INFLUENCE OF GAP SIZE ON MICROSITE CONDITIONS, REGENERATION, STRUCTURE AND SPECIES DIVERSITY OF WOODY VEGETATION IN SOUTH-WESTERN MAU FOREST, KENYA

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented in this university or any other for the award of a degree.

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Recommendation

This thesis has been submitted with our approval as University supervisors.

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DEDICATION

I dedicate this work to my parents and siblings; Lucy, Hellen, David, Rose, Beatrice and Keziah for their unwavering support during my studies. Receive much blessings from God.

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ABSTRACT

Tropical forests are facing amalgam of disturbances cropping from human and natural stresses. South-Western (SW) Mau Forest reserve is experiencing poor natural regeneration and loss of species diversity due to these disturbances. The objective of this study was to determine the influence of canopy gap sizes on microsite conditions, regeneration, structure and diversity of woody vegetation species in SW Mau Forest reserve. The study involved field experiment employing Nested Research Sampling Design (NRSD) in disturbed and undisturbed sites. In disturbed sites, a plot of 500 by 500 m was nested and gaps randomly sampled in Itare, Maramara and Ndoinet blocks. A Handheld GPS device (Garmin e-Trex 10) was used to obtain gap coordinates. Microsite conditions (soil moisture, soil temperature and light intensity), regeneration, species diversity and tree phytosociological parameters (height, diameter at breast height) were measured in these micro-plots (gap sizes). Light intensity was measured using Luxmeter (model HTC LX-104) while soil moisture and soil temperature were measured using Kensizer soil tester (3-in-1 soil moisture/light/pH…). Regeneration was determined using two quadrats; 5 by 5 m and 1 by 1 m thrown four times and eight times for saplings and seedlings respectively. Tree height and dbh were measured using Suunto clinometer and diameter calliper/tape respectively while Shannon-Weiner Diversity Index was used for species diversity. In undisturbed sites, another plot of 500 by 500 m was laid in every block and sub-plots of 20 by 30 m thrown randomly and parameter determination repeated. Data was analysed using RStudio and Microsoft excel. A total of 41 canopy gaps and 19 sub-plots of 20 by 30 m were randomly selected as the sample units. The study revealed a significant difference in soil temperature (Kruskal-Wallis chi-squared=19.00, df=3, *P*=0.00*) among the gap sizes with large gap sizes recording the highest mean (18.60^{0}C). Additionally, there was a significant difference in light intensity between disturbed and undisturbed sites (W=555.00, *P*=0.01) with disturbed sites recording the highest mean light intensity (804.00 Cd). Forest structure also differed significantly between disturbed and undisturbed sites (*P*=0.01). Disturbed sites showed a more complex forest structure; Holdridge's Complexity Index (HCI) 332.70 compared with the undisturbed sites (204.60). Non-significant results were attributed to *Piper capensis* invasion in SW Mau Forest reserve. It was concluded that canopy cover influenced gap micro-environment by creating shade and utilizing soil moisture which in turn influenced woody vegetation population parameters. Therefore, there is need for enrichment planting using highly valued indigenous species in most disturbed sites for faster regeneration and forest continuity.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS/SYMBOLS

CBD	Convention on Biological Diversity
Cd	Candela
CFAs	Community Forest Associations
cm	centimetre
D	Simpson's Dominance
dbh	diameter at breast height
df	Degree of freedom
Dist.	Disturbed
E.	Emergent canopy layer
eco	ecosystem
EM	Ellipse Method
EST	Ecological Shade Tolerant
FCMA	Forest Conservation and Management Act
Garea	Gap area
ggplot	grammar of graphics plot
GIS	Geographical Information System
GPS	Global Positioning System
Gsize	Gap size
H'	Shannon-Weiner's diversity index
ha	hectares
HC	Holdridge's Complexity
HCl	Holdridge's Complexity Index
HE	Shannon Equitability
IPCC	Intergovernmental Panel on Climate Change
ISLA	Initiative for Sustainable Landscape
KFS	Kenya Forest Service
KIFCON	Kenya Indigenous Forest Conservation
km^2	square kilometres
L	Large
LGS	Large Gap size
LI	Light Intensity
M	Medium
M.	Main canopy layer

m^2	square metre
MGS	Medium Gap size
mm	millimetre
NPP	Net Primary Productivity
NRSD	Nested Research Sampling Design
PA	Plot Area
PAW	Photosynthetic Active Wavelength
PFM	Participatory Forest Management
PPFD	Photosynthetic Photon Flux Density
S	Small
Sa	Sapling
SDGs	Sustainable Development Goals
SGS	Small Gap size
Spp.	Species
SW	South-Western
TGA	Total Gap Area
U.	Under canopy layer
Undist.	Undisturbed
UTCF	Urban Tree Challenge Fund
W	Wilcoxon

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Tropical forests are critical terrestrial ecosystems with multiple importance of eco goods and services accruing from them. Examples of ecosystem goods include; firewood, charcoal, fodder, food (fruits), medicine, poles and raw materials for industries, such as timber, resin and gum (Robi & Edris, 2017). They also play an integral role in providing ecosystem services, such as global water cycle, carbon sequestration, climate regulation biogeochemical cycles and energy flow (Wang *et al*., 2012). Nonetheless, these forests are facing disturbances mostly related to human activities which have compromised their stability and resilience to disturbances (Chaudhry, 2019). Forest regeneration and species diversity are important in forests as they enhance natural forest ecology sustainability. Regeneration particularly helps in conservation of indigenous species; thus, promotes forest resilience, stability and diversity in the ecosystem. However, regeneration and species diversity are influenced by forest disturbances due to their reliance on disturbance regimes (Hammond *et al*., 2021).

Unfortunately, tropical forests are under serious threats especially from human disturbances (Hammond *et al.*, 2021). Approximately 22% of the adjacent rural communities' income comes from forests in developing countries (Silva *et al.*, 2019). Globally, about 2.4 billion people uses forest as sources of firewood and by 2010, about 0.14% of forest cover was lost as a result of anthropogenic activities. Over 7-15 million ha is lost annually due to deforestation (Kimutai & Watanabe, 2016). Continued increase in human population has induced more pressure on forest resources resulting into more forest fragmentation (Vuyiya *et al.*, 2014). Abiotic and biotic disturbances, such as wildfires, storms, climate change and pathogens have also contributed to loss of some indigenous woody species in forests (Laurance & Peres, 2006). Kenyan forests are also undergoing threats due to unsustainable utilization of forest resources (Kogo *et al.*, 2019); overexploitation, forest fragmentation (Teucher *et al*., 2020), land degradation and introduction of invasive species. Kenya lost approximately 241,000 ha of its forests between 1990-2010 due to human disturbances majorly deforestation and over-utilization of forest resources (Kimutai & Watanabe, 2016).

Nevertheless, forest disturbances either natural or artificial creates canopy openings which initiates growth cycles in forests. These canopy openings/gaps ecologically define forest structure, species diversity and composition (Hammond *et al*., 2021). This is because the openings expose forest floors to direct sunlight which encourages proliferation and coexistence of diverse woody species. Forest successions normally transpire under the canopy openings (Hubbell *et al.,* 1999). Species composition may vary depending on canopy gap sizes, shapes, orientations and aspects attributed to response of species to different disturbances and microsite conditions within the forest (Hammond *et al.*, 2020). Therefore, there is need to understand species composition and diversity under canopy gaps to critically evaluate forests sustainability, conservation and management of forest ecosystems (Hammond *et al.*, 2021). Canopy gaps provide environmental resources that initiates succession processes in forests which enhance species regeneration and diversity (Hubbell *et al.,* 1999).

To enhance forest management, Participatory Forest Management (PFM) approach was introduced in 1997 (Matiru, 1999). By 2005, PFM approach was legalized and Kenya Forest Service (KFS) was formed to oversee the management of all state forests (Matiru, 1999). The Act also led to creation of Community Forest Associations (CFAs) to offer conservation, protection and management of designated forests in Kenya (Kimutai & Watanabe, 2016). As a result, spatial plans, conservation strategies, policy and institutional frameworks were put in place for better management and conservation of forests and their resources (Teucher *et al.*, 2020). Moreover, various national laws and regulations have been passed; in 1998, there was a ban on logging of indigenous public and community forests (Teucher *et al*., 2020). Additionally, charcoal regulations was passed in 2009, Forest Conservation and Management Act (FCMA) in 2016 (Kenya Forest Service [KFS], 2021) all for conservation of forest resources (Teucher *et al*., 2020). Paradoxically, there has been slow implementation of PFM associated with poor legislation, weak Organization of the CFAs, conflict of interest, lack of finance and poor accountability laming the management process of forests, ergo more degradation (Kimutai & Watanabe, 2016).

Even though several studies have been done on canopy gap influence on regeneration, species diversity, dominance (Bobiec, 2007; Devagiri *et al.*, 2016; Hammond *et al*., 2020; Hammond *et al*., 2021) and forest structure (Bi *et al.,* 2020), few research in SW Mau Forest reserve exist to determine forest gap sizes and how they influence microsite conditions, regeneration, forest structure and species diversity. Studies done in Mau Forest have been those revolving around human encroachment (Kinyanjui, 2009), effects of human activities on forest composition and natural regeneration (Kipkorir *et al*., 2018; Ronoh *et al.,* 2018). The main objective of this study was to determine canopy gap sizes resulting from the forest disturbances and how they influence forest microsite conditions, species regeneration, forest structure and species diversity. This was to contribute to the overall forest regeneration and conservation of biodiversity.

1.2 Statement of the problem

South-Western Mau Forest reserve has been experiencing continuous exploitation of woody vegetation for timber, charcoal, medicine, fodder, and firewood among others, targeting specific highly valued tree species. Approximately 25% of the reserve was excised by the government for settlement of the Ogiek community displaced by ethnic clashes (Githumbi *et al.,* 2021; Kinjanjui *et al.,* 2013). Besides, the reserve has been targeted by the neighbouring communities due to its biodiversity, consequently, experiencing deforestation, selective logging, burning and clearing for farming creating many canopy openings (Sandel & Svenning, 2013). The anthropogenic degradation and natural disturbances in the forest have led to creation of canopy gaps of different sizes. As a ramification, there is poor natural regeneration and loss of species diversity in SW Mau Forest reserve.

In this study, different canopy gap sizes were examined based on the number of trees dead/injured/cut or removed and canopy gap sizes calculated for categorization in disturbed sites. As a control, undisturbed sites were also examined for comparison for significant differences. The objective was to determine, through ecological survey, how different canopy gap sizes influenced microsite conditions (soil moisture, soil temperature and light intensity) and woody vegetation population parameters (regeneration, forest structure and species diversity) in SW Mau Forest reserve. This was to provide solutions to the above ecological and socio-economic problem.

1.3 Objectives of the study

1.3.1. General objective

To contribute to the overall conservation of forest ecosystems by determining the influence of various forest canopy gap sizes on microsite conditions and woody vegetation population parameters.

1.3.2 Specific objectives

i. To characterize forest gap sizes within SW Mau Forest reserve and their influence on the forest microsite conditions.

ii. To determine the effects of various gap sizes on woody vegetation population parameters (regeneration, forest structure and species diversity) in SW Mau Forest reserve.

iii. To compare microsite conditions (soil moisture, soil temperature and light intensity), regeneration, vegetation structure and species diversity of woody vegetation in disturbed and undisturbed sites of SW Mau Forest reserve.

1.4 Research hypotheses

i. Forest gap sizes have no influence on microsite conditions within SW Mau Forest reserve.
ii. Gap sizes have no influence on woody vegetation population parameters (regeneration, vegetation structure and species diversity) in SW Mau Forest reserve.
iii. There is no difference in microsite conditions (soil moisture, soil temperature and light intensity) and woody vegetation population parameters (regeneration, vegetation structure and species diversity) between disturbed and undisturbed sites of SW Mau Forest reserve.

1.5 Significance of the study

South-Western Mau Forest reserve is endowed with a broad diversity of flora and fauna. Like other forests, it provides ecosystem goods and services (Kimutai & Watanabe, 2016). It serves as a major water catchment area in the region and a source of carbon sink from its components. However, the forest has been facing diverse disturbances that has brought adverse consequences to it. The disturbances have been caused by coalescence of factors which include human, biotic and abiotic factors which compromise its capacity to provide ecosystem goods and services through loss of biodiversity (Bewernick, 2016).

To help save the situation, urgent information is needed on the current status of the forest and its ability to continue through regeneration. This is to widen species diversity and to single out which species are severely impacted by various gap sizes in order to prescribe enrichment and conservation measures. The study focused on bringing to understanding different gap sizes in SW Mau Forest reserve and how they influence woody vegetation population parameters for biodiversity conservation.

This study contributes to the overall Government target of attaining 15% forest cover by 2030. It also contributes to Sustainable Development Goals (SDGs) pillars which include; abatement of climate change impacts, ensure healthy living with a cleaned atmosphere through increasing forest cover, ensuring sustainable management of water catchment areas and protection, as well as management and restoration of forest ecosystems for biodiversity conservation. It will also be useful to Convention on Biological Diversity (CBD) by meeting its target of reducing natural habit loss (forest) and attain sustainable management of forests among targets.

The expected result of this study to provide information to decision makers at the County and National level on the management methods that can be employed to protect and conserve the forest.

1.6 Scope/Limitations/Assumptions

1.6.1 Scope of the study

The study was conducted in South-Western Mau Forest reserve which included Ndoinet, Maramara and Itare forest blocks. This was done late March to early April of 2022 before the onset of long rains. The study focused on two regions of the forest; disturbed and the undisturbed sites towards the interior. In disturbed sites, gaps were included as the sample units. The study also encompassed canopy gaps created by either natural or artificial disturbances and various gap sizes within the forest were considered. In the study, only indigenous woody vegetation was included. Additionally, trees within/neighbouring the gaps were included in the study for parameter determination in disturbed sites. Regeneration of species was included taking in consideration saplings and seedlings as the variables.

1.6.2 Limitations to the study and their delimitations

i. There were inadequate means of transport to some study sites due to steep and rugged terrain. This was solved through using private transport means.

ii. Unpredictable weather patterns especially too much rainfall which made the roads to some sites impassable. This was solved by starting fieldwork very early in the morning (latest 7 am).

iii. Presence of wild animals and traps in the interior parts of the forest hindered accessibility. Security was fostered by forest guides who were armed and had the knowledge on traps' locations.

1.6.3 Assumptions

i. All the woody vegetation species within the forest were indigenous growing in situ and free from human manipulation.

ii. All the gap sizes within the forest were randomly distributed and created by either artificial or natural disturbances.

1.7 Operationalization of terms

Canopy cover	Ground percentage covered by outermost layer of natural spread of twigs, foliage and branches.
Disturbance	Forest damage by biotic or abiotic factors negatively affecting forest vigour and productivity.
Disturbed forest	Forests with various intensity of logging indicating wide forms of secondary forests.
Forest Structure	Vertical stratification of trees and other plants within forested areas.
Forest	Land with more than 10% of canopy cover with an area of at least 0.5 ha.
Gap	An opening or hole in forest canopy extending through all levels towards forest floor at a height of at least 1.5 metres above the ground.
Large gap size	Canopy openings created by large-scale disturbances covering a relatively large geographical area.
Medium gap size	Canopy openings created by medium-scale disturbances not covering a relatively large geographical area.
Regeneration	Re-establishment of a new cohort of tree species within forest stand by natural means following a disturbance whether natural or human induced.
Sapling	A young tree with a height of >1 to 3 metres.
Seedling	Any sapling of a tree with developed roots for planting purpose with a height less than 1 m.
Small gap size	Refers to canopy opening created when a single or few canopy trees die/injured/ removed from a forest.
Species diversity	All tree forms found within forests adapted to the changing environmental conditions performing different roles.
Tree	Woody perennial with either one erected trunk or several stems when coppicing with more or less definite canopy cover and a height > 3 m.
Undisturbed forest	Forested areas indicating natural dynamics of species composition, indicators of dead wood, senescence, regeneration without human intervention and able to maintain its characteristics.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter is about studies that have been done in relation to the topic under study. It includes; indigenous forest cover in Kenya, causes of gaps in forests, gap dynamics, gap sizes within forests. The chapter also include gap size influence on woody vegetation population parameters; regeneration, vegetation structure and diversity of woody vegetation species within the forest. The theoretical framework, research gaps and conceptual framework are also entailed herein.

2.2 Indigenous forest cover in Kenya

Woody vegetation in Kenya entails; forests, woodlands, bushlands and wooded grasslands. Therefore, forests are defined as continuous stands of trees at least 10 m high with interlocking crowns (Matiru, 1999). The types of forests found in Kenya entails; lowland rain forest found in the western, montane forests (Mount Elgon, Mount Kenya, Mau Forest), dryland forests (Marsabit, Maralal) and riverine forests (Tana, Ewaso Nyiro, Turkwel). Montane forests mostly consist of *Ocotea*-*Polyscias* and *Podocarpus*-*Cassipourea* associations with *Juniperus*-*Olea* association dominating the top layer (Teucher *et al*., 2020).

While about 64% of the forest reserves in Kenya is covered by indigenous forests, 25% is covered by non-forest vegetation and 9% are plantation forests (Matiru, 1999). Even if there is an increment in Kenya's forest cover to 8.83% (KFS, 2021) of its total land cover, closed canopy is still trailing low at 2% of the total area (Maua *et al*., 2020). To expound more, Kenya Indigenous Forest Conservation Programme (KIFCON) estimate that the total gazetted native forest cover is 1.06 million ha excluding mangroves. Consequently, the area assumed by indigenous closed canopy forests not gazetted is estimated to compound 180,000 ha of the entire land under forest (Kogo *et al.*, 2019). Truly, indigenous forests are facing a lot of pressure from human activities; thus, potential conflict between closed canopy forests and agriculture (Obati, 2007).

Studies reveal that human interest in forest resources have resulted into dwindling in forest lands. For instance, between the year 1994-1999, about 6,442.6 ha (Annex VII) was de-gazetted and between 1995-1999, 44,502.8 ha (Annex XI) was excised in Kenya on soil conservation programme (Matiru, 1999). It is estimated that 2.9 million people reside in close proximity to closed forests who depends on forests for livelihood. Indeed, this could have been one of the reasons for increased forest degradation and fragmentation as reported by

Mutugi and Kiiru (2015). The Anthropocene have converted forests into cultural entities rather than natural entities leading to increased forest fragmentation (Peltorinne, 2004). To make adjacent communities feel part of the conservation, it is true that there should be inclusive forest management, whereby Community Forest Associations (CFAs) are used. This should include youths, women and men.

2.3 Factors causing forest canopy gaps

In any natural forest, tree mortality can be associated with exogenous or endogenous factors (Kneeshaw & Bergeron, 1998). Additionally, death may be due to biological or physical factors acting on the trees. Death can leave the tree standing/lying/in soil, snapped off by the effects of wind, flood, pathogens, insect, drought, wildfire as reported by most authors (Franklin *et al*., 1987; Lutz & Halpern, 2006; Wang *et al*., 2012). Even though most disturbances in forests are as a result of natural factors, human activities have also been included. For example, Solomon *et al.* (2018) says that deforestation is one of the worst human activities causing wide canopy openings with others being; logging, agriculture, settlements (Geeraert *et al.*, 2019) and land use changes (Vuyiya *et al.*, 2014).

2.3.1. Natural causes of forest canopy gaps

Wind damages cause economic loss in forests all over the world facilitated by wind throw (Feldmann *et al.*, 2018). This may occur when the lateral forces on the crown supersedes its anchorage in the roots, hence snapped off. In fact, this can be determined by the Archi-tectonic and anatomic characteristics of the tree species, soil type and physical characteristics of that tree which dictates whether the tree will be uprooted or broken at the base (Franklin *et al*., 1987). Consequently, wind in combination with uneven growth in the forest is one of the factors that increases mortality of trees due to edge effect (Solomon *et al.*, 2018) and this is called Gap Contagiousness (Hunter *et al.*, 2015).

