	0	0	7	**8**	**5.9**
Plastic materials	0	0	0	1	**1**	**0.7**
Cow dung pile	0	20	0	0	**20**	**14.7**
Cow footprint	0	5	0	0	**5**	**3.7**
Goat pellets	0	1	0	0	**1**	**0.7**
Cattle present	0	1	0	0	**1**	**0.7**
Browsing signs	0	1	0	0	**1**	**0.7**
Fodder collection	0	1	0	0	**1**	**0.7**
Footpaths	0	0	22	0	**22**	**16.2**
Total	**41**	**29**	**22**	**44**	**136**	**100.0**
Human disturbance (%)	**30.1**	**21.3**	**16.2**	**32.4**	**100**	
Chi- square test		$\chi^2 = 9.24$	$df = 3$	$p = 0.026$		

The Chi-Square test was conducted to compare whether human disturbances differed significantly within the impacted area

For instance, the presence of footpaths, cow dung piles, and many trespass routes indicated that grazing was regularly practiced in the forest. Besides, the signs of fresh grazing were abundant in grassland patches of the forest (Plate 3). Plates 3 (a), (b), and (e) represent fresh cow dung piles. Plate 3 (c) represents recent tree uprooting, and soil heaps respectively, as examples of the observed human disturbances in the forest which were fresh. Other human disturbances such as log hive making and debarking were fresh [Plate 3 (d & h)] but were the least within the area (Table 2). Contrary to this, mining activities in the forest were mostly observed along the riverine forest in the interior parts. Some of the mined areas were observed to be old while others were quite recent relative to the time of the study [Plate 4 (a, b, & c)]. The mining activities were estimated to have taken approximately less than two months ago relative to the time of the study (June and July 2019) based on the freshness of the soil heaps and mined holes and bareness of the excavated areas.

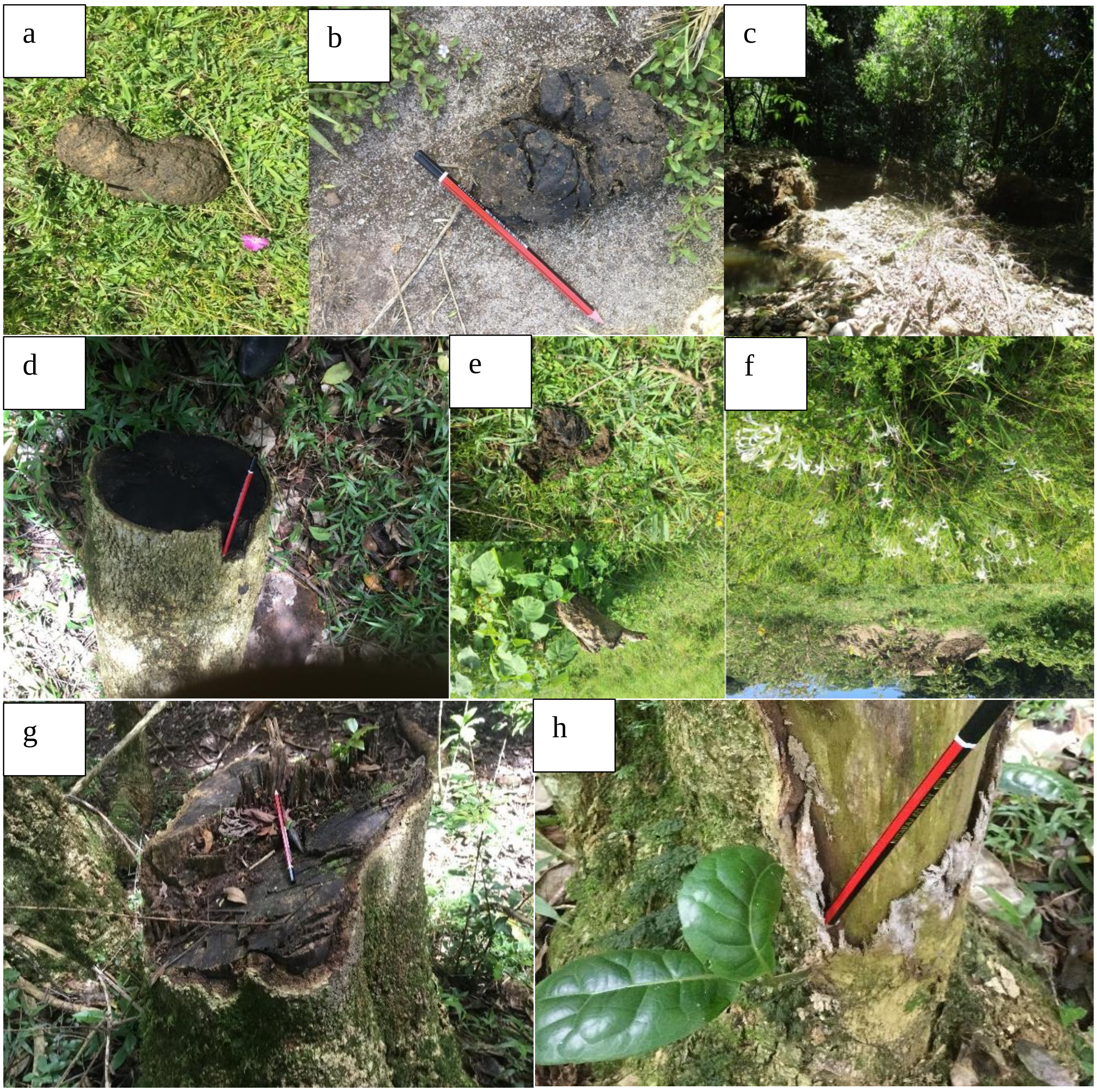

Plate 3: **Signs of human disturbance observed in human-impacted areas in Marang' Forest. Cow dung piles (a and b), Excavated cleared area with soil heap and uprooting (c), Log hive constructed from a *Syzygium guineens* tree (d), Wood extraction associated with livestock grazing activities within the grassland patch in the forest (e) grazing (f), logging (g), and debarking (h)**

Wood extraction was either associated with mining activities by uprooting [Plate 3 (b & c)] or grazing [Plate 3 (e)]. In a few cases, wood extractions were associated with traditional honey collection within the forest. Most of the tree species affected by wood extraction were *Croton mycrostachyus*, *Rauvolfia caffra*, *Casearia battiscombei*, and *Teclea nobilis* while other tree species were least-affected by wood extraction (Table 3). Furthermore, most of the stumps were estimated to have been felled within 5- 10 years ago, based on the decay levels on the stump cut surface (Table 4).