Drought is another natural re-occurring event that is extreme in forest environments and influences ecological systems. Precisely, drought has strong implications on forests since it impacts moisture availability in the soil facilitating tree mortality (Wang *et al*., 2012). It is also true that drought incidences cause adverse ecological impacts in all ecological levels, such as ecosystems and biomes (Kinyanjui, 2009). Presently, incidences of drought have been rampant due to climate change reducing the global Primary Net Productivity (PNP) of forests as shown by Wang *et al*. (2012) and Lu *et al*. (2018).

Many studies have reported that fire has adverse impacts on forests. It can be a natural event in tropical forests caused by increase in the above ground nutrients, contained in plants biomass catalysed by increased temperatures (Hammond *et al.*, 2020). Fire leads to loss of approximately 16 million ha of forest land globally per year. It can consume part of or the whole vegetation leaving behind bare but undestroyed soil (Vuyiya *et al.*, 2014). Fire is known to limit seed dispersal effectiveness, consequently, affecting the composition and diversity of naturally regenerating plant species. As a fact, this increases susceptibility of the forests to droughts, floods among other disturbances as earlier reported by Kinyanjui (2009). It is, therefore, a major barrier in regeneration of forests because it affects the abundance and richness of species. It also reduces the number of species being recruited from soil seed bank and propagules impoverishing forest community (Hooper *et al*., 2004).

Even though other natural processes, such as senescence, pests and diseases can also lead to tree mortality (Franklin *et al*., 1987), other studies by Lutz and Halpern (2006) report the vitality of tree mortality. The authors states that mortality has a role in the establishment and development of forests as it also performs a role in the turnover of species composition, structure, nutrient cycling while piling biomass on forest floor. However, Wang *et al*. (2012) stated that increase in tree mortality leads to a threatened forest stability. This is true because, seedlings are exposed to strong environmental conditions, such as extreme temperatures and low soil moisture affecting transition to other stages (Gray & Spies, 1996). It is also supported by Khaine *et al.* (2018) that the environmental conditions lead to changes in the over-storey structure affecting composition, diversity and regeneration capacity of some tree species within forests.

2.3.2. Artificial causes of forest canopy gaps

Forests have a global endowment harbouring above 50% of the world's species richness (Geeraert *et al.*, 2019). However, human settlement has been the most challenge that is affecting tropical natural forests. Rapid urbanization, encroachment, deforestation, settlements, agriculture have resulted into dramatic shrinking in the forests creating wide canopy openings, which threatens biodiversity (Yu *et al.*, 2020). Moreover, the anthropogenic footprint has resulted into massive changes in forests, whereby forest lands are being transformed in other land uses (Sandel & Svenning, 2013).

Furthermore, human population increase coupled with poverty, shortage of food, wood fuel, fodder and timber have led to destruction of forest lands (Laurance & Peres, 2006). Truly, this adversely degrades primary forests affecting forest ecosystem functions as stated by Zhu *et al.* (2019). Besides, the degradation results into multiple problems, such as dwindling in vegetation cover, loss of species diversity, effects on soil, such as through soil erosion among others (Vuyiya *et al.,* 2014). Additionally, most of the poor people living near marginal forest lands exploit forests for resources causing more fragmentation (Peltorinne, 2004). Previous studies indicate that most forest lands are neighboured by poorest families who depend entirely on forests for livelihood, thus more degradation (Mutugi & Kiiru, 2015; Vuyiya *et al.,* 2014).

Besides, there is increased soil compaction and deterioration of soil biochemical properties (destructions caused by fire negligence), ergo affecting natural regeneration of woody vegetation species (Hooper *et al*., 2004). Even if agriculture is the backbone of Kenya’s economy, it is considered as the main driver to deforestation. It is reported that about 2.8 billion ha of forest lands have been lost in agriculture imposing threats to carbon pools and biological diversity (Sandel & Svenning, 2013). In tropical forests, between 1980-2000, there was an expansion of agricultural land, whereby 55% of the farms were obtained through deforestation (Geeraert *et al.*, 2019).

In addition, deforestation can induce further degradation due to edge effect which make forests more vulnerable to other disturbances, such as wind as reported by Solomon *et al.* (2018). Over the past 150 years, changes in land use, such as logging and agriculture (Sandel & Svenning, 2013); clearing forests for pasture, fires have adversely affected forest cover (Vuyiya *et al.,* 2014). As a matter of fact, deforestation and degradation of forests are the second largest emitters of carbon dioxide in the atmosphere as they result into loss of above ground biomass which is carbon pool (Solomon *et al.*, 2018).

2.4 Forest gap dynamics

Gap dynamics is the process by which gaps left in forest canopy are filled by other trees that were initially suppressed or from seeds, coppices or lateral branches (Yamamoto, 2000). The gaps created makes sunlight, moisture and other resources available for the shadowed species (Zhu *et al*., 2019). Besides, gap dynamics is initiated by disturbances within the forest. Therefore, disturbance can be defined as any event that disrupts forest ecosystem, community or population structure, consequently resulting into canopy openings which affect resource availability within the forest (Kathke, 2010).

Many studies unanimously agree that the rate of growth in gaps is driven by the ability of a particular species to compete well for the available resources and its resilience towards competition (Busing & Brokaw, 2002). Therefore, gap dynamics explains why shade intolerant species can still be able to regenerate and maintain their population under mature old-grown forest trees (Gray *et al.,* 2002; Hunter *et al.,* 2015). This is because at old age, most trees are missing twigs and branches allowing solar radiation to reach the understorey concurring with the findings by Yamamoto (2000).

Therefore, tree species perform differently due to gradients in resource availability within canopy gaps (Runkle, 1989; Whitmore, 1989). This is what contributes to the differences in species coexistence (Brokaw & Busing, 2000). On the other hand, community dynamics are changes in the community structure and composition over time. These changes may be induced by environmental disturbances, such as fires, volcanoes, earthquakes, climate change and storms (Franklin *et al*., 1987). Community with a stable structure is said to be at equilibrium but after disturbances, that community may not recover its original state. Therefore, Succession describes the sequential appearance and disappearance of species in a community over time, hence expounding more on gap dynamics.

2.5 Forest gap sizes

Gap size is one of the gap characteristics considered to be the most important given its significant role in characterizing resource availability (Denslow, 1987). While indicating the intensity of a disturbance and the extent of environmental heterogeneity (Yang *et al.*, 2017), gap size also depends on the magnitude and the extent of a disturbance (Devagiri *et al.*, 2016; Yamamoto, 2000). It is beyond doubt that gap size correlates with resource availability in forest ecosystem, therefore, crucial features that determine forest composition (Whitmore, 1989).

Because gap size influences microsite conditions, it results into difference in successional patterns in temporal dimension (Kneeshaw & Bergeron, 1998). Indeed, this is due to its influence on distribution of resources in the forest resulting into variation in species diversity. The availability of resources differs within and among gap sizes which in combination with competition techniques leads to specialization on the various resources available (Runkle, 1989), this is termed as ‘gap niche partitioning’ (Whitmore, 1989).

The frequency and distribution of forest gaps depends on the geographical location (Hammond *et al.*, 2020) and the topography of the area (Lorimer, 1989). Topographic and edaphic changes dictate the rates and distribution of gaps in a region. Therefore, forests on montane regions are more vulnerable to wind throws because of high wind intensity (Denslow, 1987). In addition, loose soils are likely to have more gaps with different characteristics (Franklin *et al*., 1987). In collaboration with this statement, loose soils have poor anchorage to vegetation, therefore, susceptible to wind snapping due to edge effect as demonstrated by Solomon *et al.* (2018).

On the other hand, old forests have high chances of gap creation caused by senescence (Franklin *et al*., 1987). It is true that such forests are vulnerable to natural disturbances, such as snagging which are frequent. Functional processes in forest ecosystems are, therefore, controlled by local canopy gap dynamics (Silva *et al.*, 2019).

2.5.1 Small gap sizes and their influence on forests

Small gaps occur when a single or few canopy trees die, injured or removed from a forest (Yamamoto, 2000), small canopy openings called gaps are created (Kern *et al*., 2012). According to Hammond *et al.* (2020), patches are created in the forest canopy whose coverage depends on the size and the number of trees removed. Small gaps are predominant spanning from branch breakage, selective logging to attack by pests and diseases among others in small scale (Yang *et al.*, 2017).

Reduced resources, such as light in small gap sizes lowers stand productivity and the suppressed seedlings and saplings may not all transit to higher levels (Lorimer, 1989). This is true since the population of saplings in forests is usually lower compared with seedling population. Also, saplings population is somehow higher than pole size trees during transitions. Variability in resources favours the establishment of different species of shade tolerance and according to 'Gap Partitioning Hypothesis' (Berdugo & Dovciak, 2019), saplings of different life history coexist between closed canopy and gap centre (Kern *et al*., 2012).

Small scale disturbances causing tree fall results in soil movement, consequently redistributing nutrients and organisms attached to it (Valverde & Silvertown, 1997). This enhances soil nutrient, microbial biomass and the activity of enzymes. Therefore, small gap sizes are appropriate in forest management (Muscolo *et al.*, 2014). Very tiny gaps from the fall of one tree may be filled by lateral ingrowth of the surrounding trees that cannot get enough space to spread their branches (Valverde & Silvertown, 1997).

Even though studies have been done on canopy gap sizes, there still exists a lacuna as to what coverage exactly constitute small gap size in forests. Several authors have given different findings; however, none seem to corroborate with other results. For instance, Hammond *et al.* (2020) reports that small gap sizes are <700 m^2 in area, Devagiri *et al.* (2016) argues that it is between 25 -< 300 m^2, while Yamamoto (2000) review it to be <0.1 ha in area. Additionally, Sapkota and Oden (2009) reports it to be 60-200 m^2 while Guo *et al.* (2019) mentions it to be <100 m^2. These results are not unanimous and one cannot really understand the exact area for small gap sizes. Even if the gaps occur differently in diverse forest types, there should be a definite area that constitute small gap size. This study was, therefore, expected to bridge the gap of what coverage constitute small gap size in SW Mau Forest reserve, an Afromontane forest.

2.5.2 Intermediate gap sizes and their influence in forests

Intermediate gap sizes are the links between small and large gap sizes (Kern *et al*., 2012). They can maintain wetter soils than small and large gap sizes. This is because the total input of rainfall is less in small gap sizes due to interception losses and in large gaps due to increased evaporation. Seedling density is larger in medium to large gap sizes compared with small gap sizes (Gray *et al*., 2002). This is in order because of enough space for seeds to settle without interceptions implying that medium gap sizes are important for regeneration of most tree species (Guo *et al.*, 2019).

Moreover, medium gap sizes are important in reproduction and survivorship of most tree species, however, this is dictated by variations in species characteristics (Hammond *et al.*, 2020). Intermediate gap sizes, therefore, moderates resources and the microclimate, hence multiplies species diversity (Kern *et al*., 2012).

Even though medium gap sizes are the best in resource availability, few studies exist to indicate the actual medium gap size in Afromontane forests. Most studies report on small and large gap sizes without the linkage (Devagiri *et al.,* 2016; Hammond *et al.,* 2020). However, Sapkota and Oden (2009) state that medium gap sizes range from 200-400 m^2 in the study. This shows that many authors concentrate on the two extremities without considering the neutral gap size which is favourable to many woody vegetation species.

2.5.3 Large gap sizes and their influence in forests

Large gap sizes are caused by large-scale disturbances which covers a relatively large geographical area. However, large gap sizes are usually less common compared with small gap sizes whose disturbances are small-scale yet more often (Yamamoto, 2000). Centre of large gap sizes receives higher sunshine intensity for a longer period of time compared with small gap sizes. This is true because there is less light and rainfall interception in large gap sizes favouring sun plants to thrive well (Denslow, 1987). In addition, Photosynthetic Photon Flux Density (PPFD) at the gap centre is also determined by gap shape, alignment, topography of the area and the height of the nearby trees (Denslow, 1987). Nevertheless, large gap sizes have microclimates that affects forest ecology and soil ecosystems (Muscolo *et al.*, 2014).

Many studies for example; Devagiri *et al.* (2016), Muscolo *et al.* (2014) and Sapkota and Oden (2009) among other studies demonstrate that canopy openings influence forest microsite conditions. And that, local conditions within large gap sizes are influenced by gap orientation, edge effects and the plants present in the cleared area (Solomon *et al.,* 2018; Vuyiya *et al.,* 2014). This determines which species is to colonize the gap. The occurrence of large-scale disturbances reduces the frequency of small gap sizes since old age trees that are susceptible to natural disturbances are cleared at once (Lorimer, 1989).

Large gap sizes are, however, important in the regeneration of most species especially pioneer species due to availability of much light and exposed soils (Kern *et al*., 2012). They are also suitable for shade intolerant species, long distance seed dispersal and fast-growing seedlings fit to regenerate (Kern *et al*., 2012). Additionally, shade intolerant (pioneer) species are the first plants that emerges after large-scale disturbance in a forest, hence are indicators of forest disturbance (Swaine & Whitmore, 1988).

Many studies have been done on forest gap sizes, however, there is no definite area that constitute large gap size. Every researcher has an independent finding, for example, Hammond *et al.* (2020) says >700 m^2 in area, Sapkota and Oden (2009) reports >600 m^2 while Devagiri *et al.* (2016) states >300 m^2. Also, Babaasa *et al.* (2004) reports it to be >650 m^2. This imply that every forest type has its own gap size area depending on constant disturbances within, more especially natural. Therefore, there is need to provide a definite area constituting large gap sizes in Afromontane forests since the above researchers reports on boreal, temperate, tropical and Sal forests. This study was, therefore, determined to find out what area coverage constituted large gap sizes in SW Mau Forest reserve.

2.6 The microsite conditions in forest canopy gap environments

Canopy gaps are treated as fixed as far as light availability and vegetation height is concerned (Hunter *et al.,* 2015). Indeed, gaps play an important role in forest ecology by influencing nutrient cycle, biological changes and plant successions (Yang *et al.,* 2017). Canopy gaps regulates microsite conditions within forests; thus, influencing woody vegetation in terms of regeneration, vegetation structure and species diversity (Devagiri *et al*., 2016). Studies by Devagiri *et al*. (2016) and Sapkota and Oden (2009) agrees that there are differences in light, nutrients, moisture and temperature within canopy gaps creating potential niches for species diversity, regeneration and structural development. This is because the rate of regeneration is higher in canopy gaps than in closed canopy (Devagiri *et al*., 2016).

Furthermore, forest canopy gaps have an influence on species survival and ecosystem functions as suggested by gap and gap-size partitioning hypotheses (Berdugo & Dovciak, 2019). Also, they improve micro-environment, consequently, influencing nutrient, moisture and light availability for seedling establishment (Gray *et al.*, 2002). In the process of changing the environments, canopy gaps promote changes in the surrounding forest (Hunter *et al.*, 2015). Truly, canopy gaps impact the composition of the underneath species entailing saplings and seedlings of species as supported by Qiang *et al.* (2019). Besides, they provide space for the growth of new cohort of trees, therefore, creating environmental heterogeneity (Yang *et al.*, 2017). This implies that they play an integral role in changing stand structure, hence renewal of the forest (Whitmore, 1989).

Many studies have reported that canopy gaps increase irradiance and moisture, thus influencing soil temperature. Also, variations in environmental conditions caused by canopy gaps influences litter chemistry and microbial activities impacting nutrient release in the soil (Yang *et al.*, 2017). Naturally, higher temperature and moisture catalyses decomposition (by microbial activities) of plant litters, therefore, stimulating mineralization of nitrogen in the soil (Forrester *et al.*, 2013). This increases nutrient availability in the soil which is used by plants for growth (Wang *et al.*, 2012). Nevertheless, less moisture reduces the rate of decomposition of plant litters, hence less nutrients in the soil (Ni *et al.*, 2018).

Moreover, forest canopy gaps are also known to have an influence on slope stability. In a forest where there are patches of vegetation across the slope, problems such as soil erosion sweeps soils and nutrients down the slope (Mao *et al.*, 2014). Wind is a common agent causing canopy gaps in mountainous regions. This is because wind speed can be severe at the top of the mountain/hill uprooting and felling many trees (Mao *et al.*, 2014). Extreme winds with low pressure results into death of many trees especially on the windward side as compared with the leeward side of the forest due to downslope movement of wind from the top. Slope also influences the species of plants to colonize a region in that at steep slopes, the vegetation types are usually short in stature (Gaudel, 2019).

Studies exists on the influence of canopy openings on microsite conditions (Devagiri *et al.*, 2016; Gray *et al.*, 2002; Ni *et al.*, 2018). However, no study has been done on canopy gap sizes and their influences on microsite conditions in SW Mau Forest reserve. This study was, therefore, focused on determining how different canopy gap sizes affected light intensity, soil moisture and soil temperature in the forest.

2.7 Forest canopy gap sizes and woody vegetation population parameters

2.7.1 Ecology of regeneration of woody vegetation

Forest regeneration is the establishment of a new tree cohort occurring during succession (Kneeshaw & Bergeron, 1998); Primary and Secondary successions entailing plants and microbes (Berdugo & Dovciak, 2019). Regeneration of species in different canopy gap sizes is determined by the species itself, growth rate, and the over-storey type (Hammond *et al.*, 2020). On top of that, regeneration process in forest ecosystem is positively influenced by the proximity to forest reserves around (Hooper *et al*., 2004) and the abundance of mother trees (Lohbeck *et al.*, 2020). This indeed ensures constant release of reproductive parts (seeds) for continuity of species in the forest. Likewise, more regeneration comes from seeds with heavy seeds being found near mother plants while far regeneration may be due to other seed dispersal agents, such as wind and animals (César *et al*., 2018; Lohbeck *et al*., 2020).

Regeneration is key as far as species existence in forest stand is concerned. The ability of seedlings and saplings to survive and regenerate successfully is a step for long-term sustainability of forest ecosystem (Khaine *et al.*, 2018). Also, regeneration in forest ecosystem is crucial as it allows for restoration of degraded forest lands (Tesfaye *et al*., 2010). However, there are variations in regeneration patterns in forests due to differences in various species that constitute the forest.

Natural regeneration comes from four pathways; seed rain (dispersed seeds) (César *et al*., 2018), soil seedbank (Lohbeck *et al*., 2020), seedling bank (suppressed) and coppices from roots/shoots (Senbeta *et al.*, 2002). Nevertheless, soil seedbank may be faced by predation and pathogen infection, therefore, affecting its effectiveness (Obati, 2007). In addition, plantation forests can enhance natural regeneration, however, seed sources are needed in the vicinity to trigger regeneration of indigenous wood species (Lohbeck *et al*., 2020). Among the dispersal agents are animals and birds that feed on fruits of the tree species and disperse them in the plantations during egestion. This fosters natural regeneration of indigenous tree species that were once extirpated from an area (César *et al*., 2018).

Understanding the structure, composition and density of the forest enables researchers to better comprehend the regeneration status of various species, thus management history in forest ecology (Senbeta *et al.*, 2002). The density structure of various plants in forests may indicate whether the distribution allows for regeneration (Tesfaye *et al.*, 2010). The distinct densities of indigenous woody tree species that naturally regenerate are dominated by shrubs or small trees and only a few make it to the upperstorey. This polarity may be attributed to less mature upper-storey trees that can produce seeds for continuity, dispersal mode and the nature of the agents dispersing these seeds (Senbeta & Teketay, 2001).