Plate 4: Signs of mining recorded along the riverine forest within the Marang' Forest; Siltation on river banks (a), excavated areas with pits, soil, and sand heap in recent mined areas (b and c)

Table 3: Frequently observed tree species stumps in Marang' Forest

Stump botanical name	No. of Stumps	Percent (%)	Average stump diameter (cm)
Casearia battiscombei	5	12	33.0
Croton mycrostachyus	13	30	12.8
Ekebergia capensis	1	2	39.0
Erythrococca fischeri	2	5	12.8
Fagaropsis angolensis	2	5	12.0
Prunus africana	2	5	115.0
Psychotria riparia	1	2	15.0
Rauvolfia caffra	7	16	24.7
Syzygium guineens	1	2	57.0
Teclea nobilis	4	9	6.3
Vangueria madagascariensis	1	2	10.0
Vernonia auriculifolia	1	2	5.5
Xymalos monospora	3	7	19.3
Total	**43**		

Most of the counted stumps from wood extraction like *Croton mycrostachyus and Teclea nobilis* had an average diameter ranging between 10 cm and 12 cm. On the other hand, the small number of large stumps that included *P. africana* and *Syzygium guineens* could have resulted from harvesting for timber and log hive making (Table 3; Plate 2 (d & g).

(ii) The severity of human disturbances in Marang' Forest

In this study mining and grazing were observed to be the most severe human disturbance based on their estimated percentage of occurrence in the sampled plots, with an average severity of 63.1% ± 3.2 and 55.2% ± 3.8 per sampled plot, respectively.

Table 4: The average severity (± SE) of human disturbance and estimated time since disturbance as observed in Marang' Forest

Human disturbance	Average severity ± SE (%)	Estimated time since disturbance	Frequency	Percent (%)
Grazing	55.2 ± 3.8	**Total**	**29**	**100**
		< 7 days	28	97
		< 1 day	1	3
Mining	63.1 ± 3.2	**Total**	**42**	**100**
		< 1 year	14	33
		< 3 years	7	17
		< 5 years	19	45
		< 8 years	2	5
Trespassing	50.2 ± 2.9	**Total**	**22**	**100**
		< 1 year	6	27
		< 7 days	16	73
Wood extraction	37.8 ± 2.3	**Total**	**43**	**100**
		< 1 year	5	12
		< 5 years	13	30
		< 8 years	7	16
		< 10 years	18	42

The severity of the disturbance calculated as the total estimated occurrence percentage of individual human disturbance over the total estimated severity of a particular disturbance in all sampled plots (Makero & Kashaigili, 2016) showed that mining and livestock grazing were severe in the interior part of the forest and within the grassland patches. Most signs of livestock grazing (97%) were < 7 days old, while about 33% of signs of mining were < 1 year old and a few signs of mining (5%) were > 8 years old (Table 4). Grazing was most severe in the grassland patch of the forest and these areas were largely dominated by shrubs particularly the *Sida massaica* (Plate 5).

Plate 5: *Sida massaica* shrub dominating the area affected by grazing in Marang' Forest

The areas with signs of mining had significantly lower tree species diversity compared to areas with signs of fresh livestock grazing and wood extraction (Fig. 7).

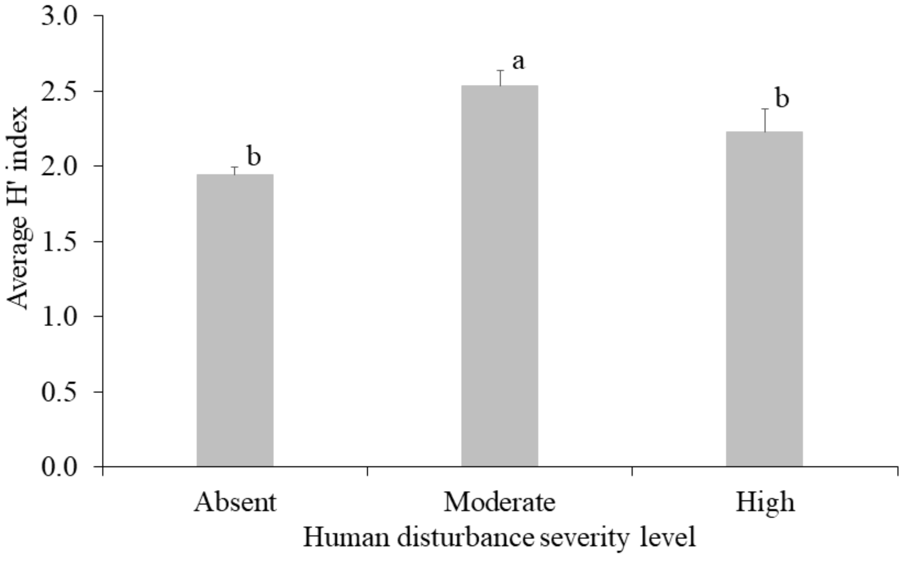

Figure 7: Average ± SE Shannon diversity index (H') for tree species across different levels of human disturbance severity in Marang' Forest

The severity of human disturbance had significantly reduced the tree species diversity within the human-impacted areas, particularly those areas with relatively recent mining activities. When the diversity index was compared across the plots with different human disturbance severity levels, it was established that the areas with moderate disturbance (H' = 2.5 ± 0.1), had a high species diversity compared to those with a high severity level of human disturbances (H' = 2.2 ± 0.2) and those without disturbances (non-impacted areas.) (H' = 1.9 ± 0.1; F = 12, $df = 2$, $p < 0.001$) (Fig. 7).

4.1.5 Richness and abundance of large mammalian herbivores in Marang' Forest

The frequently large mammalian herbivores recorded in both impacted and non-human-impacted areas were elephants (*Loxodonta africana*) and Buffalo (*Syncerus caffer*). Other herbivores recorded only in impacted areas were red duiker (*Cephalophus harveyi*) and bushpig (*Potamochoerus larvatus*) (Fig. 8). The signs of large mammalian herbivores were significantly higher in the impacted areas than the non-impacted areas by about 35% (t = 2.04, df = 118, p = 0.043).