2.7.2 Influence of canopy gap size on regeneration of woody vegetation

Relatively small canopy gap sizes obscure the effect of solar on regeneration capacity of most tree species (Zhu *et al.*, 2014). Also, regeneration of woody vegetation in large canopy gap sizes is inhibited by competition for resources from herbs and other shade intolerant species (Busing & Brokaw, 2002; Lu *et al*., 2018). However, intermediate canopy gap size tends to balance between large and small gap sizes, hence more appropriate for regeneration and growth of tree species (Gray *et al*., 2002; Hammond *et al.*, 2020). This is the optimum range of canopy gap size that promotes natural regeneration because it provides moderate micro-climate and resources that are vital for the growth of young tree species (Kern *et al*., 2012). Even though most studies report that medium and large gap sizes facilitates regeneration, others report of higher species richness in terms of regeneration in undisturbed sites than in disturbed. This can be due to less constant disturbances in the undisturbed sites (Babaasa *et al*., 2004).

The population of seedlings found in forest understorey is not constant since their density and diversity keeps on changing due to variations in resources (Lorimer, 1989). Also, the variations may be due to abiotic factors, such as drought or biotic factors which may include herbivory, pests (Gaudel, 2019), diseases and competition hindering the growth of some indigenous tree species (Lu *et al.*, 2018). Therefore, tree seedling ecology can be helpful in providing means of forest recruitment, establishment, growth and improvement of tree species. Natural regeneration is, therefore, given a thumb up since it has a significant influence on forest management, conservation and restoration (Tesfaye *et al*., 2010).

A lot has been done on forest canopy gaps and how they influence regeneration of tree species (Babaasa *et al.*, 2004; Devagiri *et al.*, 2016). However, studies on Mau Forest have been those revolving around human disturbances and their influence on regeneration among other woody vegetation parameters. For example, Kipkorir *et al.* (2018), Obati (2007) and Ronoh *et al.* (2018) mentioned human disturbances hindering natural regeneration. However, fewer study exists on various forest canopy gap sizes created by these disturbances and how they influence woody species regeneration in SW Mau Forest reserve.

2.7.3 The influence of canopy gap size on forest structure

Forest stands are composed of vegetation with differences in vertical and horizontal stratification (Gray & Spies, 1996). However, disturbances, such as fire creates large canopy gap sizes clearing almost every vegetation along its way (Kinyanjui, 2009). According to Kane *et al*. (2013), when fire frequently strikes, there is a likelihood of having a more homogeneous open structure because only hardy species can survive. After fire, grasses and herbaceous plants colonize first, small bushes and trees begin to emerge later. Fast growing evergreen trees then develop faster to maturity while shade tolerant trees (climax species) develop in the understorey resulting in variations in the vertical stratification (Yassir *et al*., 2010).

Canopy gap sizes and debris are characteristics of old grown forests (Johnson *et al*., 2021). They facilitate changes in the structural features of forests; recovering the characteristics of the old forests, maintaining a continuous release of ecosystem services and biodiversity, necessitating structural complexity in mature forests (Forrester *et al*., 2013; Franklin *et al*., 1987).

The alteration in forest structures caused by tree fall creates an environmental mosaic in the community determined by a gap age dependent process (Bi *et al*., 2020). The spatial and temporal heterogeneity of forest structure is determined by; speed at which canopy gaps are being created, sizes of the canopy gaps which are determined by the number of trees that falls/dies/removed, shapes determined by canopy types and location of the gap in the forest (Bi *et al*., 2020). Tree communities indicate different modes of death depending on the physical factors, such as wind and biological factors, such as pests; thus, affecting canopy texture (Zhang & Yi, 2021).

Natural disturbances occasionally destroy old trees and emergent layers within forests impacting vertical stratification of forest items. It also reduces density of old trees and increases density of saplings (Gray & Spies, 1996). Close up due to lateral extension of branches and establishment of new trees in small gaps (Kovács *et al.*, 2018) results into an imbalance in forest structure in terms of sizes and ages (Berdugo & Dovciak, 2019). The two processes; gap formation and close up are crucial in forest structure since they influence periods and speeds of the ecological processes transpiring in a forest (Valverde & Silvertown, 1997).

Forest canopy structure is, therefore, determined by stand characteristics (Whitmore 1989), for instance; species diversity, forest composition and tree sizes which indicate the successional stages within the forest and severity of disturbances, physiographic features including soil topography, moisture and soil fertility (Fotis *et al.*, 2018).

No study has been done on canopy gap size influence on forest structure in SW Mau Forest reserve. Studies about the forest have been on human disturbances (Obati, 2007;

Ronoh *et al.,* 2018) without stating the resulting canopy gap sizes and their implications on woody vegetation population parameters. This study therefore intended to bridge this gap.

2.7.4 Influence of canopy gap size on diversity of woody vegetation species

A recent study by Hammond *et al.* (2020) defines species diversity as the presence of a given plant species within a community in a particular habitat. Large canopy gap sizes promote early succession of plant species, such as those buried in the soil. Additionally, it enhances coexistence among species through competition for resources (Brokaw & Busing, 2000). This is because, different species have different mechanisms of acquiring the resources (Gray & Spies, 1996). Difference in light interception, light utilization and exploitation of soil moisture and nutrients result in variations in the composition of forests, thus explaining the element of species diversity in natural forests (Hammond *et al.,* 2020).

Canopy gap size affects species diversity within forest facilitating coexistence of different species in the same locality (Brokaw & Busing, 2000). This is due to the interaction between the population of various species and communities that influences the functioning, productivity, stability and resources that are needed for species establishment (Hammond *et al.*, 2020). Canopy gaps are important in forest ecology because of the positive influence on species diversity (Sapkota & Oden, 2009). Due to increased regeneration rates in large canopy openings, there is high species diversity resulting from the availability of good conditions for growth. In this case, vegetation type ranges from pioneer to non-pioneer species (Spies & Franklin, 1989).

Canopy gaps results in coexistence of different species (Brokaw & Busing, 2000; Hammond *et al.,* 2020) having diverse life histories and ecological requirements. This results into diversity in plant communities in the forest (Busing & Brokaw, 2002; Whitmore, 1989). Gap partitioning hypothesis shows that resource gradients is usually wide from closed canopy to canopy gaps and cannot be occupied by one species (Berdugo & Dovciak, 2019). This leads to the establishment of different tree species in relation to canopy gap size and plant techniques of acquiring the resources (Gray & Spies, 1996). Canopy gaps are known to induce replacement of some species in forest ecosystem (Swaine & Whitmore, 1988). This causes variations in the floristic composition, species abundance and structure between the canopy gaps and nearby forests. Some tree species increases in population in relation to canopy gap sizes while some may be affected by canopy gap sizes (Guo *et al.*, 2019).

2.8 Undisturbed forest sites

2.8.1 Microsite conditions in undisturbed sites

Under closed canopy, low intensity sun flecks reach the forest floor. This radiation is low in Photosynthetic Active Wavelengths (PAW) (Gray & Spies, 1996). During day times, the total Photosynthetic Photon Flux Density (PPFD) is received for a short duration and mostly diffuse. This has an impact on plant growth rate because growth is correlated to direct amount of light reaching the plant for photosynthesis. This affects carbon balance in seedlings due to low rate of photosynthesis, thus slow growth rate (Zhang & Yi, 2021). Soil nutrients in such forests are added through fixation, soil organic mineralization, weathering of rocks and atmospheric deposition with the rates of nutrient addition varying depending on the site and tree species (Forrester *et al*., 2013).

In closed forests, the soils are rich in nutrients, such as nitrogen, calcium, magnesium, potassium and sodium as a result of organic matter. However, as trees grows up, they utilize the nutrients and stores them in their bodies in form of carbohydrates (Kinyanjui, 2009). They also facilitate leaching of nutrients as they absorb water explaining why closed canopy forests have few understorey species. This is because, the soil is not fertile and also less light intensity reach the forest floor (Su & Shangguan, 2019).

2.8.2 Woody vegetation population parameters in undisturbed sites

Natural forests free from human disturbances have complex ecosystems with different tree species having different ages and sizes (Kinyanjui, 2009). In closed canopy, there are less undergrowth as the floor is carpeted with debris which cannot allow for regeneration from seeds (Johnson *et al*., 2021). However, the trees within are usually big in size with heterogeneity of structure. Such forests are usually dominated by specific species of trees and diversity through seed dispersal (seed rain). Shade from the upper canopy affects the abundance and distribution of tree species by influencing nutrient availability, moisture and sunlight explaining the reason for low regeneration (Denslow, 1987).

Even if some forests are undisturbed, canopy structure is deemed to vary with age. This explains why even in undisturbed forests, gaps are still expected to occur by nature, such as from branch breaking and senescence (Hansen *et al.*, 2014). Additionally, canopy structure, height and cover tend to vary due to variations in temperature, precipitation, topographic, soil, solar radiation and pH as reported by Hansen *et al.* (2014). Some undisturbed forests are still characterized by canopy gaps without human and natural disturbances. According to Hitimana *et al.* (2004), gap occurrence relates to altitude, that is, higher altitudes have less closed canopy cover than low, this also affect seedling population up the slope, hence less regeneration.

2.9 Theoretical framework

Gap theory

Gaps are openings in forest canopy spanning from openings due to mortality of one branch all the way to large scale by catastrophic disturbances (Yamamoto, 1992). All forests experiences compositional and structural phases undergoing cycles of variations. The phases include; gap, building and mature phases which are natural with time period (Yamamoto, 2000). Small gap sizes created may be filled by the lateral branches (Lorimer, 1989) or the shooting up of the suppressed seedlings and saplings. This phenomenon is called gap dynamics (Gray *et al*., 2002) and is related to the ecological theories in forest ecosystem, such as zonation of species diversity, adaptability of species (Denslow, 1987) and niche partitioning (Hammond *et al.*, 2020).

Gap theory also state the presence of shade-intolerant species in mature forest through regeneration (Gray *et al.*, 2002). This can be due to the presence of scattered tree branches in old trees allowing for light to reach the forest floor (Yamamoto, 2000). Additionally, it assumes that small gap sizes from natural branch breakage can occur in closed forest over time, therefore, influencing microsite conditions (Yamamoto, 1992). This was the overall theory to this study involving both the disturbed and undisturbed parts of the forest resulting into dynamisms in canopy gaps.

Gap partition theory

It suggests the difference in species autecological responses in microsite conditions in canopy openings (Whitmore, 1989). This is what results into species preferences for specific canopy gap sizes or even position in large gap sizes. It provides for shifting of species in various gap sizes, hence, coexistence and diversity among species due to niche specialization (Hammond *et al.*, 2020).

It stresses on micro-environmental heterogeneity, traits of species; such as; seed size, dispersal, germination mode, as well as physiological responses including; photosynthesis, nutrient utilization and shade tolerance. This explains why some species are found in small gap sizes while others in large gap sizes. According to ‘Gap Partitioning Hypothesis’ (Berdugo & Dovciak, 2019), saplings of different life history coexist between closed canopy and gap centre (Kern *et al*., 2012). In addition, shade-intolerant species are found at the gap centre. Gradients in resource availability in canopy gap sizes creates potential niches for species (Devagiri *et al*., 2016). This theory was used to investigate which species did well in which gap size.

2.10 Conceptual framework

Dwindling biodiversity in natural forests is often caused by coalescence of human and natural disturbances. Human activities have led to increased demand for forest resources which have resulted in overexploitation (Ronoh *et al.,* 2018). Forest renewal following disturbances is influenced by nature and intensity of the disturbance, species diversity and the mode of reproduction of the species (Whitmore, 1989). Therefore, constant disturbances imply reduced forest renewal while complexity in forest species implies resilience to disturbances.

Therefore, disturbances in forests avail resources which results in competition and gap partitioning among plant species (Berdugo & Dovciak, 2019; Hammond *et al.*, 2020) . Gaps affect forest architecture influencing the establishment, growth and reproduction of tree species (Runkle, 1989). Species react differently due to latitudinal differences; two equal gap sizes, shapes and formation mechanisms provide different regeneration opportunities in tropical forests. One mechanism is heterogeneity in light resource level resulting in gap specialization (Brokaw & Busing, 2000).

Large gap sizes result in diversity in tree species in addition to those previously present before the disturbances. The occupying species differs in growth rate due to differences in resource utilization techniques, species type and requirement as well as the ability to withstand competition. Species with high survivorship dominate the top canopy followed by those that are not strong in competition (Brokaw & Busing, 2000). However, in small gap sizes, seedlings and saplings still compete for the limited resources according to the environmental influence differing in growth rate (Denslow, 1987; Whitmore, 1989). Therefore, regeneration, structure and species diversity in forests depend on gap sizes (Figure 2.11).

The missing link was an approach to canopy gaps management for species diversity in SW Mau Forest reserve, an Afromontane forest. This was because the forest was experiencing increased disturbances especially human based which threatened its equilibrium. This study was determined to aid in understanding future trends in the forest in relation to species diversity under canopy openings in disturbed sites. Nevertheless, there was need to provide vital information for better understanding of the drivers to canopy gaps within the forest and their impacts, hence the need to conserve the ecosystem for biodiversity. Similarly, there should be provision of information to forest stakeholders and decision-makers on species that are adversely affected by specific gap sizes in order to provide for further protection and conservation.

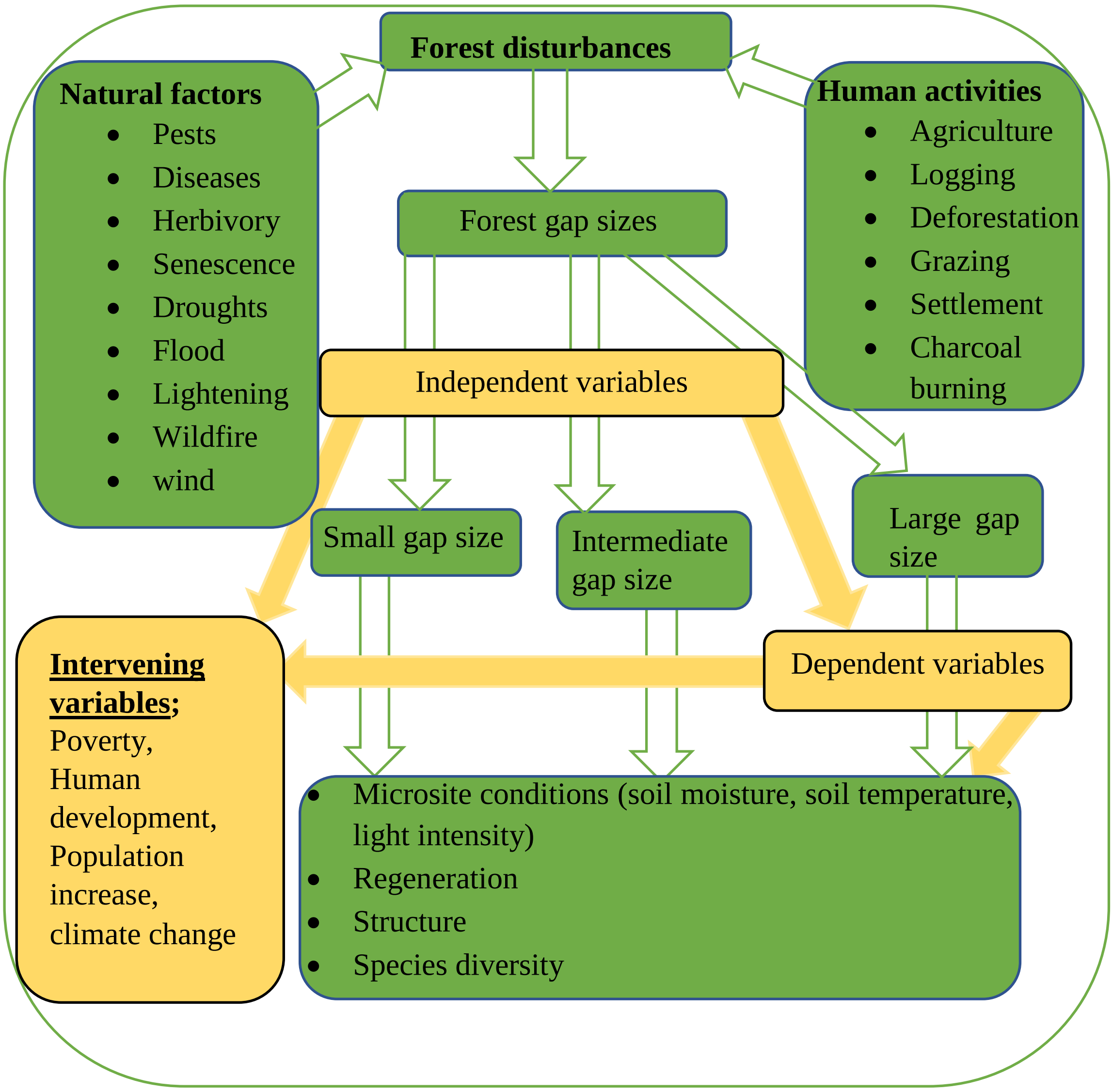


Figure 2.11: Schematic presentation of the conceptual framework

CHAPTER THREE
MATERIALS AND METHODS

3.1 Introduction

In this chapter, materials and methods that were used to collect and analyse data in relation to the objectives of the study are explained. The outline entail; study area, research design, target population, research instruments, sampling procedures, data collection and analysis.

3.2 Study area

The study was conducted in SW Mau Forest reserve (Figure 3.1.1) which is one of the reserves of Mau Forest. It has three blocks; Itare, Maramara and Ndoinet. The study was done in the period between late March to early April 2022 before the onset of long rains. The study site was of interest since it is the largest remnant indigenous reserve of Mau forest with broad base of flora and fauna yet experiencing a lot of human disturbances. This has brought concern on the ability of the forest to maintain its biodiversity and its continuous supply of ecosystem goods and services; as well as contribution to the global gradual change in climate system.

As a ramification, SW Mau Forest reserve has decreased from 84, 000 ha to 60,000 ha in area between 1990s and early 2000 due to human encroachment (Kinyanjui, 2009). Therefore, reclamation process was started in Ndoinet block which was severely affected. There was enrichment planting by Initiative for Sustainable Landscape (ISLA) and IDH-the Sustainable Trade Initiative agencies with the intention of facilitating regeneration in the forest. They also fenced the most disturbed sites to allow for natural regeneration (Butynski & De, 2016).

Altitude and location

South-Western Mau Forest reserve has a latitude of 0˚15'S- 0˚47'S and longitude of 35˚28'E - 35˚69'E (Kinjanjui *et al.,* 2013). The forest has an altitude ranging from 2100 to 3300 m above sea level (Wanyama *et al*., 2018). The forest reserve is located in Bomet County in the Rift Valley Province of Kenya and is one of the 21 gazetted forest blocks that make up the Mau Forest Complex (Kinjanjui *et al.,* 2013).

Rainfall

South-Western Mau Forest reserve receives a bimodal rainfall pattern with long rains from April to August. It receives rainfall amount of 2000-3000 mm annually (Kinyanjui, 2009). It also has three to five drier months without rainfall (Wanyama *et al*., 2018).

Temperature

It is located in a semi-humid climatic zone with air temperature ranging from 15^0 C to 18^0 C annually (Wanyama *et al*., 2018) with the mean temperature varying from 16^0 C in July to 22^0 C in September (Kinjanjui *et al.*, 2013).