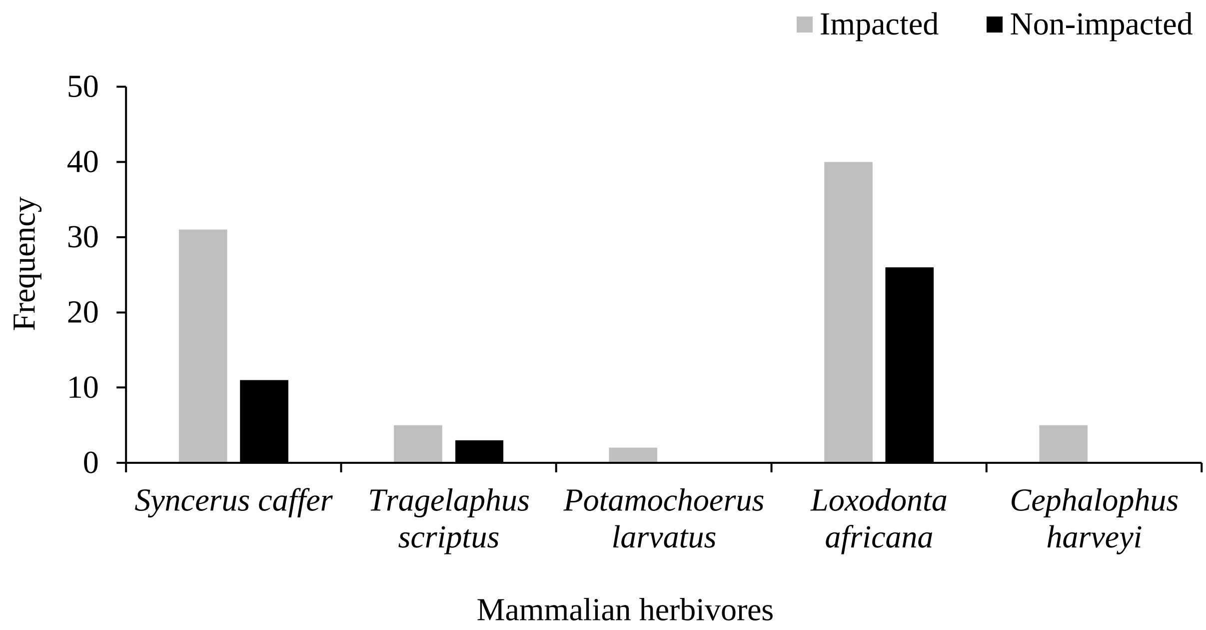

Figure 8: Frequency (=number of times the signs observed) of large mammalian herbivore signs encountered in impacted and non-human impacted areas in the Marang' Forest in June to July 2019

The frequencies of large mammalian herbivore signs indicate that elephants and buffaloes were the most potential large herbivores utilizing the impacted areas of Marang' Forest. The relative frequency of the signs for large mammalian-herbivores was calculated as the proportion of a particular large mammalian-herbivore sign in a given site (impacted or non-impacted areas) multiply by 100 (Fig. 9), whereby the total signs (n = 83 signs in impacted areas and n = 40 signs in the non-impacted area) as counted in June and July 2019.

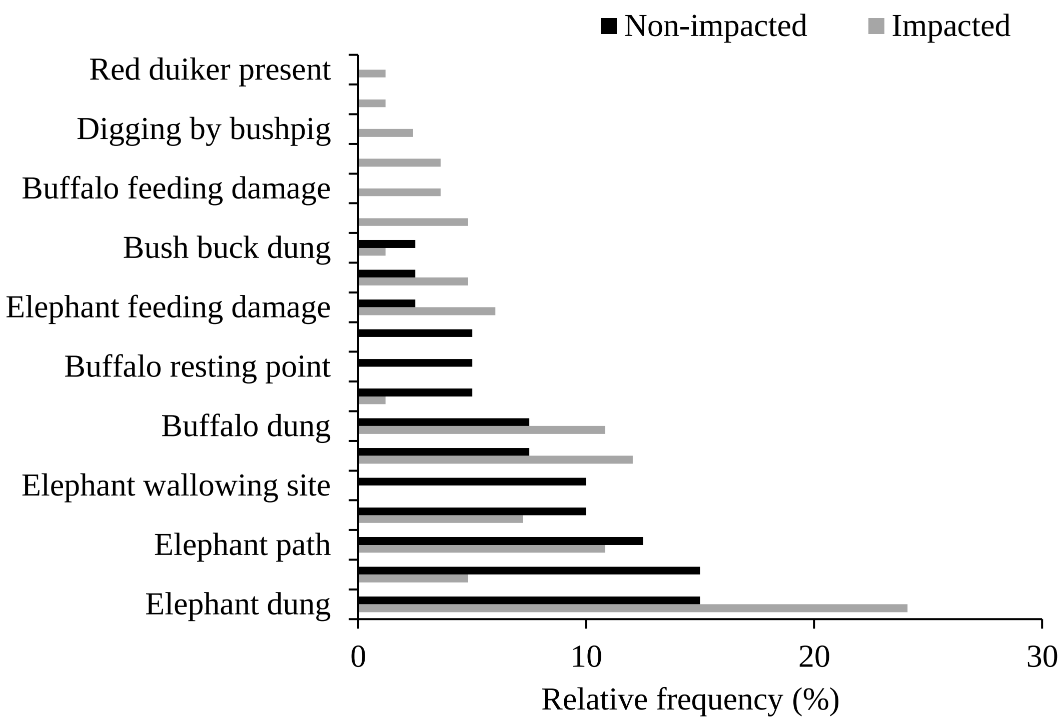

Figure 9: Relative frequency of the signs for large mammalian-herbivores observed in Marang' Forest

Figure 9 shows the frequency of occurrence of signs of large mammalian-herbivores in MF while Plate 5 demonstrates some of the signs of large herbivores and examples of the large mammalian-herbivores that were observed in the forest. Of these, dung piles of elephants and buffalo, footprints of elephant, elephant, and buffalo paths were the most frequently occurring signs in the forest. It was noted that elephants utilize more of the grassland patch as a wallowing site and drinking site as this area is waterlogged areas [Plate 6 (e & f)]. Frequently, dung piles, footprints, and paths of elephants and buffalo were observed in impacted areas than in non-impacted areas (Fig. 9).

Furthermore, the signs counted indicate that human-impacted areas were rich in large mammalian-herbivores compared to non-impacted areas as on average of 33% more signs for different herbivores were observed in the impacted areas (Fig. 9). The distribution of other signs and indicators of other observed species of large mammalian-herbivores across the impacted and non-impacted areas of the forest are provided in Fig. 9. Some of these species occurred only in impacted areas of the forest and were not observed in the non-impacted areas (Fig. 8).

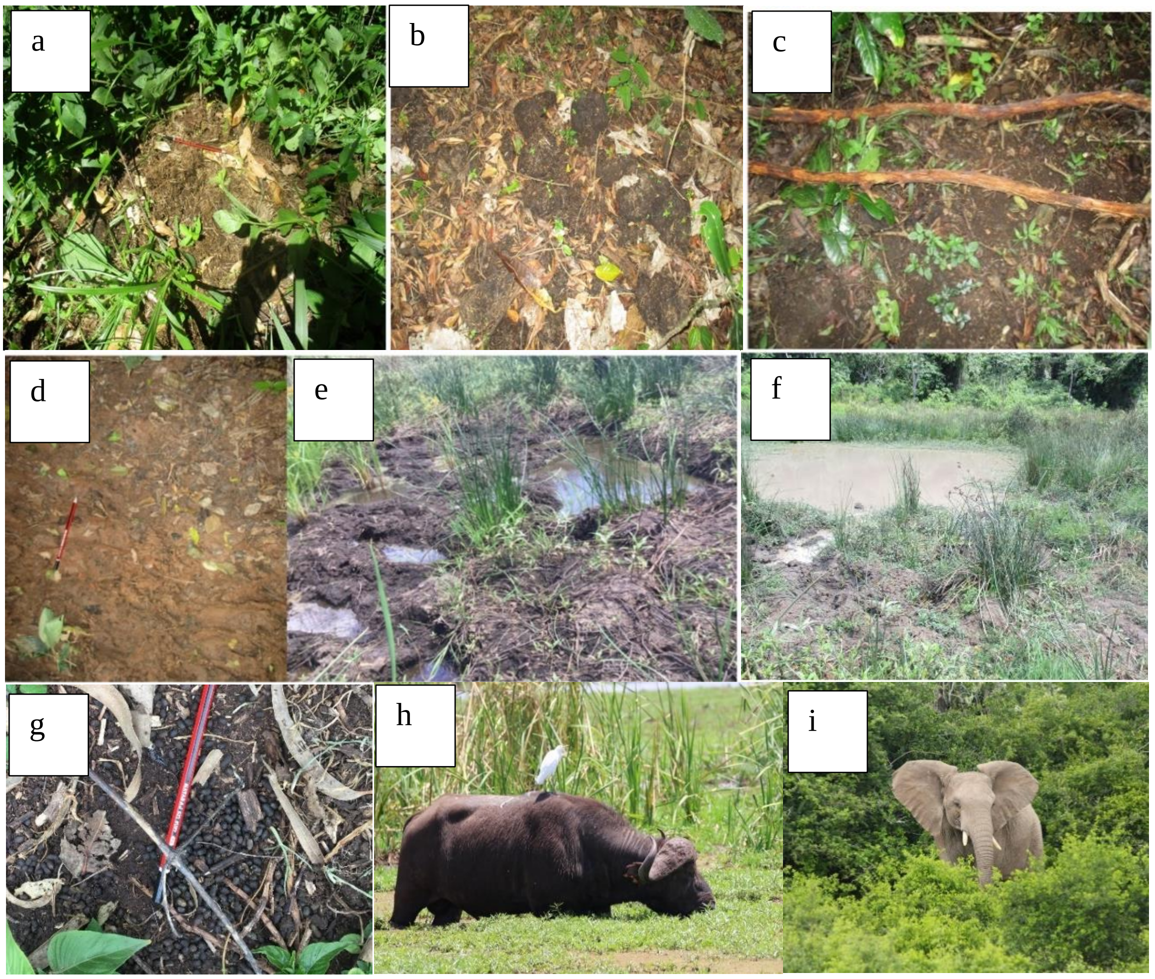

Plate 6: Signs of large herbivores and examples of the large herbivores observed in Marang' Forest.(a) Buffalo dung (b) Elephant dung, (c) Damages caused by elephant feeding, (d) Elephant footprints (e) Elephant footprints (f) Elephant wallowing site (g) Bushbuck dung, (h) buffalo, and (i) Elephant

4.2 Discussion

4.2.1 Tree species diversity in Marang' Forest

The present study established that most tree species were common in both human and non-human impacted areas while a few were unique to either of the two areas. In general, the high tree species diversity in the impacted areas was mostly caused by pioneer and opportunistic tree species. These observations are similar to studies by Mwakosya and Mligo (2014), Wekesa *et al.* (2019), Ndangalasi *et al.* (2014), Tenzin and Hasenauer (2016), and Abdo *et al.* (2017) who noted higher numbers of pioneer and opportunistic tree species in disturbed forests. The H' ranged between 1.9 and 2.3 in the impacted areas, which is within the range reported in other protected forests in eastern Africa montane forests (Girma & Maryo, 2018; Gizachew *et al.*, 2020; Kiyingi *et al.*, 2010; Wekesa *et al.*, 2019). This highlights the importance of deterring human disturbances to the minimum level that allows the improvement of the diversity of tree species. The enhancement of tree diversity is likely a result of improved enforcement of conservation laws following the upgrading of MF to a National Park which has high-ranked protection status. Other studies in forests with intervention on the way of forest resources conservation and protection have also highlighted that high tree species diversity is partly caused by minimum previous human disturbance (Calle & Holl, 2019; Kimaro & Lulandala, 2013; Linying *et al.,* 2006; Pereira *et al.,* 2007; Wekesa *et al.*, 2019) and the findings of the present study concur with the intermediate disturbance hypothesis (Collins, 1995). The studies by Chazdon (2003) and Chazdon and Guariguata (2016) show that natural recovery of forest species diversity occurs gradually and depends on the severity of the prevailed disturbance, and we see the first stages of this recovery in MF after its upgrading from a decade ago since 2009 (TANAPA, 2014). Studies by Pandey *et al.* (2014), Calle and Holl (2019), and Chowdhury *et al.* (2019) also show that upgrading of forest reserves to higher conservation status such as National Parks has allowed forest diversity to recover.

The present study also established that there was only a little dominance among tree species, which suggests that most tree species contributed to forest diversity relatively evenly (Chowdhury *et al.*, 2019). This was also reported in other forests elsewhere that have applied forest management regime interventions to reduce human disturbance (Pandey *et al.*, 2014). The ID values obtained in the present study are comparable to other protected forests of the Eastern Arc Mountains and Great Rift valley montane forests within Tanzania and Kenya (Omoro *et al.*, 2010; Wekesa *et al.*, 2019).