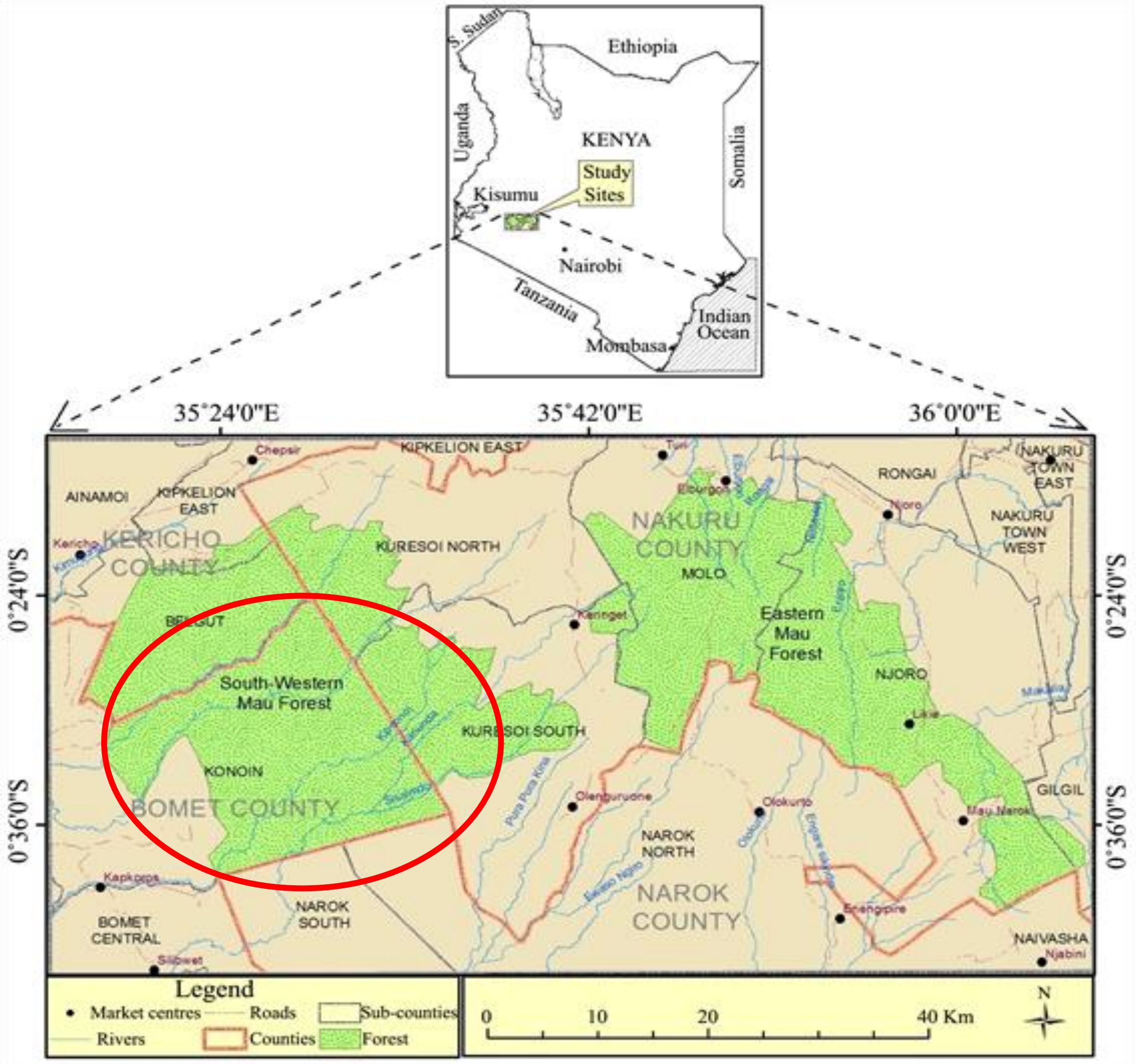


Figure 3.1.1: Map of SW Mau Forest reserve

Source: Jebiwott et al. (2021). The circled part in red is the SW Mau Forest reserve.

Hydrology and drainage

South-Western Mau Forest reserve is one of the blocks in Mau Forest that receives heavy reliable rainfall composed of many streams. These streams feed; Lake Victoria, Lake Nakuru, and Lake Turkana. Sondu river which flows from the block feed Lake Victoria, thus providing for Nile River (Bewernick, 2016). It provides water for drinking, livestock, wildlife, supports major hydro-electric power plants and irrigation schemes (Butynski & De, 2016).

Soils

The soils of SW Mau Forest reserve are fertile, well drained with high levels of organic matter especially on the top layers of the forest floor (Butynski & De, 2016). Soils are mollic andosols derived from tertially volcanic parent material (Kinjanjui *et al.*, 2013).

Vegetation

Its vegetation type is classified as Afro-montane mixed forest dominated by broad-leafed species, examples are, *Polyscias fulva, Macaranga capensis, Tabernaemontana stapfiana,* Croton, Olea (Klopp & Sang, 2011). It is characterized by tree species, such as, *Strombosia scheffleri* and *Aningeria adolfi-friedericii*. In less disturbed sites; *Podocarpus latifolius, Albizia gummifera, Olea capensis* and *Prunus africana* can be found in patches (Obati & Breckling, 2015).

Land use

The communities around engross in energy production, tourism activities, agriculture (cash crops, subsistence crops, and livestock), as well as water supply to urban centres and industries. The main cash crop in SW Mau Forest reserve is tea (Klopp & Sang, 2011). Subsistence crops grown include; maize, millet, beans, wheat, Irish potato, bananas and vegetables. Other land uses include eucalyptus plantations and settlements (Wanyama *et al*., 2018), dairy, beef cattle, sheep and goat production which are important sources of income to the communities (Butynski & De, 2016).

Population

The forest was traditionally inhabited by the Ogiek community (Jebiwott *et al.*, 2021) who were hunter-gatherers. However, the adjacent area is currently dominated by the Kipsigis sub-group of the Kalenjin community, and other settlers; Kikuyu, Luhya, Luo and Kamba (Klopp & Sang, 2011).

Drivers of tree cover change

Over the last decades, approximately 25% of SW Mau Forest reserve has been lost through excisions, encroachment and illegal logging. Other key threats to South-Western Mau Forest reserve have been illegal extraction and unsustainable use of forest resources for commercial purposes, especially for timber, wood fuel and charcoal, cattle grazing and land resettlements (Klopp & Sang, 2011).

3.3 Research design

The study was experimental involving Nested Research Sampling Design, whereby, a total of 6 plots of 500 by 500 m each were demarcated in disturbed and undisturbed sites of the forest reserve. Canopy openings were randomly selected within the three plots in disturbed sites to constitute the sample units. In undisturbed sites, sub-plots of 30 by 20 m were randomly demarcated in the main three plots using simple random sampling design. Within the selected sampling units, ecological survey was employed to determine canopy gap size influence on woody vegetation population parameters and microsite condition. The undisturbed sites were used for comparison.

3.4 Target population

The study targeted all indigenous woody species in SW Mau Forest reserve (Ndoinet, Itare and Maramara blocks) in disturbed and undisturbed sites. The variables of interest included regeneration, forest structure and species diversity as influenced by canopy gap sizes. SW Mau Forest reserve was chosen because it was the largest remnant indigenous reserve of Mau Forest threatened by human disturbances in addition to natural factors which causes canopy openings.

3.5 Research instrument and validity

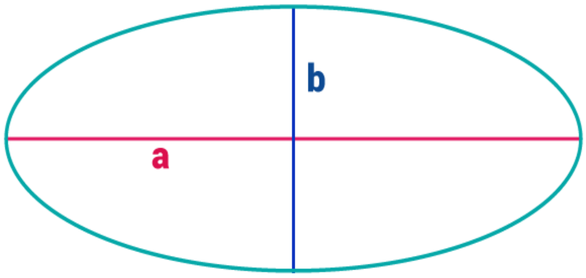
Forest inventory score sheets were used to collect data on woody vegetation population parameters. The variables collected included; woody species, tree height, dbh, crown class and growth stages (saplings and seedlings). In addition, soil moisture, soil temperature, light intensity and GPS coordinates were also recorded.

The instruments used to collect data (forest inventory score sheets) was validated by the two supervisors from Egerton university and KFS. They ensured that the score sheets covered all the variables under study and also ensured that the instrument fully addressed the objectives of the study.

3.6 Sampling procedure and data collection

3.6.1 Gap size determination

A plot of 500 by 500 m was laid in disturbed sites of Ndoinet, Maramara and Itare blocks at 100 m from the forest edge (cutline). Within the plots, canopy gaps were randomly selected as sample units. Gap coordinates were taken using Handheld GPS (Garmin e Trex 10) and the coordinates used in GIS (ArcMap) to locate distribution of the identified gap sizes in a map (Hammond *et al.*, 2020). Gap centre was determined using digital Nikon camera equipped with a monitor (Bobiec, 2007). Ellipse Method (EM) was used to calculate the area of the gap sizes since most gap sizes were regular in shape **(**Figure 3.2.1 and Plate 3.2.1).



a

b

Figure 3.2.1: Ellipse formula for gap area calculation

Plate 3.2.1: Image of a canopy opening in Ndoinet

Source: De Lima (2005).

a) is the formula for gap size calculation while b) is the photograph of canopy gap taken in the field to display the shape of most gap sizes in the field.

$$A = \pi \frac{ab}{4} \quad \text{.. (i)}$$

Where;

π=ratio of circumference of any circle (3.14159); *a*= was the longest distance from the gap edge to the centre O; *b*= was the longest distance perpendicular to the length at point O (De Lima, 2005).

Gap percentage per sample plot was calculated using the following formula by Odhiambo *et al*. (2004);

$$^{0}/_{0}\, Gap = \frac{TGA}{PA} \times 100 \quad \text{.. (ii)}$$

Where;

TGA = Total Gap Area in a plot

PA = Plot Area

3.6.2 Microsite conditions determination

To determine microsite conditions, light intensity was measured using luxmeter (model HTC LX-104) exposed at the centre of every gap size (Devagiri *et al.*, 2016). Soil moisture and temperature were measured using Kensizer soil tester (3-in-1 soil moisture/light/pH…). Soil moisture and temperature measurements were taken at a depth of 10 cm from the floor surface. For the microsite conditions, measurements were taken four times per sampled gap size and averaged for that particular sample plot.

3.6.3 Regeneration

Regeneration was determined by randomly throwing 2 quadrats; 5 x 5 m four times and 1 x 1 m eight times in every gap size for saplings and seedlings respectively. All species with heights of 1-3 m (saplings) and <1 m (seedlings) were identified, specific names inventoried and their population recorded.

3.6.4 Species diversity within the gap sizes

In each sample plot, there was identification of all indigenous woody species, followed by recording of their specific names. Two diversity indices were used to determine species diversity and these included;

Shannon-Weiner's Diversity Index (*H'*) to estimate species diversity;

$$H' = -\sum_{i=1}^{s}(P_i)\ln(P_i) \qquad \text{(iii)}$$

Simpson's Diversity Index (1-*D*) to estimate species dominance;

$$D = \sum\left(\frac{n_i}{n}\right)^2 \qquad \text{(iv)}$$

Where;

H'= Shannon-Wiener's Diversity Index,

S= number of genera,

Pi= was obtained by ni/n

where ni= the total number of individuals of species i,

n= the total number of all the individuals in total,

ln= natural $\log_{10}$ of Pi (Shannon, 1948)

D = Simpson's Diversity (Hammond *et al.*, 2020).

3.6.5 Forest structure

Tree species were categorised into various growth levels; seedlings (< 1 m in height), saplings (1-3 m in height), small trees (4-15 cm dbh-understory), medium trees (16-35 cm dbh-main canopy) and large trees (> 35 cm dbh-emergent layer) (Odhiambo *et al.*, 2004). Heights were taken at two levels; for trees with dbh of 4 cm and above, Suunto pm-5 series clinometer was used, saplings and seedlings were measured using a graduated rod of 3 m. Diameter of trees bordering the gaps were measured using a diameter calliper (Hammond *et al.*, 2020); haglof aluminium calliper (65 cm for small trees) at the diameter breast height (dbh) (Obati, 2007) and diameter tape for very large trees (> 65 cm dbh).

Forest structure was determined qualitatively and quantitatively, whereby qualitative was determined by assessing the diversity of species which brought differences in the horizontal and vertical stratification. Quantitative on the other hand entailed considering tree heights and diameter (dbh) that influenced canopy texture.

Structural complexity of the forest was determined by quantifying trees having dbh >3 cm using Holdridge's Complexity Index (Holdridge & Grenke, 1971) as per the following formula;

$HC = (A \times d \times n \times h) / 1500\ m^2$ ……………………………………………………(v)

Where;

HC = Holdridge's Complexity index,

A = basal Area (m^2)

d = tree density i.e., of the trees/1500 m^2,

n = number of species/1500 m^2,

h = mean tree height in meters.

3.6.6 Parameter determination in undisturbed sites

A plot of 500 by 500 m was randomly laid towards the interior parts of the blocks presumed to have fewer human disturbances. Sub-plots of 30 by 20 m were randomly nested within the plot 19 times in SW Mau Forest reserve blocks and these were distributed as follows; Itare 5, Maramara 6 and Ndoinet 8 times. Microsite conditions were taken 4 times per sub-plot within the plot and average calculated. All species in the plot were identified and names inventoried. The diameter (dbh >3 cm) and height of the identified woody species were measured using diameter calliper/tape and clinometer (Suunto clinometer) respectively as in disturbed sites.

Regeneration was determined by throwing 2 quadrats; 5 by 5 m four times in the sub-plot (30 by 20 m) and 1 by 1 m eight times for saplings and seedlings respectively. All species with heights of 1-3 m (saplings) and <1 m (seedlings) were identified, names inventoried and population recorded accordingly (Figure 3.2.6).

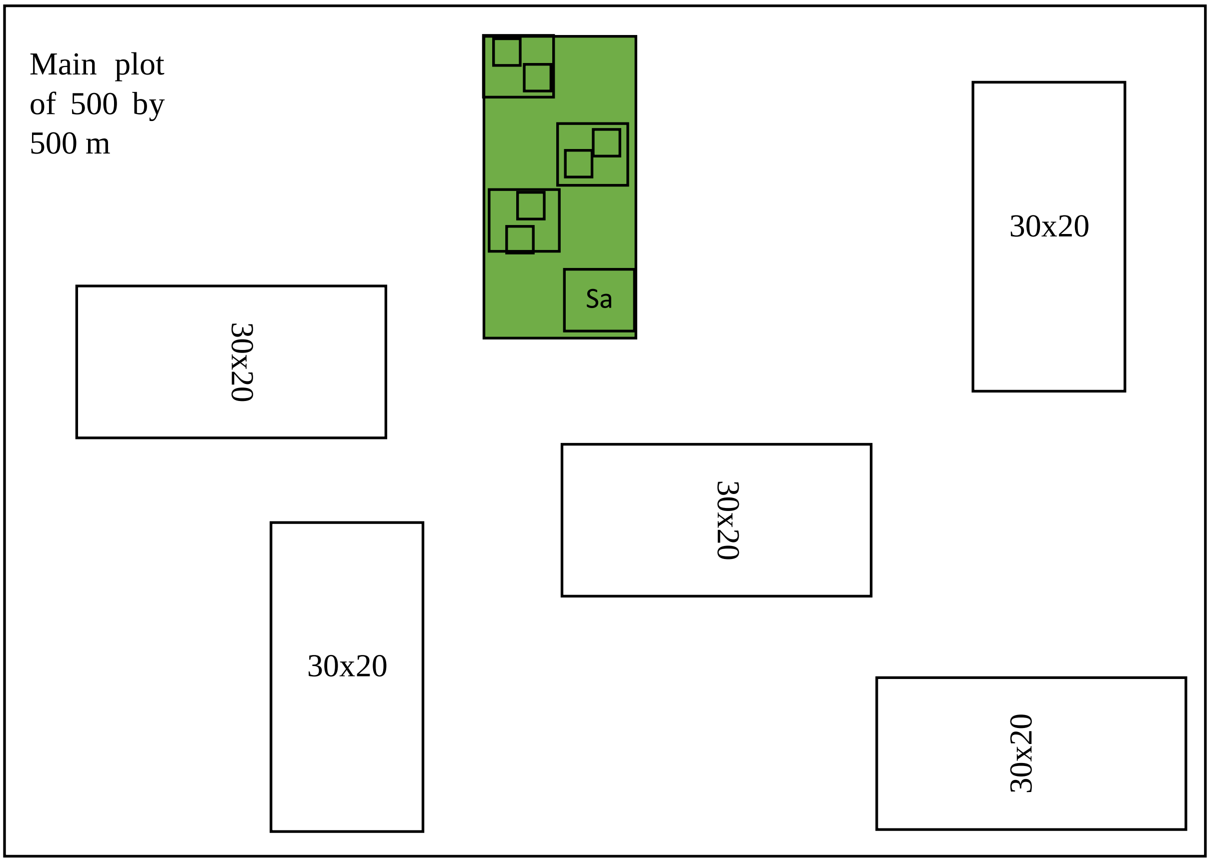


Figure 3.2.6: Illustration on regeneration, structure and species diversity determination

Main plot of 500 by 500 m, sub-plot of 30 x 20 m, saplings 5 x 5 m and seedlings 1x1 m.

3. 7 Data analysis

Gap sizes were categorized into three groups; small, medium and large and descriptive statistics was carried out for the three blocks (Hammond *et al.*, 2020; Zhu *et al.*, 2019). Descriptive statistics was again carried out to determine mean in microsite conditions, regeneration, structure and species diversity in the three gap sizes and in disturbed and undisturbed plots. Kruskal-Wallis rank sum test was employed to determine significant differences in microsite conditions and vegetation population parameters in the three gap sizes, since data was not normally distributed. Similarly, Wilcoxon rank sum test with continuity correction was used to compare microsite conditions and the three vegetation population parameters between disturbed and undisturbed sites of the forest (Table 3.7).

Table 3.7: Statistical data analysis

Research Objectives	Variables	Statistical data analysis method
i) To characterize forest gap sizes within SW Mau Forest reserve and their influence on forest microsite conditions.	**<u>Independent variables</u>** -Small gap sizes -Medium gap sizes -Large gap sizes	-Descriptive statistics tables, graphs
	<u>Dependent variables</u> -Soil moisture -Light intensity -Soil temperature	-Nonparametric Kruskal-Wallis rank sum test.
ii) To determine the effects of various gap sizes on woody vegetation population parameters.	**<u>Independent variables</u>** -Small gap sizes -Medium gap sizes -Large gap sizes	- Descriptive statistics.
	<u>Dependent variables</u> -Regeneration -Forest structure. -Species diversity.	- Nonparametric Kruskal-Wallis rank sum test.
iii) To compare Microsite conditions and woody vegetation population parameters between disturbed and undisturbed sites of the forest.	**<u>Independent variables</u>** -Disturbed sites -Undisturbed sites	-Descriptive statistics.
	<u>Dependent variables</u> -Soil moisture -Light intensity -Soil temperature -Regeneration -Species structure -Species diversity	-Wilcoxon rank sum test with continuity correction.

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter presents various findings that were reported in relation to the variables targeted in SW Mau Forest reserve. Results are given in terms of tables and graphs followed by hypothesis testing for the given objectives under study. Most parts of the SW Mau Forest reserve were disturbed with human activities (grazing, settlement, cutting, debarking, footpaths, selective logging etc.) which were the common in creating gap sizes. This was greatly related to the livelihood of those communities around the forest.

4.2 South-Western Mau Forest reserve canopy gap sizes and how they influence microsite conditions

4.2.1 South-Western Mau Forest reserve canopy gap size categorization

Gap sizes were categorized into three groups; small gap size ranging between 6-100 m^2 in area, medium gap size ranging from 101-300 m^2 while large gap size was classified to be above 300 m^2. Giving the synopsis of the results, a total of 41 gaps were encountered of which 7 were large gap sizes, 11 medium gap sizes while small gap sizes dominated with 23 (Table 4.2.1 and Appendix I). Additionally, Ndoinet recorded the highest number of gaps (17) with the common being small gap sizes (14) occasionally from anthropogenic activities.

Table 4.2.1: Distribution of gap sizes in disturbed sites of SW Mau Forest reserve blocks.