4.2.2 Tree species composition in Marang' Forest

The results of the present study show that tree species within the human-impacted areas were not evenly distributed within different growth stages, highlighting the impact of selective wood extraction, clearance during mining activities, and livestock grazing, which likely increased seedlings and saplings (Gebeyehu *et al.*, 2019). These observations are similar to those of Chhetri and Shrestha (2019) in Eastern Nepal who also noted that the removal of forest biomass through human disturbances such as grazing or tree harvesting affected the forest's succession process. Most tree species in the human-impacted areas were in the seedling, sapling, and sub-mature growth stages, with a diameter between 10 cm and 30 cm, which is similar to results by Igu (2017). Only a few species such as *E. capensis, A. gummifera,* and *F. thonningii,* had larger diameters, which indicates that these species can quickly regrow as within the impacted areas there less competition for resources such as light due to openness of the canopy (Gebeyehu *et* *al.,* 2019; Mwakosya & Mligo, 2014; Tsegaye *et al.,* 2017). However, the existence of many small trees also shows the potential recovery of forests, resulting in secondary forests (Chazdon & Guariguata, 2016). Further, the results also revealed the recovery of most extracted valuable tree species such as *O. capensis*, which is a commercially important timber plant internationally (Petro *et al.,* 2016), and *P. africana,* a species used for medicinal and timber products both locally and internationally (Lukumbuzya & Sianga, 2017; Nsawir & Ingram, 2007; Vinceti *et al.,* 2013). The findings are in line with other studies conducted in protected forests in Africa including in Cameroon, Ethiopia, and Zimbabwe which show that most of the exploited tree species had more stems in lower classes comprising seedlings and saplings (Jimu *et al.,* 2013; Kabede *et al.,* 2014; Stewart, 2009). Furthermore, *P. africana* is presently listed as a vulnerable tree species to the IUCN red list of threatened tree species (World Conservation Monitoring Centre, 1998). This signifies the effect of selective wood extraction on tree species in MF. According to Pfeifer *et al.* (2012), the protection strategies in the forest reserves in East Africa are not sufficient, and human disturbance threatens many species within the reserves, particularly those which have commercial values. Moreover, *X. monosphora* and *T. ventricosa* were the most abundant species, both in the impacted and non-impacted areas, showing that they are less exploited by the local community (Dharani, 2011).

4.2.3 Tree population structure and composition in Marang' Forest

The overall higher number of seedlings, saplings, and sub-mature trees in the impacted sites might reflect a recovery stage which has also been observed in other protected forests (Chazdon, 2003; Chazdon & Guariguata, 2016; Igu, 2017). The study established that some areas in the forest contained more trees of small to medium diameter probably because they were recovering from previous human disturbances as asserted by Igu, (2017). These findings are also in line with those of Ndembwike (2010) and Rija *et al.* (2013), which also showed that MF has been under constant threat from different human activities such as mining that dated back to the 1970s. Apart from mining activities, this forest is also threatened by other human activities such as firewood collection, tree cutting for building materials, domestic animal grazing, and collection of non-timber forest products (AWF, 2003), which were all confirmed in the present study. These human disturbances open up gaps that allow the fast-growing tree species to take over and colonize the area quickly (Mligo, 2018). For example, the presence of many sub-mature trees of pioneer species such as *M. capensis, C. macrostachyus,* and *C. africana* are indications of forest recovery from the previous disturbances after the conservation intervention by TANAPA (Riggio *et al.,* 2019; Rosa *et al.,* 2018). Furthermore, seedlings and saplings of tree species which are sensitive to disturbance (Hitimana *et al.*, 2009; Lovett, 1993; Mwakosya & Mligo, 2014; Tesfaye *et al.*, 2010) such as *B. antidysentrica, C. malosana, Chionanthus battiscombei, Ilex mitis, Lepidotrichilia volkensii, Ochna holstii, P. africana, Psychotria riparia, Rytignia uhilgii, Trimeria grandifolia, V. infausta, and V. madagascariensis* indicate the recovery of pioneer species only, which leads to an overall stable forest tree community (Gebeyehu *et al.*, 2019). The presence of many seedlings and saplings of *S. didymobotrya* and *A. longicuspe* in MF further confirm that it has previously been disturbed by human activities (Kaburi & Medley, 2011; Loth, 1999). However, other tree species seedlings and saplings that regenerated in disturbed areas such as *P. africana, C. africana*, *V. infausta*, and *C. anisata* imply a recovery and potential stabilization of the forest ecosystem, though with secondary forest growth (Chazdon, 2003). The regeneration of seedlings and saplings of species intolerant to disturbances such as *P. africana* signify that MF has a high capacity for recovering. Nevertheless, the number of seedlings can quickly be destroyed by livestock grazing, particularly within areas near to grassland patches within the forest as has been shown by Kikoti and Mligo (2015).

4.2.4 Human disturbance and severity of disturbance in Marang' Forest

(i) Human disturbance in Marang' Forest

The present study established that illegal grazing within MF still occurs regularly, probably due to the availability of quality grass within the grassland patches. Mining activities were also still frequently encountered when this study was conducted, probably because people had been used to mining legally in the forest and were still aware of the mineral potential areas. These incidences of illegal mining within the forest were likely due to irregular patrols in the interior part of the forest (Mwakosya & Mligo, 2014). Most human disturbances, either legal or illegal, involve removing and damaging tree species (Garcin *et al.*, 2018; Kleinschroth & Healy, 2017). Cattle browsing and trespasses can also damage leaves and tender twigs of seedlings and saplings, and subsequently allow the area to be dominated by unpalatable shrubs rather than trees (Kikoti & Mligo, 2015).

The dominance of *Sida massaica* which is a shrub that indicates frequent grazing was established (Kikoti & Mligo, 2015) in the surveyed grassland patches where grazing was severe. Kikoti and Mligo (2015) also established the increase of shrubs in areas affected by livestock grazing within the Kilimanjaro montane forest. Wood extraction might have affected stem density ha^{-1} and cause changes in structure and composition of the tree species within the forest as this removed valuable tree species such as *P. africana* and *O. capensis*. However, the presence of tree species such as *B. abyssinica* and *C. malosana* indicate that the disturbance within the forest is likely declining as these tree species are indicators of low disturbance in montane forest ecosystems (Kikoti & Mligo, 2015; Mwakosya & Mligo, 2014; Ndangalasi *et al.*, 2014). Nevertheless, the increase of tree species diversity in the moderate human-impacted areas within the forest might be taken into consideration into the risk of the increasing dominance of high successful pioneers and opportunistic tree species.

(ii) The severity of human disturbances in Marang' Forest

The severity of the human disturbances in MF varied and was subjected to how often the human activity occurred within the areas and its persistence since the occurrence. Generally, grazing was the most severe form of disturbance in the grassland patches of the forest. This finding is in line with those of Arroyo-Vargas *et al.* (2019) who observed that cattle assemblage was more numerous in the grassland areas of the *Araucaria-Nothofagus* Forest Reserves. This indicates that illegal grazing occurs regularly in the forest most probably because of the preferences of the livestock herders to feed their livestock on the quality grass available within the grassland patch of the forest. This finding is comparable to the observation by a study conducted in the montane forest of Mount Kilimanjaro that found that livestock headers go to the forest to look for the quality fodders for their livestock (Kikoti & Mligo, 2015). Furthermore, the mining activities in MF were found to be severe probably because people were used to legally mining in the forest in the past years when the forest was still a reserve (Ndembwike, 2010) and was well knowledgeable of the areas where minerals are found (Kideghesho & Msuya, 2012).

Most of the human disturbances, legal or illegal, when is severe in the forest ecosystem damage tree species and other biological diversities (Gogoi & Sahoo, 2018). Besides, the levels of severity of these disturbances in forest ecosystems can modify the diversity, composition, and structure either positively or negatively (Malik *et al.*, 2014). For instance, minimum human disturbance can influence the diversity of forests by opening up gaps that allow the growth of more tree species or new tree species to colonize the opened gaps (Fletcher *et al.*, 2018). On the other hand, these disturbances when are severe can destroy the forest ecosystem by degrading the composition and structure of tree species which is the major attribute of the forest ecosystem (Sahoo *et al.*, 2020).

4.2.5 Richness and abundance of large mammalian-herbivores in Marang' Forest

The observation of many potential signs of large mammalian-herbivores in the human-impacted areas of MF might be contributed by the improved protection after the upgrading of the forest's protection status. These findings are similar to those of Kiffner *et al.* (2017) who pointed out that the dispersal of wildlife inside and outside the protected areas depends on the safety level of the area. For these herbivores, the impacted areas are the safest as they can see an predator easily while browsing or grazing. In some parts of the forest within the impacted areas, there is habitat heterogeneity where the forest meets with an extensive patch of permanently waterlogged grassland areas, offering a feeding ground for buffaloes and wallowing sites for elephants, and drinking sites for both buffalo and elephants (Litjens, 2017; Williams *et al.*, 2017). This also might increase the chances for the observation of the large mammalian-herbivores signs within the impacted areas (Danquah, 2016; Litjens, 2017).

Furthermore, the likely high abundance of buffaloes and elephants in the impacted areas might have been influenced by the gaps created by wood extraction and the opening of the grassland patch where the animals could easily be seen and their signs were easily detectable. This observation is in line with other studies conducted in protected forests in Africa such as in Ndoki Forest Reserve in Congo, which shows that elephants were abundant in the open-canopy forest and swampy areas (Blake, 2002). This finding is comparable to the observation from studies conducted in Ruaha National Park in Tanzania (Roug *et al.*, 2020), Dhati Walal National Park, in Ethiopia (Shanko *et al.*, 2018), Bia National Park, and Bia Resource Reserve in Ghana (Danquah, 2016) that established that buffaloes and elephants were more numerous in areas with permanent water sources.

The frequency of encountering buffalo and elephant signs in the forested area within MF indicated that their population was low in non-impacted areas compared to impacted areas. These findings are similar to that reported by Danguah (2016) in the Bia National Park and Bia Resource Reserve in Ghana who established that elephants preferred disturbed forest areas to undisturbed areas. This signifies that the availability of resources such as food for buffalo was limited in the dense forest as most of the observed signs were footpaths and footprints, not dung piles. The animals probably utilize the area as a pass way to other areas where the food resources are available. On the other hand, the relative abundance of elephants in non-impacted areas was high compared to other large herbivore species. Probably because elephants utilize forest tree species materials for their food. For example, many feeding damages were found on

Rauvolfia cafra trees in non-impacted areas which are known to be largely consumed by elephants in the montane forest.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The present study showed that the human disturbances within the forest have declined. The declining of the human disturbances has improved the forest condition and enhance the diversity, composition, and structure of the tree species as well as the large mammalian herbivores within MF. Most of the areas impacted by human activities seem to recover and allow more tree species to regenerate and regrow as there is many seedlings and saplings within the impacted areas. Though mostly were pioneer tree species including *A. longicuspe, C. macrostachyus, and S. didymobotrya* that are often favored by disturbances. The presence of C. *macrostachyus, and S. didymobotrya* is an indication that the forest had been exposed to disturbances. Nevertheless, the potential regeneration of disturbance-intolerant tree species such as *C. malosana, C. africana, C. battiscombei,* and *P. africana* a vulnerable tree species, is an indication of recovery and stabilization of the forest, which is possibly a result of recent conservation intervention. This demonstrates that the decrease in human interferences to the forest has reduced the severity of the human disturbances to a moderate level, consequently improving tree species diversity and the forest biodiversity, including the large herbivores. The human disturbances have been reduced up to a minimum level probably as a result of changing the protection status of the forest through effective enforcement of protection and conservation regulations. Therefore, the present study calls for governmental actors and conservation agencies to reinforce protected forest conservation regulations to guarantee the long-term persistence of native, endangered, and highly valued tree species and the forest wildlife by safeguarding their habitats.

5.2 Recommendations

Different management regimes of protected forests have largely been successful, indicating that the protection of forest resources against human disturbances has maintained sustainable biodiversity. Although forest resource-rich tropical countries of the global south, including Tanzania, host an extensive network of protected forests, the protection of forest resources seems less effective. Thus, it is recommended that protected forests that are important in the conservation of biodiversity should be upgraded to higher- ranks of protection such as National Parks to secure forest resources.

Considering the roles of such protected forests in achieving biodiversity conservation, studies on changes of forest diversity, structure, composition, and forest associated ecological communities should be given priority. Furthermore, empirical evidence for recommending a better way of conserving the forest resources within these forests is essential.

Governmental actors and conservation agencies must increase enforcement of conservation regulations to secure the montane forest resources. Conservation agencies should reinforce regular patrolling of protected forests to guarantee the long-term persistence of native, endangered, and highly-valued tree species as upgrading the protection status of the reserved forests alone is not enough to protect the forest resources.