Sites		**Itare**	**Maramara**	**Ndoinet**	**Gap size total**
Gap sizes	*Large*	3	3	1	7
	Medium	7	2	2	11
	Small	3	6	14	23
Grand total		13	11	17	**41**

Additionally, Maramara recorded the second in small gap sizes (6) followed by Itare (3). However, Itare recorded the highest number of medium gap sizes (7) compared with Maramara and Ndoinet which tied at 2 gaps each. Moreover, Itare and Maramara blocks recorded 3 large gap sizes each while Ndoinet recorded only 1 large gap size (Figure 4.2.1).

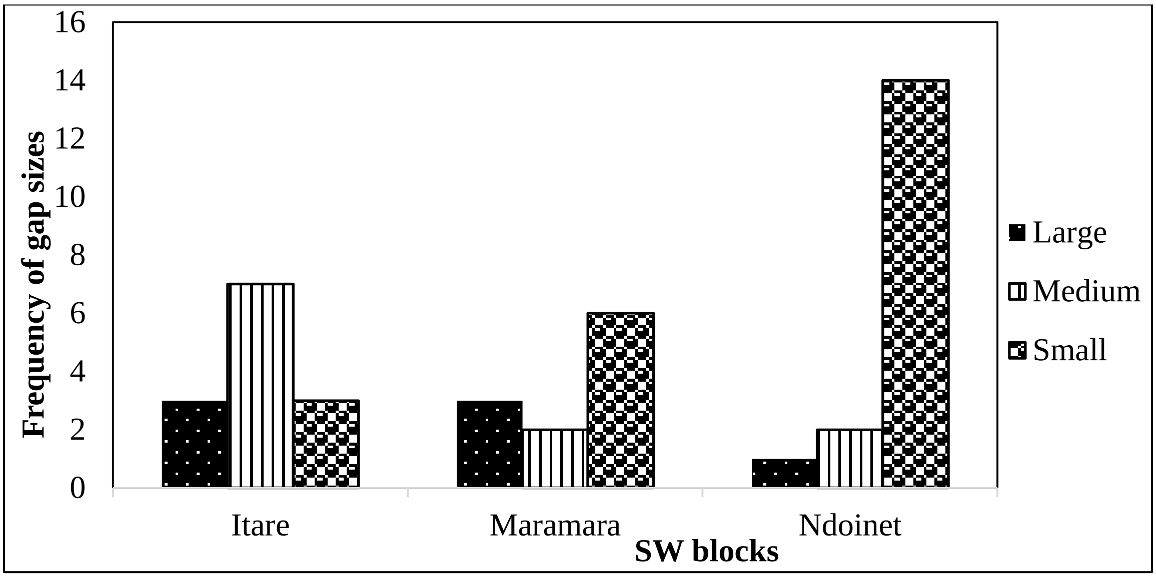


Figure 4.2.1: Frequency of gap sizes in the three study blocks of SW Mau Forest reserve

Large gap sizes recorded areas between 330-518 m^2, medium gap sizes between 101-300 m^2 while small gap sizes ranged between 6-91 m^2 as shown in Figure 4.2.2. Moreover, Itare recorded the highest mean in gap area followed by Maramara and lastly Ndoinet (see Appendix I).

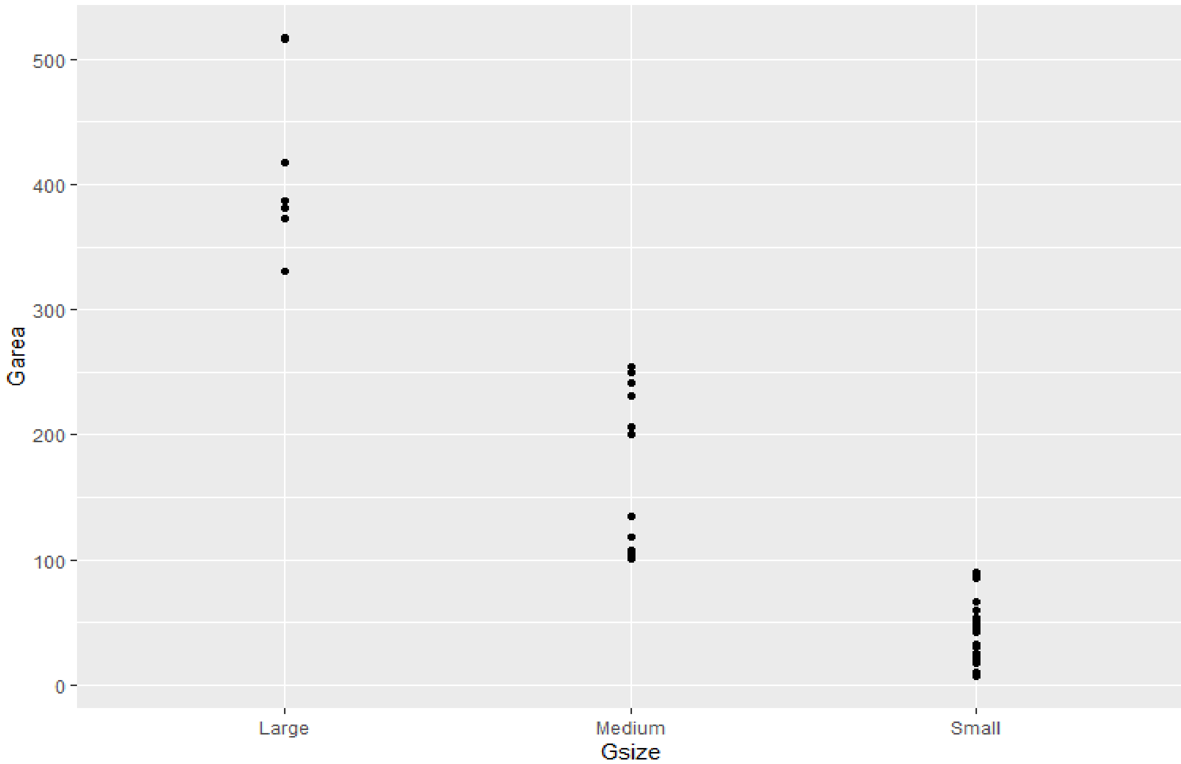


Figure 4.2.2: Canopy gap size areas in SW Mau Forest reserve

Garea represent gap area while Gsize represent gap size.

The figures below (Figure 4.2.3 and Figure 4.2.4**)** show how the sampled gap sizes in disturbed sites were distributed in the 500 by 500 m plots of Ndoinet, Maramara and Itare blocks using GPS coordinates.

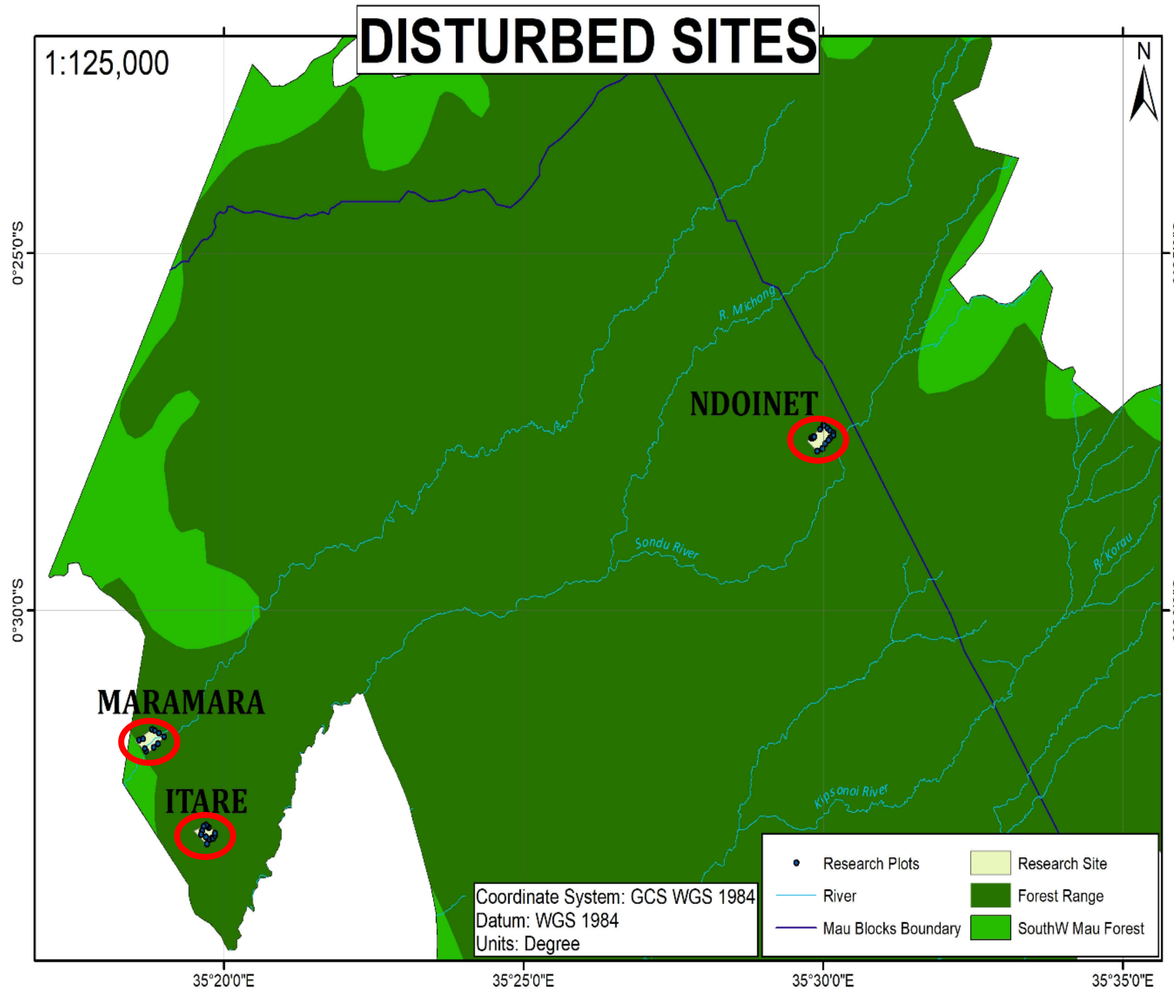
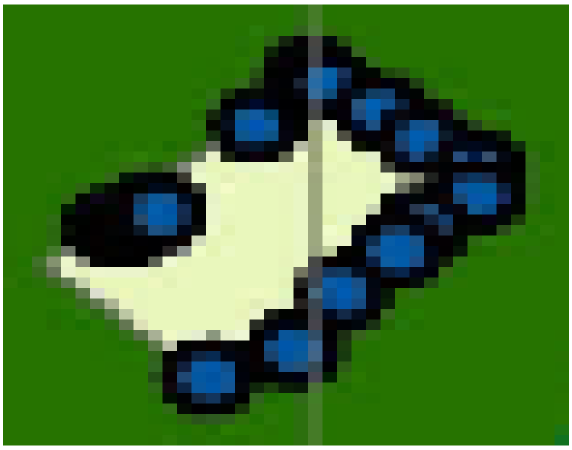
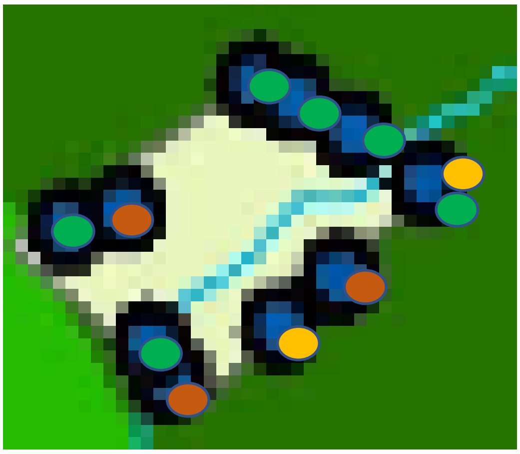


Figure 4.2.3: South-Western Mau Forest reserve canopy gaps distribution

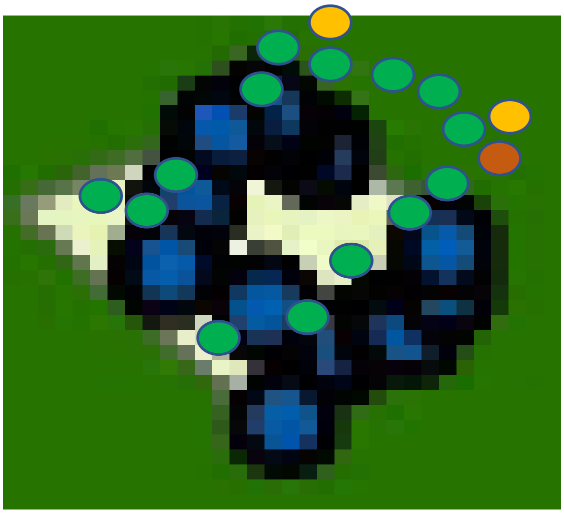
The dots represent the points where the sampled gap sizes were located while the cream yellow rectangular patches represent the main plot of 500 by 500 m. The red circles show where the plots were located in the blocks.



Ndoinet



Maramara



Itare

Figure 4.2.4: Distribution of sampled canopy gap sizes in SW Mau Forest reserve blocks.

The green patches represent small gap sizes; orange patches represent medium gap sizes while yellow patches represent large gap sizes.

The results on percentage gap area in the three blocks showed that Itare recorded the highest gap percentage (1.06 %), followed by Maramara (0.76 %) and lastly Ndoinet (0.52 %) (Figure 4.2.5 and Appendix I). This difference could have been brought by tree size variations which could have been determined by disturbance types within the forest. For example, Itare experienced a lot of wind snapping due to high number of huge trees.

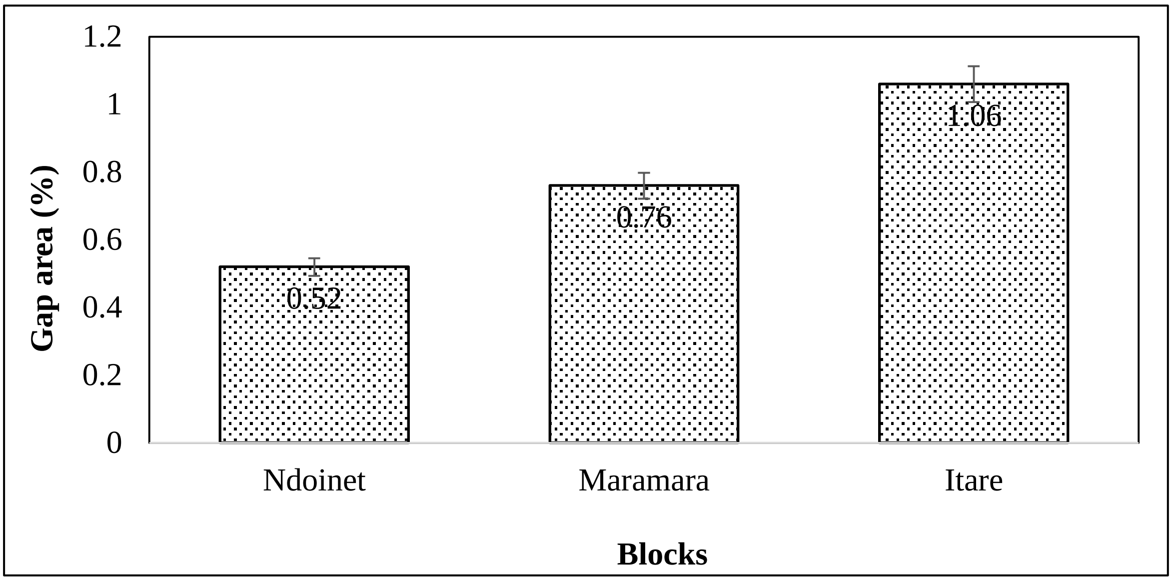


Figure 4.2.5: Percentage canopy gap area in the three blocks of SW Mau Forest reserve

4.2.2 Influence of canopy gap size on microsite conditions in SW Mau Forest reserve

Three microsite conditions were considered under this sub-topic; soil moisture, soil temperature and light intensity **(**Table 4.2.2 and Appendix I**).**

Table 4.2.2: Mean of microsite conditions in SW Mau Forest reserve canopy gap sizes

Gap sizes	Soil moisture (%)	Light intensity (Cd)	Soil temperature (^{0}C)
Large	21.10	888.00	18.60
Medium	22.40	783.00	17.50
Small	24.70	707.00	16.80

Light intensity was measured in Candela (Cd).

Influence of canopy gap size on soil moisture in SW Mau Forest reserve

Small gap sizes recorded the highest mean in soil moisture (24.70%) compared with medium (22.40%) and large gap (21.10%) sizes (Table 4.2.2). However, Kruskal-Wallis rank sum test revealed a non-significant difference in soil moisture in the three gap sizes; chi-squared = 16.72, df = 10, P = 0.08. Since P was above 0.05, null hypothesis could not be rejected, hence was concluded that gap size had no influence on soil moisture in SW Mau Forest reserve.

Influence of canopy gap size on soil temperature in SW Mau Forest reserve

Large gap sizes recorded the highest mean in soil temperature (18.60^0C) compared with medium (17.50^0C) and small gap sizes (16.80^0C) (Table 4.2.2). The Kruskal-Wallis rank sum test results were as follows; chi-squared = 19.00, df = 3, *P* =0.00*, which showed a significant difference in soil temperature in the three gap sizes. A *posthoc* test was then done, whereby pairwise comparisons using Wilcoxon rank sum test with continuity correction indicated that small and medium gap sizes differed significantly (*P*= 0.02). Since *P* value was <0.05 (*P* =0.00*), null hypothesis was rejected and was concluded that gap size had an influence on soil temperature in SW Mau Forest reserve.

Influence of canopy gap size on light intensity in SW Mau Forest reserve

Light intensity was again recorded higher in large gap sizes (888.00 Cd) compared with medium (783.00 Cd) and small gap sizes (707.00 Cd) (Table 4.2.2). However, Kruskal-Wallis rank sum test resulted that chi-squared = 30.73, df = 27, *P* = 0.28. This, therefore, implied that there was no significant difference in light intensity in the three gap sizes, therefore, null hypothesis could not be rejected and was concluded that gap size had no influence on light intensity in SW Mau Forest reserve.

4.3 Influence of canopy gap size on woody vegetation population parameters in SW Mau Forest reserve

Under this sub-topic, only three woody vegetation population parameters were considered. They included; regeneration, forest structure and species diversity.

4.3.1 Influence of canopy gap size on regeneration of woody species in SW Mau Forest reserve

Small gap sizes showed the highest number of regenerating seedlings (959) compared with medium (664) and large gap sizes (412) (Table 4.3.1). In addition, small gap sizes recorded 20 families, 21 genera and 22 species. Medium gap sizes on the other hand recorded 18 families, 19 genera and 19 species. Large gap sizes recorded the highest; 21 families, 23 genera and 23 species regenerating (Appendix III). *Psydrax schimperiana* was the dominant species (218) followed by *Macaranga kilimandscaricha* (199), *Syzygium guineensii* (195) in the small gap sizes. The total count of regeneration in medium gap sizes was 664 with *Psydrax schimperiana* (155) taking the lead followed by *Tabernaemontana stapfiana* (149).

Large gap sizes, however, recorded the least count in regeneration (412) with *Tabernaemontana stapfiana* taking the lead (111) followed by *Macaranga kilimandscharica* (81) (Figure 4.3.1).

Table 4.3.1: Occurrence and composition of regenerating species in canopy gap sizes

Family	Genus	Species	SGS (%)	MGS (%)	LGS (%)
Rubiaceae	*Psydrax*	*Psydrax schimperiana*	218(22.73)	155(23.34)	55(13.35)
Euphorbiaceae	*Macaranga*	*Macaranga kilimandscharica*	199(20.75)	42(6.33)	81(19.66)
Myrtaceae	*Syzygium*	*Syzygium guineense*	195(20.33)	25(3.77)	41(9.95)
Apocynaceae	*Tabernaemon tana*	*Tabernaemontana stapfiana*	79(8.24)	149(22.44)	111(26.94)
Podocarpaceae	*Podocarpus*	*Podocarpus latifolius*	41(4.28)	21(3.16)	3(0.73)
Mimosaceae	*Albizia*	*Albizia gummifera*	33(3.44)	45(6.78)	11(2.67)
Primulaceae	*Rapanea*	*Rapanea melanophloes*	30(3.13)	3(0.45)	1(0.24)
Meliaceae	*Trichilia*	*Trichilia emitica*	27(2.82)	67(10.09)	5(1.21)
Euphorbiaceae	*Neoboutonia*	*Neoboutonia macrocalyx*	26(2.71)	70(10.54)	32(7.77)
Fabaceae	*Acacia*	*Acacia mearnsii*	24(2.50)	----------	---------
Celastraceae	*Maytenus*	*Maytenus rotudos*	15(1.56)	----------	14(3.40)
Myricaceae	*Morella*	*Morella salicifora*	15(1.56)	----------	---------
Rosaceae	*Prunus*	*Prunus africana*	13(1.36)	3(0.45)	2(0.49)
Sapindaceae	*Allophylus*	*Allophylus abyssinicus*	9(0.9)	29(4.37)	8(1.94)
Rutaceae	*Zanthoxyllum*	*Zanthoxyllum gilletii*	9(0.94)	28(4.22)	8(1.94)
Fabaceae	*Millettia*	*Millettia dura*	7(0.73)	1(0.15)	12(2.91)
Araliaceae	*Schefflera*	*Schefflera volkensii*	3(0.31)	--------	3(0.73)

Monimiaceae	*Xymalos*	*Xymalos monospora*	3(0.31)	2(0.30)	8(1.94)
Flacourtiaceae	*Dovyalis*	*Dovyalis abyssinica*	2(0.21)	1(0.15)	---------
Fabaceae	*Acacia*	*Acacia lahai*	1(0.10)	----------	1(0.24)
Alariaceae	*Polyscias*	*Polyscias capensis*	1(0.10)	----------	1(0.24)
Others	*Others*	*Others*	9(0.94)	----------	2(0.49)
Pittosporaceae	*Pittosporum*	*Pittosporum viridiflorum*	-------	4(0.60)	---------
Asparagaceae	*Dracaena*	*Dracaena steudneri*	-------	11(1.66)	2(0.49)
Boraginaceae	*Ehretia*	*Ehretia cymosa*	-------	4(0.60)	9(2.18)
Hamamelidaceae	*Trichocladus*	*Trichocladus ellipticus*	--------	4(0.60)	---------
Meliaceae	*Ekebergia*	*Ekebergia capensis*	--------	--------	1(0.49)
	Teclea	*Teclea nobilis*	-------	--------	1(0.49)
S20,M18,L21	**S21,M19,L23**	**S22,M19,L23**	**959(100)**	**664(100)**	**412(100)**

SGS in the table represent small gap size, MGS represent medium gap size while LGS represent large gap size. S, M and L also represent small, medium and large gaps respectively.

Population spread of species regenerating in the three different gap sizes were also distributed as indicated in Figure 4.3.1.

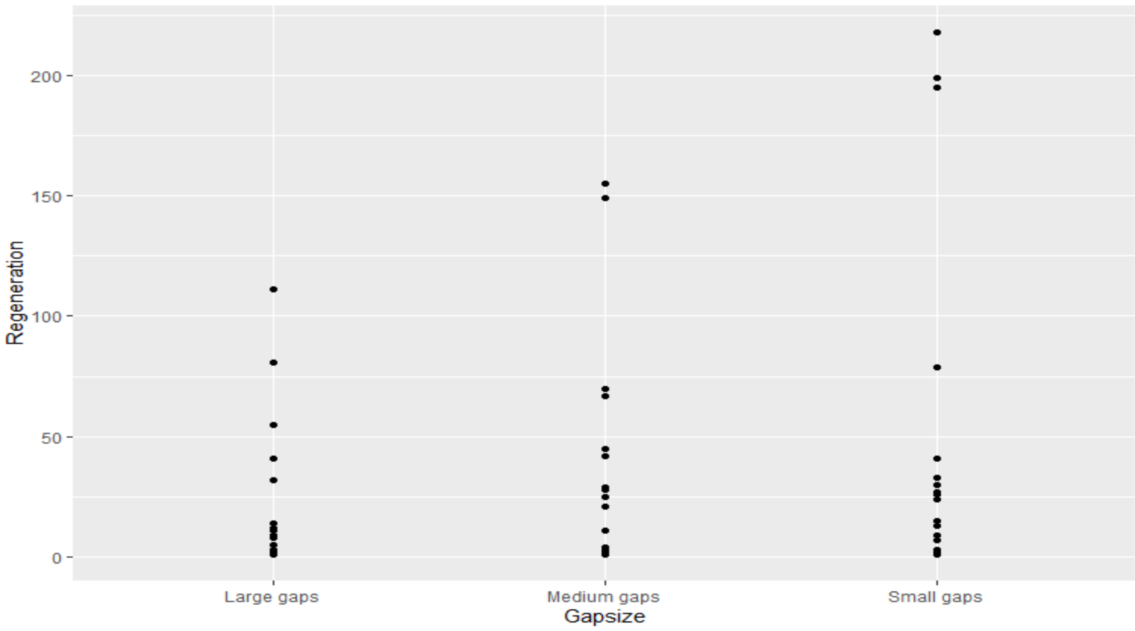


Figure 4.3.1: Ggplot showing regeneration distribution in the gap sizes.

The mean regeneration in the three gap sizes showed that there was high regeneration in the small gap sizes (43.59) compared with medium (35.95) and large gap sizes (17.91) (Figure 4.3.2). The means were equivalent to 45.00%, 36.00% and 19.00% respectively for the three gap sizes.

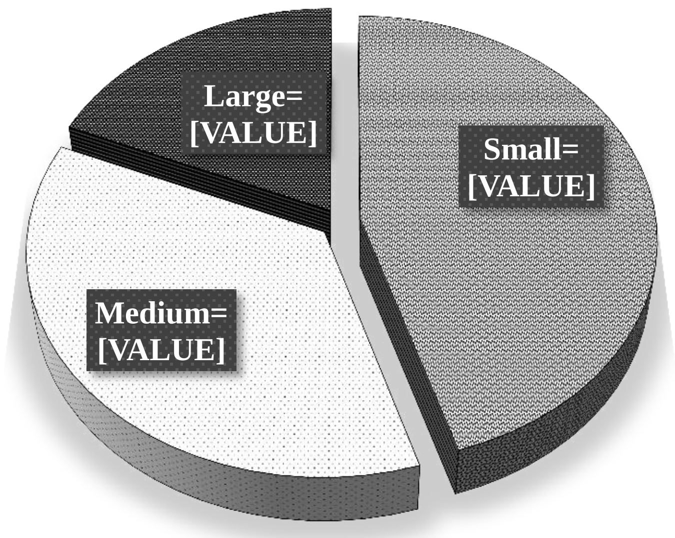


Figure 4.3.2: Mean regeneration in the different gap sizes of SW Mau Forest reserve.

Results on species regeneration in the different gap sizes using Kruskal-Wallis rank sum test recorded; chi-squared = 36.77, df = 36, *P* = 0.43). *P*>0.05 which showed that there was no significant difference in regeneration in the three gap sizes. Therefore, null hypothesis failed to be rejected and was concluded that gap size had no influence on forest regeneration in SW Mau Forest reserve.

This phenomenon could be attributed to the existence of ground cover species, such as *Ribes* spp., ferns and *Piper capensis*. These formed a dense canopy in the gaps and resulted into shedding of excess debris on the forest floor which could not allow for adequate seed germination of woody species (Plate 4.3.1).

a b

Plate 4.3.1: Images of goose berries (Ribes spp.) in Ndoinet forest block

a) Goose berries debris and b) goose berries shoots. S

4.3.2 Influence of canopy gap size on forest growth and structure in SW Mau Forest reserve

Results on forest structure categorization using dbh and tree heights showed that most of the life forms were seedlings followed by saplings in the three gap sizes. Over 60.00% of the count belonged to seedlings in the three gap sizes while saplings were 20.00% in small and medium gap sizes implying that the forest was still at the early stages of natural succession following disturbances. Table 4.3.2 shows the distribution of woody vegetation in the ground, understorey and canopy layers of the forest.

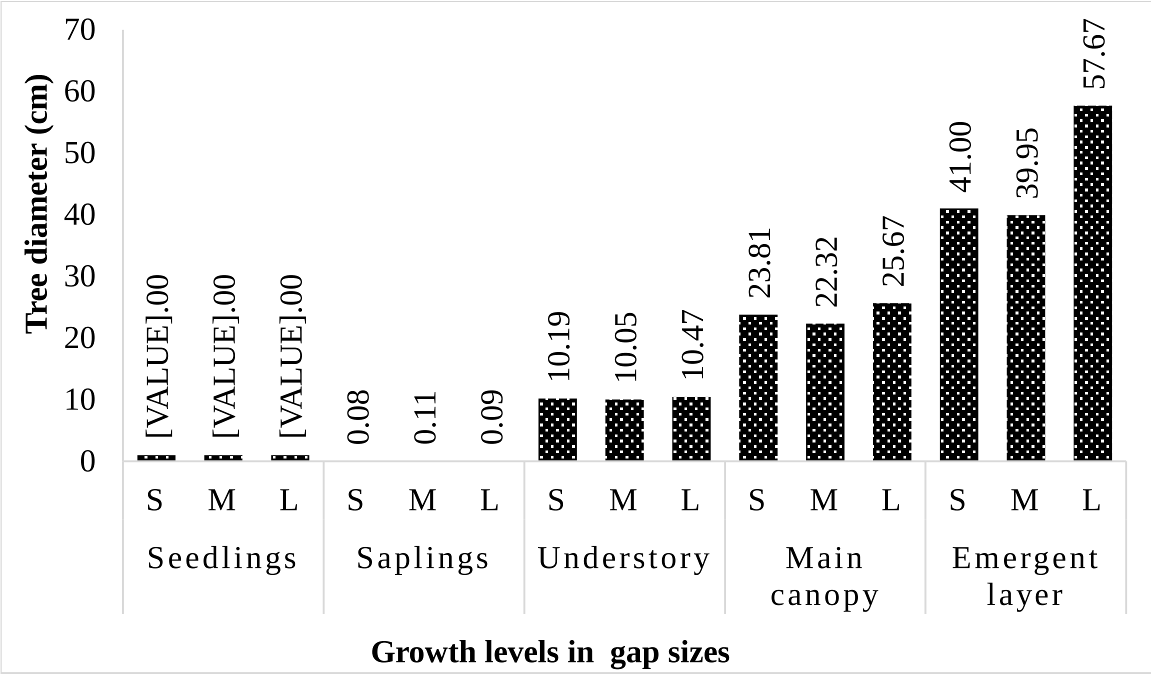
Table 4.3.2: Diameter and height distribution in the canopy gap sizes across forest vertical layers.

Gsize		Diameter (cm)			Height (m)		
Vertical layers		Freq	Mean	%	Freq	Mean	%
Seedlings	S	665.00	1.00	60.62	665.00	1.00	60.62
	M	509.00	1.00	65.85	509.00	1.00	65.85

	L	338.00	1.00	65.50	338.00	1.00	65.50
Saplings	S	259.00	0.08	23.61	259.00	2.24	23.61
	M	158.00	0.11	20.44	158.00	2.34	20.44
	L	78.00	0.09	15.10	78.00	2.41	15.10
Understorey	S	27.00	10.19	2.46	27.00	10.82	2.46
	M	19.00	10.05	2.46	19.00	4.57	2.46
	L	19.00	10.47	3.70	19.00	10.65	3.70
Main canopy	S	125.00	23.81	11.39	125.00	23.19	11.39
	M	68.00	22.32	8.80	68.00	23.51	8.80
	L	64.00	25.67	12.40	64.00	24.15	12.40
Emergent layer	S	21.00	41.00	1.91	21.00	43.33	1.91
	M	19.00	39.95	2.46	19.00	44.34	2.46
	L	17.00	57.67	3.30	17.00	42.42	3.30

S represent small gap sizes; M represent medium gap sizes while L represent large gap sizes.

Mean sapling diameter was generally low in the three gap sizes. Understorey (4-15 m in height) was low throughout the gap sizes with medium gap sizes recording the least mean diameter (10.05). Medium gap sizes again recorded the least in mean diameter of the main canopy layer (22.32) as well as in emergent layers (39.95). However, at sapling level, mean height increased with increase in gap size (2.24, 2.34, 2.41 for small, medium and large gap sizes respectively). Mean height of understorey level was high in small gap sizes (10.82), followed by large gap sizes (10.65) and lastly medium gap sizes (4.57). Mean height of the main canopy and emergent layer, however, increased with increase in gap size (Figure 4.3.3).



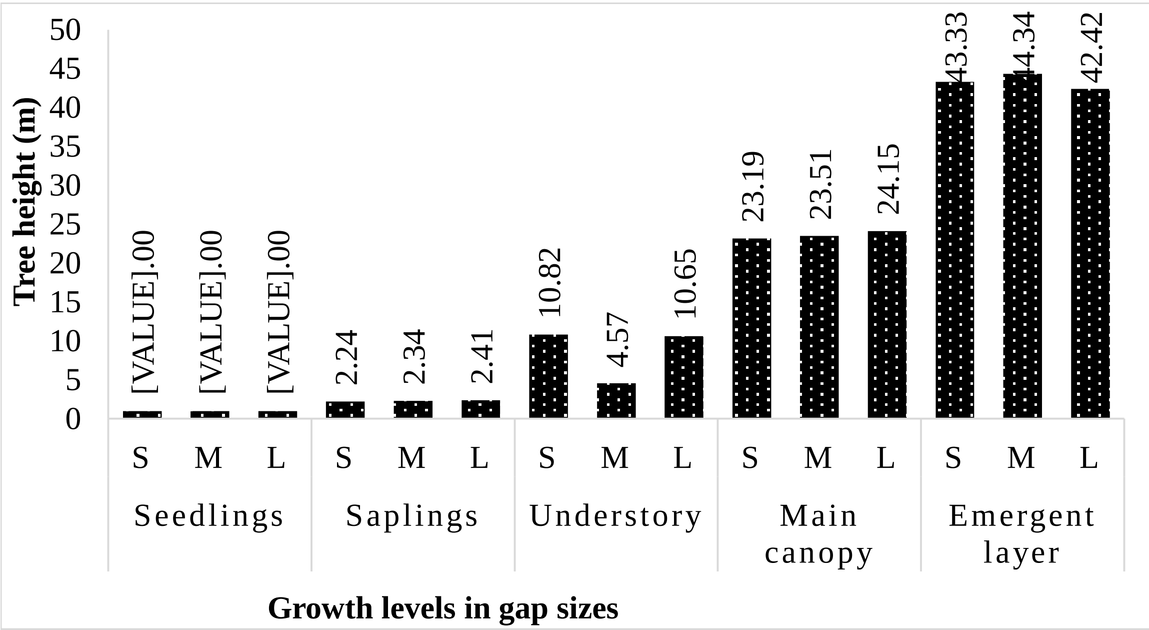


Figure 4.3.3: Horizontal and vertical forest stratification based on growth stages.

Tree species with dbh of 4 cm and above were used to determine the forest structural complexity using Holdridge's Complexity Index. Results in the different forest gap sizes showed that small gap sizes recorded the highest complexity index (HCI=40.00) based on the basal area, tree density, number of species and mean tree height compared with medium and large gap sizes which recorded <HCI 10.00 (Figure 4.3.4).

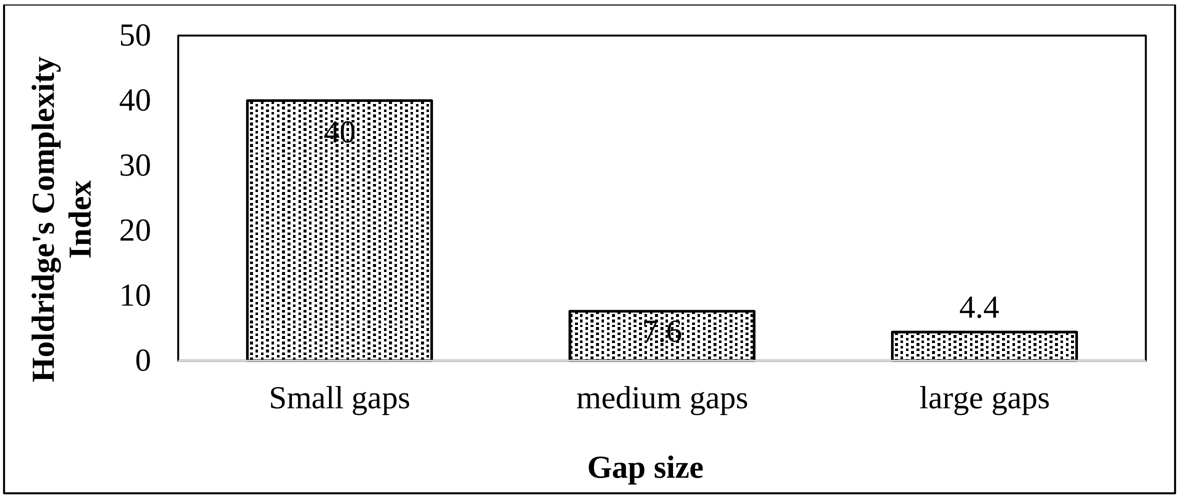


Figure 4.3.4: Holdridge's Complexity Index in the three different canopy gap sizes.

Nevertheless, there was no significant difference in forest structure in the three gap sizes as indicated by Kruskal-Wallis (chi-squared = 138.04, df = 126.00, $P = 0.22$), since P was >0.05. Therefore, null hypothesis failed to be rejected and it was concluded that gap size had no influence on forest structure in SW Mau Forest reserve.

4.3.3 Influence of canopy gap size on species diversity in SW Mau Forest reserve

Small gap sizes recorded the highest species diversity; 24 families, 26 genera and 28 species in the sample plots. Medium gap sizes followed closely with 23 families, 25 genera and 25 species while large gap sizes recorded the least; 22 families, 24 genera and 24 species. A total of 5 species were not present in small gap sizes; and these included; *Trichocladus ellipticus*, *Dracaena steudneri*, *Pittosporum viridiflorum*, *Dovyalis macrocalyx* and *Rhamnus prinoides.*

Additionally, 10 species were not reported in medium gap sizes; *Maytenus rotudos*, *Ekebergia capensis*, *Xymalos monospora*, *Acacia mearnsii*, *Diospyros abyssinica*, *Acacia lahai*, *Maytenus ovatus*, *Dovyalis abyssinica*, *Schefflera volkensii* and *Teclea nobilis.* Also, 9 species were not reported in large gap sizes; *Acacia mearnsii*, *Diospyros abyssinica*, *Dombeya torrida*, *Dovyalis abyssinica*, *Maytenus ovatus*, *Rhamnus prinoides*, *Trichocladus ellipticus*, *Pittosporum viridiflorum* and *Dovyalis macrocalyx* (Table 4.3.3 and Appendix III).