As MF being a corridor and refuge area for large mammalian-herbivores, areas with frequent occurrence of human disturbance can be identified within the forest and focus should be on promoting the recovering species.

More studies should be conducted to include both fauna and flora biodiversity. While I only focused on tree species and a few large mammalian-herbivores, the rest of the floristic composition was not assessed such as shrubs, herbs, sedges, grasses, and liana despite their importance as habitat and food for wildlife as recommended below:

(i) Botanical studies should be carried out in the MF to evaluate the spatial distribution of the most threatened tree species including *P. africana* and other valuable timber tree species.

(ii) Studies to monitor the recovery of the forest structure and composition while taking care of the dominance of pioneers and opportunistic tree species within the forest should be conducted.

(iii) The presence of elephants within the forest and their browsing pattern and movements also potentially changes in the diversity and structure of woody plants, which needs to be taken into account in future studies and

(iv) The National Park management (TANAPA) should strategize on the conservation and sustainable utilization of the forest for tourism initiatives while considering the level of human disturbances.

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APPENDICES

Appendix 1: Types of forest protection status, management regimes and authorities and management purposes of various protected forests in Tanzania

Protection status	***Management regime***	***Management authority***	***Management purpose***	***Description***	***source***
Nature reserve	Central government	Tanzania Forest Service agency	Wilderness protection	The highest protection status rank of forest established for biodiversity protection and conservation	MNRT (2006) and Santos (2017)
National forest reserve	Central government	Tanzania Forest Service Agency	Forest ecosystem sustainability and extractive utilization.	NFRs are either managed for conservation purposes or utilization purposes such as timber, fuelwood and other forest produces).	MNRT (2006) and URT (2002)
Local authority forest reserves	Local government	District council	Extractive utilization	Forest mostly managed for extractive utilization such as charcoal and timber production	URT (2002)
Village land forest reserves	Local government	village council	Extractive utilization	Forest managed for both extractive utilization and protection such as catchment areas as soil fertility	URT (2002)
Private forest reserve	Individual or company	Individual or company	Extractive utilization	Forests that are managed for production of forest produces for domestic use commercial such as poles or timber	URT (2002)

Appendix 2: Protected areas of Tanzania coded based on IUCN categories (Dudley & Phillips, 2006; URT, 2014)

IUCN category	Purpose	Protected area type	Number	Total area (ha)
Ia	Conserved for science or wilderness protection			
Ib	Conserved for wilderness protection	Forest Nature Reserve	12	30617100
II	Conserved for ecosystem protection and recreation	National Parks	22	12882718
		Ngorongoro Conservation Area	1	829200
		Marine Reserve	15	135100
III	Conserved for conservation of specific natural features			
IV	Conserved for conservation through management intervention	Game Reserve	17	4954690
		Game controlled area	42	58556502
V	Conserved for landscape/seascape conservation or recreation			
VI	Conserved for the sustainable use of natural resources	Marine Parks	3	82200

Appendix 3: List of merged forests and names of the upgraded nature reserves in Tanzania (MNRT, 2006; Santos, 2017)

Name of the forest reserve	*Gazetted year*	*Upgraded to nature reserve*	*Year of recategorization*	*Area (ha)*	*Location (Region)*
Kwamkoro Forest Reserve		Amani Nature Forest Reserve	1997	8380	Tanga
Kwamsambia Forest Reserve					
Mnyuzi Scarp Forest Reserve					
Amani Zigi Forest Reserve					
Amani East Forest Reserve					
Amani West Forest Reserve					
Chome Forest Reserve	1957	Chome Nature Reserve	2016	14282	Kilimanjaro
Magamba Forest Reserve	1942	Magamba Nature Forest Reserve	2016	9283	Tanga
Matundu Forest Reserve	1958	Kilombero Nature Forest Reserve	2007	134511	Morogoro
Iyondo Forest Reserve	1958				
West Kilombero Scarp Forest Reserve	1976				
Rondo Forest Reserve	1909	Rondo Nature Forest Reserve	2016	11742	Lindi
Mount Rungwe Forest Reserve		Mount Rungwe Nature Forest Reserve	2016	13625	Mbeya
Minziro Forest Reserve	1947	Minziro Nature Forest Reserve	2016	25717	Kagera
Mount Hanang Forest Reserve		Mount Hanang Nature Forest Reserve	2016	5871	Manyara
Nilo Forest Reserve	1998	Nilo Nature Forest Reserve	2007	6225	Tanga

Uluguru North and South Forest Reserve	1961	Uluguru Nature Forest Reserve	2008	24115	Morogoro
Bunduki I and II and Bunduki gap corridor Forest plantation	1961				
Nguru South Forest Reserve	1955	Mkingu Nature Forest Reserve	2016	23388	Morogoro
Mkindo Forest Reserve	1954				
Uzungwa Scarp Forests	1929	Uzungwa Scarp Nature Forest Reserve	2016	32763.2	Iringa

Appendix 4: The list of tree species identified within impacted and non-impacted areas in MF and their distribution within different growth stages

Botanical name	PS	OS	ID	ITD	Impacted area	Non-impacted area	Seedling	Sapling	Sub-mature	Mature
Abutilon longicuspe	X	X	√	X	√	X	√	X	X	X
Alangium chinense (Lour.) Harms	X	X	X	√	X	√	X	X	X	√
Albizia gummifera	√	√	X	X	√	√	√	X	X	√
Bersama abyssinica	X	√	X	X	√	√	√	√	√	√
Brucea antidysentarica	X	√	X	√	√	X	√	X	X	X
Canthium oligocarpum	X	√	X	X	√	X	X	X	√	√
Casearia battiscombei	√	X	X	X	√	√	√	√	√	√
Cassipourea malosana	X	X	X	√	√	√	√	√	√	√
Celtis Africana	√	X	X	X	√	√	X	√	√	X
Chionanthus battiscombei (Hutch.) Stearn	X	X	X	√	√	√	√	√	√	√
Clausena anisate	X	√	X	X	√	X	√	X	X	X
Croton macrostachyus	√	X	X	X	√	√	√	√	√	√
*Deinbollia borbonica (*Scheff.)	X	√	X	X	√	√	√	√	√	√
Dovyalis abyssinica	√	X	X	X	√	√	√	X	X	√
Dracaena steudneri ((Engl. (M))	X	√	X	X	X	√	X	X	X	√
Ehretia cymose	X	√	X	X	√	X	√	X	X	X
Ekebergia capensis	√	X	X	X	√	√	X	X	√	√
Ensete ventricosum	X	X	X	√	X	√	X	X	X	√
Erythrococca fischeri (Pax)	X	√	X	X	√	√	√	√	√	√
Eucalyptus camaldulensis (Dehnh)	X	X	√	X	√	X	X	X	√	√
Eucalyptus saligna (Sm.)	X	X	√	X	√	X	X	X	√	√
Euclea divinorum (Hiern)	X	√	X	X	√	√	X	X	√	√
Ficus sur (Forssk.)	X	√	X	X	√	√	√	√	√	√
Ficus thonningii	X	√	X	X	√	X	X	√	√	X
Galiniera saxifrage	X	√	X	√	√	√	X	X	√	X
Ilex mitis (L.) Radlk.	X	X	X	√	√	√	√	√	√	√