Table 4.3.3: Status of species in the different canopy gap sizes

Family	**Genus**	**Species**	**SG**	**MG**	**LG**
Euphorbiaceae	*Macaranga*	*Macaranga kilimandscharica*	+	+	+
Myrtaceae	*Syzygium*	*Syzygium guineense*	+	+	+
Rubiaceae	*Psydrax*	*Psydrax schimperiana*	+	+	+
Apocynaceae	*Tabernaemontana*	*Tabernaemontana stapfiana*	+	+	+
Meliaceae	*Trichilia*	*Trichilia emitica*	+	+	+
Euphorbiaceae	*Neoboutonia*	*Neoboutonia macrocalyx*	+	+	+
Myricaceae	*Morella*	*Morella salicifora*	+	+	+
Celastraceae	*Maytenus*	*Maytenus rotudos*	+	-	+
Podocarpaceae	*Podocarpus*	*Podocarpus latifolius*	+	+	+
Primulaceae	*Rapanea*	*Rapanea melanophloes*	+	+	+
Rutaceae	*Zanthoxyllum*	*Zanthoxyllum gilletii*	+	+	+
Mimosaceae	*Albizia*	*Albizia gummifera*	+	+	+
Alariaceae	*Polyscias*	*Polyscias capensis*	+	+	+
Sapindaceae	*Allophylus*	*Allophylus abyssinicus*	+	+	+
Fabaceae	*Millettia*	*Millettia dura*	+	+	+
Fabaceae	*Acacia*	*Acacia lahai*	+	-	+
Meliaceae	*Ekebergia*	*Ekebergia capensis*	+	-	+
Monimiaceae	*Xymalos*	*Xymalos monospora*	+	-	+
Fabaceae	*Acacia*	*Acacia mearnsii*	+	-	-
Ebenaceae	*Diospyros*	*Diospyros abyssinica*	+	-	-
Sterculiaceae	*Dombeya*	*Dombeya torrida*	+	+	-
Flacourtiaceae	*Dovyalis*	*Dovyalis abyssinica*	+	-	-
Boraginaceae	*Ehretia*	*Ehretia cymosa*	+	+	+

Celastraceae	*Maytenus*	*Maytenus ovatus*	+	-	-
Rosaceae	*Prunus*	*Prunus. africana*	+	+	+
Araliaceae	*Schefflera*	*Schefflera volkensii*	+	-	+
Rutaceae	*Teclea*	*Teclea nobilis*	+	-	+
Others	Others	*Others*	+	-	+
Rhamnaceae	*Rhamnus*	*Rhamnus prinoides*	-	+	-
Hamamelidaceae	*Trichocladus*	*Trichocladus ellipticus*	-	+	-
Asparagaceae	*Dracaena*	*Dracaena steudneri*	-	+	+
Pittosporaceae	*Pittosporum*	*Pittosporum viridiflorum*	-	+	-
Flacourtiaceae	*Dovyalis*	*Dovyalis macrocalyx*	-	+	-
SGS24	***SGS26***	***SGS28***			
MGS23	***MGS25***	***MGS25***			
LGS22	***LGS24***	***LGS24***			

SGS represent small gap size; MGS represent medium gap size while LGS represent large gap size. Moreover, + represent presence while - represent absence of a species.

However, species diversity was higher in the three gap sizes (Shannon-Weiner's Diversity Index >2.00) with large gap sizes being the highest (2.63) followed by medium gap sizes (2.60) and lastly small gap sizes (2.58). In terms of species dominance and evenness, large gap sizes still took the lead followed by medium and small gap sizes (Figure 4.3.5 and Appendix III).

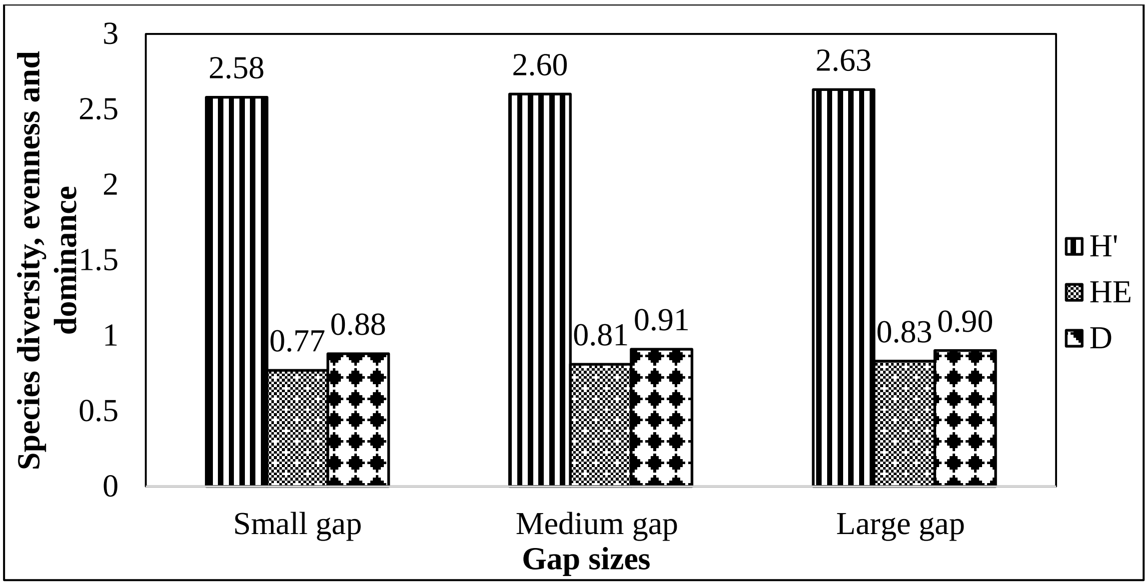


Figure 4.3.5: Species diversity, evenness and dominance in SW Mau Forest reserve
H` represent Shannon-Weiner's Diversity Index, HE represents Shannon evenness and D represent Simpson's Diversity Index.

However, the test for significant difference in species diversity in the gap sizes using Kruskal-Wallis gave the results as follows; chi-squared = 24.80, df = 19, P = 0.17. This showed a higher P value above 0.05, hence null hypothesis failed to be rejected and was concluded that gap size had no influence on species diversity in SW Mau Forest reserve.

4.4 Comparing microsite conditions and vegetation population parameters between disturbed and undisturbed sites of SW Mau Forest reserve

The purpose of this section is to compare microsite conditions, regeneration, forest structure as well as species diversity between disturbed and undisturbed sites of SW Mau Forest reserve. Results are presented in form of tables and graphs while Wilcoxon pairwise comparisons is used to compare parameters in the two sites for inferential statistics.

The figure below **(**Figure 4.4.1**)** shows the distribution of sample points from where data was collected in undisturbed sites. The sampling was conducted in quadrats of 30 by 20 m within the main plots of 500 by 500 m in every block.

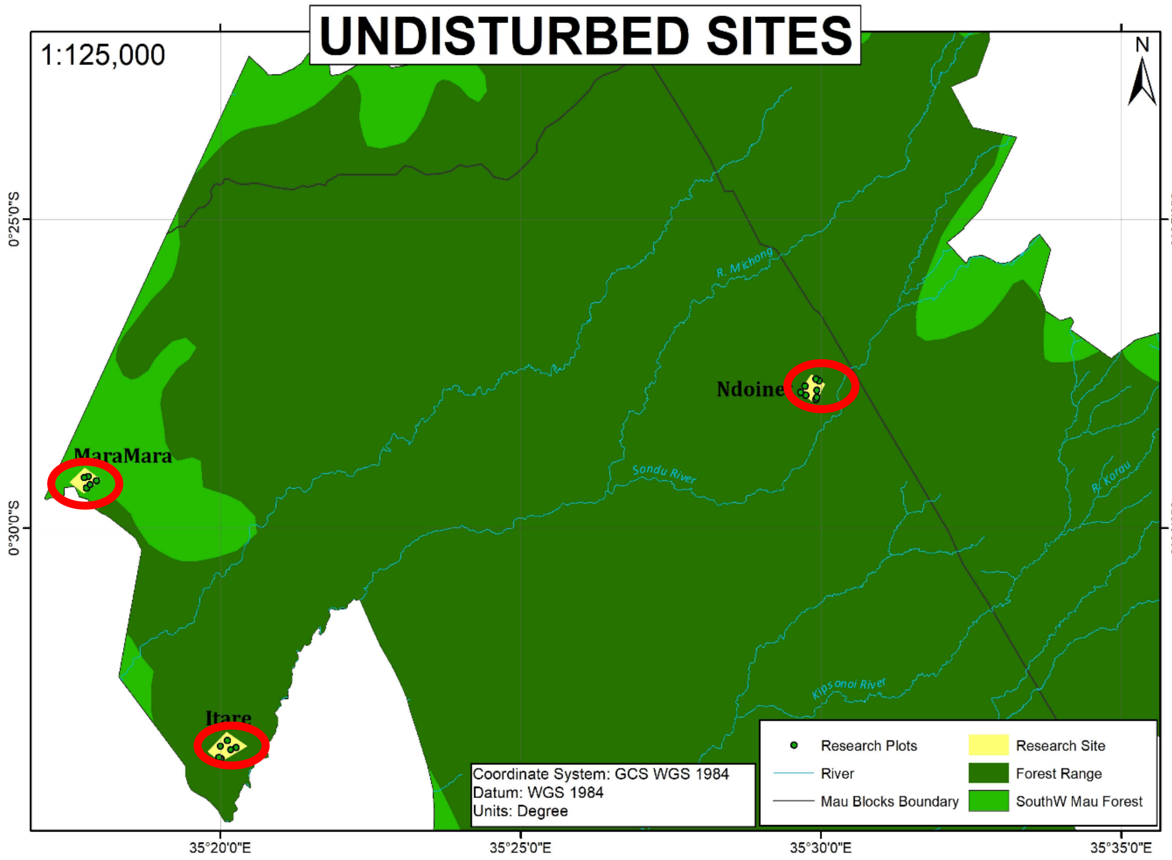


Figure 4.4.1: Distribution of sample plots in SW Mau Forest reserve blocks

4.4.1 Comparing soil moisture in disturbed and undisturbed sites of SW Mau Forest reserve

Table 4.4.1: Microsite conditions in SW Mau Forest reserve in disturbed and undisturbed sites

Site status	Soil moisture (%)	Soil temperature (^{0}C)	Light intensity (Cd)
Disturbed	22.70	17.80	804.00
Undisturbed	26.20	17.00	586.00

Mean soil moisture was higher in undisturbed sites (26.20%) compared with disturbed sites (22.70%) (Table 4.4.1). However, there was no significant difference in soil moisture between disturbed and undisturbed sites of the forest (Wilcoxon rank sum test = 275.00, *P* = 0.07), hence null hypothesis failed to be rejected and was concluded that soil moisture in disturbed and undisturbed sites was the same in SW Mau Forest reserve.

4.4.2 Comparing soil temperature in disturbed and undisturbed sites of SW Mau Forest reserve

Soil temperature was recorded slightly higher in disturbed sites (17.80^{0}C) compared with undisturbed sites (17.00^{0}C) (Table 4.4.1). When testing for significant differences in soil temperature between disturbed and undisturbed sites, Wilcoxon rank sum test = 446.00, P = 0.34, P>0.05. This showed that there was no significant difference in soil temperature between disturbed and undisturbed sites of the forest. Null hypothesis, therefore, failed to be rejected and was concluded that soil temperature between the two sites was the same in SW Mau Forest reserve.

4.4.3 Comparing light intensity in disturbed and undisturbed sites of SW Mau Forest reserve

Moreover, mean light intensity was higher in disturbed sites (804.00 Cd) than in undisturbed sites (586.00 Cd) (Table 4.4.1). Light intensity between disturbed and undisturbed sites of the forest varied significantly; Wilcoxon rank sum test = 555.00, P = 0.01, P<0.05. Therefore, there was a significant difference in light intensity between disturbed and undisturbed sites of SW Mau Forest reserve, hence null hypothesis was rejected and was concluded that, light intensity between disturbed and undisturbed sites of SW Mau Forest reserve was not the same.

4.4.4 Comparing regeneration in disturbed and undisturbed sites of SW Mau Forest reserve

Regeneration was determined based on statistics from two growth levels; seedlings and saplings. The results showed that disturbed sites had the highest number of species regeneration (2035) with a total of 29 species (Table 4.4.4 and Appendix IV). However, undisturbed sites recorded a low number of total regeneration (1163) with a total of 25 species. Moreover, *Psydrax schimperiana* was the most dominant species both in disturbed and undisturbed sites; 428 and 233 respectively followed by *Tabernaemontana stapfiana* and *Macaranga kilimandscharica* among other species**.**

Maytenus rotudos, Prunus africana, Pittosporum viridiflorum, Trichocladus ellipticus, Schefflera abyssinica, Schefflera volkensii, Acacia lahai, Polyscias capensis and *Ekebergia capensis* were not identified in the seedling and sapling categories in the undisturbed sites of SW Mau Forest reserve.

Table 4.4.4: Regeneration of species in disturbed and undisturbed sites.

Species	Disturbed sites	Undisturbed sites
Psydrax schimperiana	428(21.03)	233(20.03)
Tabernaemontana stapfiana	339(16.66)	165(14.19)
Macaranga kilimandscharica	322(15.82)	171(14.70)
Syzygium guineense	261(12.83)	64(5.50)
Neoboutonia macrocalyx	128(6.29)	17(1.46)
Trichilia emitica	99(4.86)	149(12.81)
Albizia gummifera	89(4.37)	36(3.10)
Podocarpus latifolius	65(3.19)	12(1.03)
Allophylus abyssinicus	46(2.26)	151(12.98)
Zanthoxyllum gilletii	45(2.21)	7(0.60)
Rapanea melanophloes	34(1.67)	45(3.90)
Maytenus rotudos	29(1.43)	-------
Acacia mearnsii	24(1.18)	24(2.06)
Millettia dura	20(0.98)	3(0.26)
Prunus africana	18(0.88)	-------
Morella salicifora	15(0.73)	9(0.77)
Dracaena steudneri	13(0.64)	1(0.09)
Ehretia cymosa	13(0.64)	21(1.81)
Xymalos monospora	13(0.64)	10(0.86)
Pittosporum viridiflorum	4(0.20)	--------
Trichocladus elipticus	4(0.20)	--------
Dovyalis abyssinica	3(0.15)	1(0.09)
Schefflera abyssinica	3(0.15)	--------
Schefflera volkensii	3(0.15)	-------
Acacia lahai	2(0.10)	--------
Polyscias capensis	2(0.10)	--------
Ekebergia capensis	1(0.05)	--------
Teclea nobilis	1(0.05)	7(0.60)
Others	11(0.54)	20(1.72)
Maytenus undata	--------	5(0.43)
Vungueria madagascariensis	--------	5(0.43)

Polycias fulva	---------	4(0.34)
Maytenus ovatus	--------	2(0.17)
Dombeya torrida	--------	1(0.09)
Disturbed 29	**2035(100.00)**	**1163(100.00)**
Undisturbed 25		

Values indicated in brackets represent the count %.

However, when testing for inferential statistics, pairwise comparisons using Wilcoxon rank sum test with continuity correction reported that, *P*=0.58 *P value adjustment method*: *BH*. This revealed that there was no significant difference in regeneration between disturbed and undisturbed sites of the forest. Null hypothesis failed to be rejected and was concluded that regeneration between the two sites was the same in SW Mau Forest reserve.

4.4.5 Comparing forest growth and structure in disturbed and undisturbed sites of SW Mau Forest reserve

Seedlings showed higher population compared with the other growth stages in both disturbed and undisturbed sites. However, disturbed sites recorded the highest seedling population (1511) compared with undisturbed sites (849) (Table 4.4.5). This could be due to higher means of light intensity, moderate temperatures and moisture availability which allowed for seed germinations in disturbed sites.

Table 4.4.5: Species growth stages in SW Mau Forest reserve

Diameter				**Height**		
Level	**Freq**	**Mean**	**%**	**Freq**	**Mean**	**%**
Seedlings	1511	1.00	63.49	1511	1.0	63.49
	(**849**)	(**1.00**)	(**58.03**)	(**849**)	(**1.00**)	(**58.03**)
Sapling	495	0.08	20.80	495	2.30	20.80
	(**316**)	(**0.04**)	(**21.60**)	(**316**)	(**2.14**)	(**21.60**)
U. canopy	65	10.85	2.73	65	10.54	2.73
	(**43**)	(**10.77**)	(**2.94**)	(**43**)	(**11.83**)	(**2.94**)
M. canopy	260	24.14	10.92	260	23.72	10.92
	(**197**)	(**22.00**)	(**13.47**)	(**197**)	(**24.12**)	(**13.47**)
E. layer	49	42.67	2.06	49	43.52	2.06
	(**58**)	(**45.02**)	(**3.96**)	(**58**)	(**43.96**)	(**3.96**)
Total	2380	78.74	100.00	2380	81.08	100.00
	1463	**78.83**	**100.00**	**1463**	**83.05**	**100.00**

Values in bold represent undisturbed sites while unbold represent disturbed sites. U. represent Under, M. represent Main while E. represent Emergent.

Only tree heights were used to determine the structure of the forest. The figure below (Figure 4.4.2) shows how the forest structure was stratified into layers. Emergent layer recorded the least in population. The ununiformed canopy layer resulted into canopy roughness. This could be attributed to discrepancies in resource distribution in the forest due

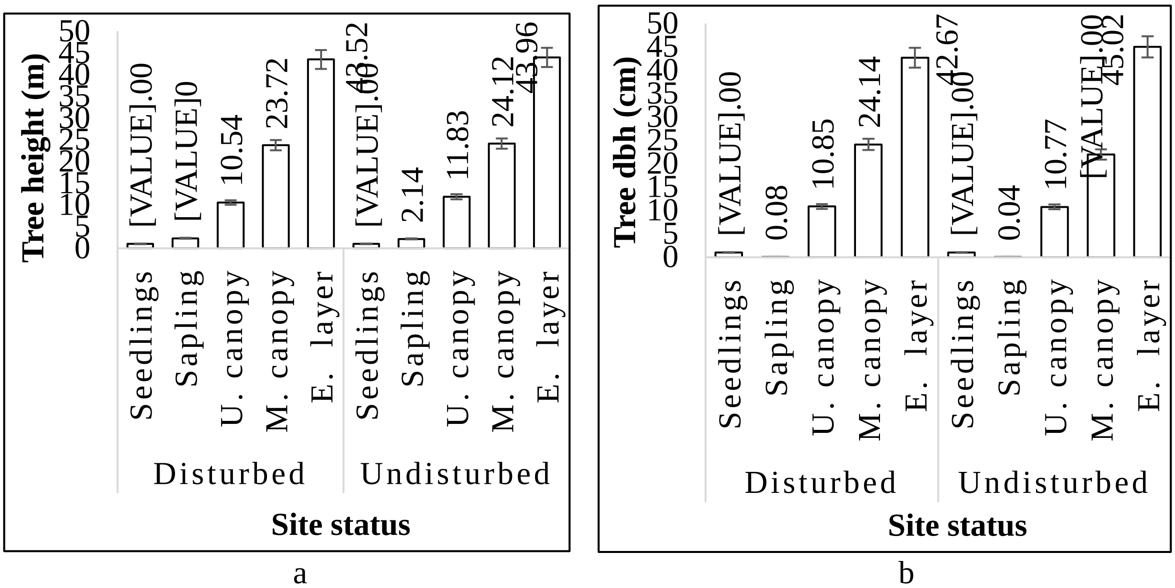


Figure 4.4.2: The forest physiognomic appearance

to interceptions.

Forest structure was taken based on; a) tree dbh and b) height in SW Mau Forest reserve.

The mean tree diameter and height was generally high in undisturbed sites (24.9 cm and 26.3 m respectively) compared with the disturbed sites (24.1 cm and 23.9 m respectively) as indicated in Figure 4.4.3. This could be explained by the fact that undisturbed sites generally lacked constant disturbances mostly from human activities unlike disturbed sites, hence trees thrived well.