Lepidotrichilia volkensii (Gürke) J.-F.Leroy)	X	X	X	√	√	X	√	X	X	X
Macaranga capensis	√	X	X	X	√	√	√	X	√	√
Maytenus heteropylla (Eckl. and Zeyh.) N.K. B	√	X	X	X	√	√	√	X	X	X
Mystoxylon aethiopicum (Thunb.) Loes.	X	√	X	X	√	√	X	√	X	√
Neoboutonia macrocalyx	√	X	X	X	√	√	√	X	X	√
Nuxia congesta	√	X	X	X	√	X	X	X	X	√
Ochna holstii (Engl.)	X	X	X	√	√	√	√	X	X	X
Olea capensis	X	√	X	X	√	√	X	√	X	X
Oncoba spinosa (Forssk.)	X	√	X	X	X	√	X	√	X	X
Pavetta abyssinica (Bridson)	X	X	X	√	X	√	X	√	√	X
Phoenix reclinata (Jacq.)	X	√	X	X	√	√	X	X	X	√
Phyllanthus engleri (Pax)	X	X	X	√	X	√	X	X	√	√
Prunus africana	X	X	X	√	√	√	√	X	X	√
Psychotria riparia	X	X	X	√	√	√	√	X	X	X
Rauvolfia caffra (Sond.)	X	√	X	X	√	√	√	√	√	√
Ritchiea albersii	X	X	X	√	X	√	X	√	X	X
Rothmania fischeri	X	X	X	√	X	√	X	√	X	X
Rytignia uhilgii	X	X	X	√	√	√	√	√	X	X
Senna didymobotrya	√	X	√	X	√	X	√	√	X	X
Sida massaica	X	X	√	X	√	X	X	X	X	X
Solanecio mannii	√	X	√	X	√	X	√	X	X	X
Strombosia scheffleri (Engl.)	X	X	X	X	√	√	X	√	√	X
Syzygium guineense (Willd.) DC	X	√	X	X	√	√	X	√	√	X
Tabernaemontana ventricosa	X	√	X	X	√	√	√	√	√	√
Teclea nobilis	X	X	X	√	√	√	X	√	√	√
Trimeria grandifolia	X	X	X	√	X	√	√	X	X	X
Vangueria infausta	X	√	X	X	√	√	√	X	X	X
Vangueria madagascariensis	X	X	X	√	√	√	√	√	√	√
Vepris simplicifolia	X	X	√	X	√	√	√	√	√	√
Vernonia myriantha	√	X	√	X	√	X	√	X	X	X
Xymalos monospora	X	X	X	√	√	√	√	√	√	√

Whereby there are pioneer species (PS), Opportunistic species (OP), Indicator species of disturbance (ID) and Intolerant species to disturbance (ITD); X = Absent, √ = Present

Appendix 5: List of tree species and their dominance index recorded in MF

	Index of dominance (ID)	
Botanical name	**Impacted area**	**Non-impacted area**
Alangium chinensis	0.000	0.006
Abutilon longicuspe	0.012	0.000
Albizia gummifera	0.017	0.016
Bersama abyssinica	0.031	0.045
Brucea antidysentarica	0.001	0.000
Canthium oligocarpum	0.002	0.000
Casearia battiscombei	0.040	0.083
Cassipourea malosana	0.024	0.021
Celtis africana	0.005	0.003
Chionanthus battiscombei	0.032	0.022
Clausena anisata	0.027	0.000
Croton macrostachyus	0.074	0.013
Deinbollia borbonica	0.022	0.009
Dovyalis abyssinica	0.002	0.004
Dracaena steudneri	0.000	0.006
Ehretia cymosa	0.005	0.000
Ekebergia capensis	0.012	0.021
Ensete ventricosa	0.001	0.012
Erythrococca fischeri	0.015	0.016
Euclea divinorum	0.005	0.006
Ficus sur	0.006	0.006
Ficus thonningii	0.004	0.003
Flacoortia indica	0.002	0.000
Galiniera saxifraga	0.011	0.015
Ilex mitis	0.007	0.004
Lepidotrichilia volkensii	0.001	0.000
Macaranga capensis	0.005	0.006
Maytenus heteropylla	0.004	0.004
Mystoxylon aethiopicum	0.004	0.001
Neoboutonia macrocalyx	0.017	0.004
Nuxia congesta	0.002	0.000

Ochna holstii	0.001	0.001
Olea capensis	0.021	0.033
Oncoba spinosa	0.000	0.003
Pavetta spp	0.000	0.003
Phoenix reclinata	0.001	0.003
Phyllanthus delypyams	0.002	0.000
Phyllanthus engleri	0.000	0.013
Prunus africana	0.001	0.031
Psychotria riparia	0.023	0.007
Rauvolfia caffra	0.035	0.046
Ritchiea albersii	0.000	0.004
Rothmania fischeri	0.000	0.001
Rytigynia uhligii	0.013	0.010
Senna didymobotrya	0.055	0.000
Solanecio mannii	0.002	0.000
Strombosia scheffleri	0.004	0.006
Syzygium guineense	0.002	0.007
Tabernaemontana ventricosa	0.155	0.163
Teclea nobilis	0.051	0.061
Trimeria grandifolia	0.007	0.001
Vangueria madagascariensis	0.021	0.019
Vangueria infausta	0.000	0.001
Vepris simplicifolia	0.040	0.082
Vernonia auriculifolia	0.012	0.000
Xymalos monosphora	0.159	0.172

RESEARCH OUTPUTS

i) Journal Articles

Nchimbi G., Moyo. F., Anna T., (2021). Tree species diversity, composition and structure across human impacted and non-impacted areas in upgraded Marang' Forest, northern Tanzania. ***Journal of Biodiversity and Environmental Sciences*** **1-15**

ii) Poster Presentation