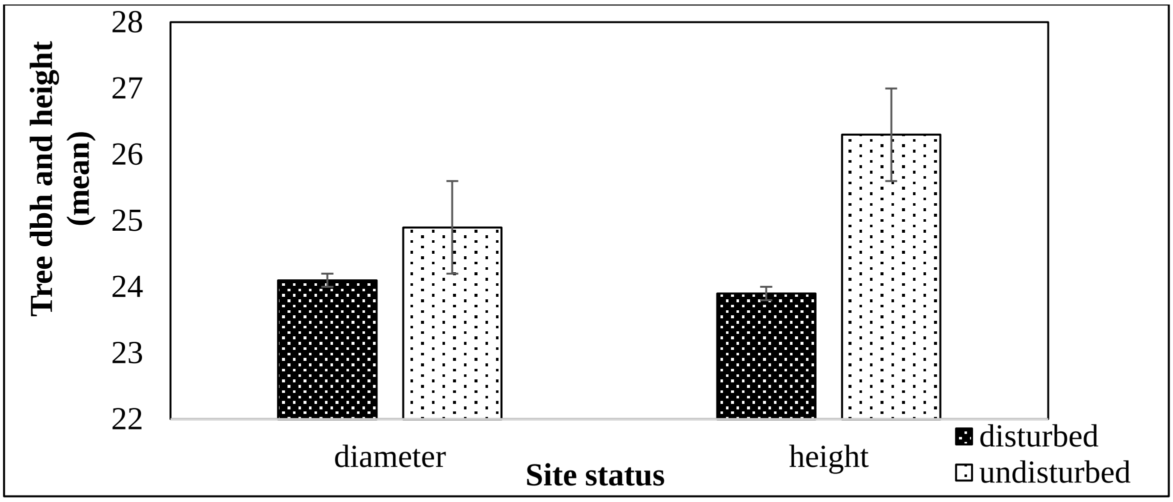


Figure 4.4.3: Tree dbh and height (%) in SW Mau Forest reserve
Tree dbh was measured in cm while tree height was measured in m.

To evaluate structural complexity of the forest, tree species with dbh of 4 cm and above were considered both in disturbed and undisturbed sites. Disturbed sites recorded the highest complexity index (HCI=332.70) compared with undisturbed sites (HCI=204.60) (Figure 4.4.4). This could be due to ruggedness in the canopy layer caused by differences in tree height.

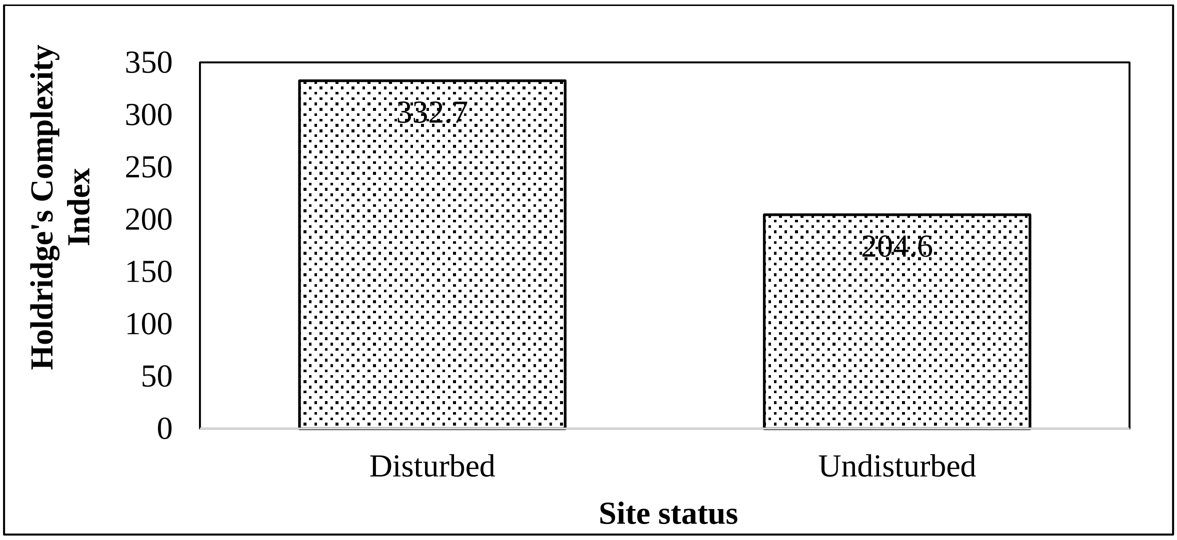


Figure 4.4.4: Holdridge's Complexity Index.

To test for significant difference in the forest structure between disturbed and undisturbed sites of SW Mau Forest reserve, pairwise comparisons using Wilcoxon rank sum test with continuity correction was used, P = 0.01; *P value adjustment method*: *BH*. This revealed that forest structure between disturbed and undisturbed sites of the forest was not the same, therefore, null hypothesis was rejected.

4.4.6 Comparing species diversity in disturbed and undisturbed sites of SW Mau Forest reserve

The distribution of species between disturbed and undisturbed sites of SW Mau Forest reserve showed a total of 29 families, 31 genera and 34 species in disturbed sites while 24 families, 26 genera and 27 species were reported in undisturbed sites. On the other hand, a total of 11 species were reported in disturbed sites which never appeared in undisturbed sites (Table 4.4.6 and Appendix II). It was observed that 4 species were present in undisturbed sites which were not present in disturbed sites. The species included; *Maytenus undata, Olea capensis, Cassipourea malosana* and *Vangueria madagascariensis.*

Table 4.4.6: Species diversity in disturbed and undisturbed sites

Family	**Genus**	**Species**	**Dist.**	**Undist.**
Euphorbiaceae	*Macaranga*	*Macaranga kilimandscharica*	+	+
Apocynaceae	*Tabernaemontana*	*Tabernaemontana stapfiana*	+	+
Euphorbiaceae	*Neoboutonia*	*Neoboutonia macrocalyx*	+	+
Rubiaceae	*Psydrax*	*Psydrax schimperianas*	+	+
Myrtaceae	*Syzygium*	*Syzygium guineense*	+	+
Meliaceae	*Trichilia*	*Trichilia emitica*	+	+
Rutaceae	*Zanthoxyllum*	*Zanthoxyllum gilletii*	+	+
Mimosaceae	*Albizia*	*Albizia gummifera*	+	+
Myricaceae	*Morella*	*Morella salicifora*	+	+
Primulaceae	*Rapanea*	*Rapanea melanophloes*	+	+
Celastraceae	*Maytenus*	*Maytenus rotudos*	+	-
Podocarpaceae	*Podocarpus*	*Podocarpus latifolius*	+	+
Sapindaceae	*Allophylus*	*Allophylus abyssinicus*	+	+
Alariaceae	*Polyscias*	*Polyscias capensis*	+	-
Fabaceae	*Millettia*	*Millettia dura*	+	+
Boraginaceae	*Ehretia*	*Ehretia cymosa*	+	+
Rosaceae	*Prunus*	*Prunus africana*	+	-
Monimiaceae	*Xymalos*	*Xymalos monospora*	+	+
Meliaceae	*Ekebergia*	*Ekebergia capensis*	+	-

Araliaceae	*Schefflera*	*Schefflera volkensii*	+	-
Fabaceae	*Acacia*	*Acacia lahai*	+	-
Sterculiaceae	*Dombeya*	*Dombeya torrida*	+	+
Asparagaceae	*Dracaena*	*Dracaena steudneri*	+	+
Rhamnaceae	*Rhamnus*	*Rhamnus prinoides*	+	-
Hamamelidaceae	*Trichocladus*	*Trichocladus ellipticus*	+	-
Rutaceae	*Teclea*	*Teclea nobilis*	+	+
Fabaceae	*Acacia*	*Acacia mearnsii*	+	+
Ebenaceae	*Diospyros*	*Diospyros abyssinica*	+	-
Flacourtiaceae	*Dovyalis*	*Dovyalis abyssinica*	+	+
Flacourtiaceae	*Dovyalis*	*Dovyalis macrocalyx*	+	-
Celastraceae	*Maytenus*	*Maytenus ovatus*	+	+
Pittosporaceae	*Pittosporum*	*Pittosporum viridiflorum*	+	-
Alariaceae	*Polyscias*	*Polyscias fulva*	+	+
Others	Others	*Others*	+	+
Rubiaceae	*Vangueria*	*Vangueria madagascariensis*	-	+
Oleaceae	*Olea*	*Olea capensis*	-	+
Rhizophoraceae	*Cassipourea*	*Cassipourea malosana*	-	+
Celastraceae	*Maytenus*	*Maytenus undata*	-	+
29	31	34		
24	**26**	**27**		

Bolded values represent species in undisturbed site while unbolded represent those in disturbed site. + represent present while - represent absent. Dist. represent Disturbed and Undist. represent Undisturbed sites.

Generally, species diversity was high using Shannon-Weiner's Diversity Index in both disturbed (H`=2.71) and undisturbed sites ($H$`=2.55) indicating higher species diversity (Figure 4.4.5). Shannon Equitability Index was also even and tallied between disturbed and undisturbed sites (*HE*=0.77) while Simpson's species dominance was recorded high in disturbed (*D*=0.90) and undisturbed sites (*D*=0.87).

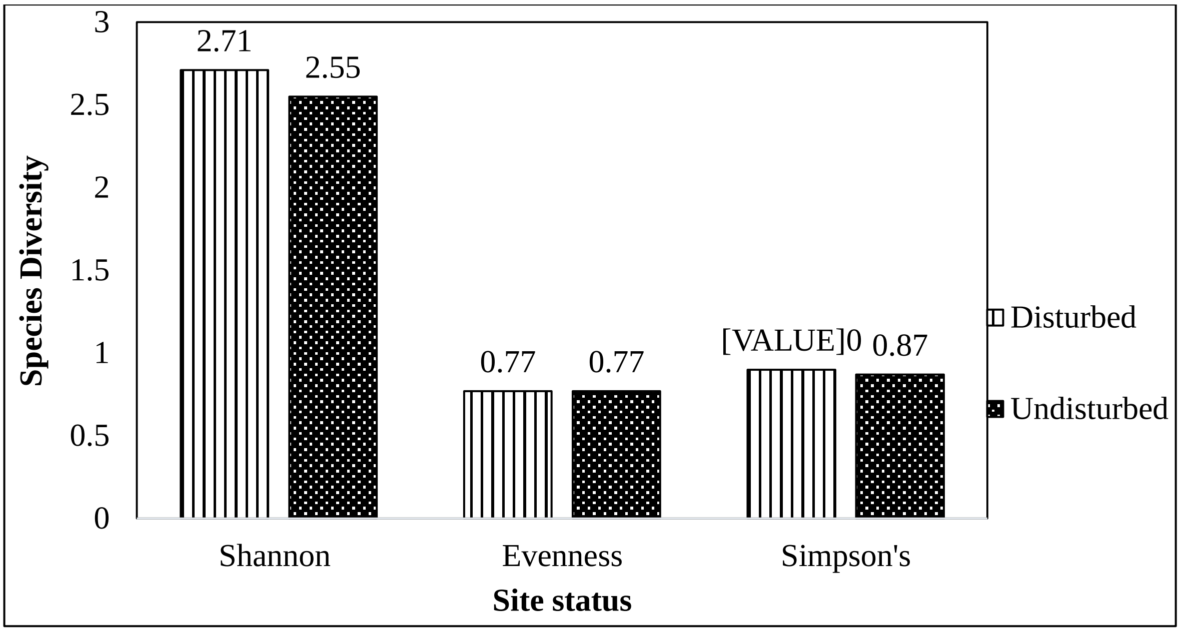


Figure 4.4.5: Species diversity, evenness and dominance in SW Mau Forest reserve

The test for significant difference in species diversity between disturbed and undisturbed sites; pairwise comparisons using Wilcoxon rank sum test with continuity correction showed P = 0.62 using *P value adjustment method*: *BH*. This revealed that there was no significant difference in species diversity between the two sites, as a result, null hypothesis failed to be rejected and was concluded that species diversity between disturbed and undisturbed sites of the forest was the same in SW Mau Forest reserve.

CHAPTER FIVE

DISCUSSION

5.1 Introduction

Under this topic, results are discussed based on the findings from the study. Relevant literatures relating to the findings are included after intensive scrutiny to support the results.

5.2 South-Western Mau Forest reserve canopy gap sizes and how they influence microsite conditions

5.2.1 South-Western Mau Forest reserve canopy gap sizes

In this study, a total of 41 canopy gaps were identified in the three plots of 500 m by 500 m in Itare, Maramara and Ndoinet. However, small gap sizes took the lead followed by medium then large gap sizes. These results were similar to those reported by Hammond *et al.* (2020) who reported a higher number of small gap sizes in Masaryk Training Forest Enterprise Křtiny. A study by Guo *et al.* (2019) also reported similar results of higher number of small gap sizes compared with other gap sizes in temperate forest of the Qinling Mountains, China. The high number of small gap sizes could be attributed to incessant human activities in addition to natural disturbances in the forest (Chaudhry, 2019; Johnson *et al.*, 2021; Lu *et al.*, 2018). This implies that SW Mau Forest reserve gap sizes commonness is determined by the communities dwelling around the forest (social determinants), hence transforming the once existed primary forest into secondary forest. Examples of the determinants entailed but not limited to; agriculture, selective logging, forest burning, settlement, charcoal burning, firewood collection, grazing, footpaths, debarking, cutting and debranching similar to the demonstration by Ocholla *et al.* (2022) and Ronoh *et al.* (2018).

Itare recorded higher number of medium gap sizes followed by large and small gap sizes tying, therefore, highest in gap percentage. On the other hand, Ndoinet recorded the highest number of small gap sizes followed by Maramara then Itare. South-Western Mau Forest reserve blocks, therefore, confirmed that small gap sizes were commonly as a result of artificial disturbances similar to the findings by Ronoh *et al*. (2018). Therefore, small gap sizes could be associated with activities, such as selective logging of some specific high value tree species (Ronoh *et al*., 2018) in the forest, example being *Macaranga kilimandscharica* which was common in Ndoinet block. Medium and large gap sizes were, however, attributed to natural disturbances, such as wind snapping of huge trees as seen in Itare and Maramara; thus, congruent to other demonstrations (Guo *et al.*, 2019; Johnson *et al.*, 2021). The presence of huge trees in Itare could have led to higher gap percentage followed by Maramara and lastly Ndoinet with small trees, therefore, corroborating with the study by Guo *et al.* (2019).

In this study, small gap sizes had an area of <100 m^2 while medium gap sizes ranged between 101-300 m^2 similar to the findings by Guo *et al.* (2019). This study was also congruent with other findings that small gap sizes are the common in most forests caused by single tree fall/removal/injury (Devagiri *et al.,* 2016). This was witnessed in relation to disturbances, such as debarking, branch breakage, senescence among others.

5.2.2 Influence of canopy gap size on microsite conditions in SW Mau Forest reserve

This study focused on three microsite conditions; soil moisture, soil temperature and light intensity. Microsite conditions in Afromontane forests for example, inter-annual temperature variations have been related to variability in climate system (Kinyanjui *et al.,* 2020). However, other factors also need to be considered, such as region, vegetation cover among others. The study confirmed that microsite conditions are spatial varying from one region to the other and cannot be equal in different gap sizes (Zhang & Yi, 2021), hence environmental heterogeneity as reported by Su and Shangguan (2019). Therefore, microsite conditions, such as light intensity and soil moisture availability have been known to influence forest growth, development, biodiversity and ecosystem functions. Reduced soil moisture slows down seedling establishment while increased soil temperature retards seedling growth, thus, affecting transitions within the forest. Increased soil and atmospheric temperature results in increased rate of moisture loses through evapotranspiration leaving the ground dry and which cannot support plant life (Zhang & Yi, 2021).

Influence of canopy gap size on soil moisture in SW Mau Forest reserve

Mean soil moisture was not the same in the three gap sizes. Small gap sizes recorded the highest mean soil moisture compared with medium and large gap sizes. Therefore, this study was contrary to other findings that gap size influence resources, such as soil moisture which increases with increase in gap size (Guo *et al.,* 2019; Zhang & Yi, 2021). Soil moisture in large gap sizes was lower compared with small and medium gap sizes, hence against the findings by Tinya *et al.* (2019) who reported increased soil moisture in large gaps.

Even though there were differences in mean soil moisture among the gap sizes, the differences were not significant. This could be explained by the invasive species in large and medium gap sizes which made the results deviate from the normally expected results, hence against the findings by Lu *et al.* (2018) that gap size influences soil moisture. The invasive species in medium and large gap sizes could have intercepted rainfall necessitating interception losses (Ni *et al.,* 2019). Additionally, the species could have allowed for moisture losses through other processes, such as evapotranspiration and percolation/infiltration (Fischer *et al.,* 2022), thus making no difference in soil moisture among the gap sizes (Su & Shangguan, 2019). Furthermore, these species could have influenced hydrological regulation of forest soils (Lozano-Parra *et al.,* 2018), therefore, affecting soil moisture distribution in the gap sizes (Ni *et al.,* 2019). The shallow roots of *Piper capensis* could have also increased soil moisture consumption through their roots leading to soil moisture deficit in the upper layers of the forest soils (Su & Shangguan, 2019).

Small gap sizes were not invaded, however, the exposure time to solar irradiance from direct sun heat when the sun was directly overhead was limited, necessitating moisture loss via evaporation (Su & Shangguan, 2019). Other moisture loss obstructions seen in the gap sizes entailed but not limited to a lot of debris from leaves, fallen twigs and cutting chippings which covered forest floor in the gaps hindering moisture loss through evaporation (Fischer *et al.,* 2022), resulting into insignificant difference in soil moisture in the three gap sizes.

Influence of canopy gap size on soil temperature in SW Mau Forest reserve

The mean soil temperature in the three gap sizes differed with large gap sizes taking the lead. This revealed that gap size had an influence on mean soil temperature, therefore, corroborating with findings from Lu *et al.* (2018), Reserve and Reserve (2005), and Zhang and Yi (2021). The significant difference in soil temperature in the three gap sizes also concurred with the previous studies by Fischer *et al.* (2022), Ni *et al.* (2019) and Przepióra *et al.* (2020) who reported that soil temperature increases with increase in gap size.

The invasive species in SW Mau Forest reserve created a generally uniform soil temperature in the gap sizes due to canopy cover, this attenuated sun heat reaching the ground but allowed more sun flecks penetration (Lozano-Parra *et al.,* 2018). They also provided an insulation to the forest floor in medium and large gap sizes during day times, hence increased soil temperature in the highly invaded large and medium gap sizes due to inside warming.

Influence of canopy gap size on light intensity in SW Mau Forest reserve

Mean light intensity was higher in large gap sizes compared with medium and small gap sizes. These results were similar to the findings by Tinya *et al*. (2019). Recent work by Johnson *et al.* (2021) assumed that canopy openings promote coexistence among species due to increased availability of light. The current study corroborated with the statement when comparing light intensity means in the three gap sizes (Velázquez & Wiegand, 2020).

Light intensity is influenced by increase in gap size as was seen in the means when large gap sizes recorded a higher light intensity mean followed by medium and lastly small gap sizes. This finding was in accordance with that reported by Lu *et al.* (2019) and Guo *et al.* (2019). Additionally, gap centres reported higher light intensity than gap peripheries (Lu *et al.,* 2018). Besides, this study also revealed a relatively low light intensity in the small gap sizes, thus congruent with the findings by Kovács *et al.* (2018) that light intensity is only high in large gap sizes. The small canopy openings provide a narrow 'sky view' due to shading from the surrounding trees (Kovács *et al.,* 2020). This could explain the reason for low light intensity in the small gap sizes compared with the other two gap sizes despite the absence of invasive species.

However, this study revealed that there was no significant difference in light intensity among the three gap sizes contrary to the findings from other studies (Lu *et al.,* 2019; Zhang & Yi, 2021). This could be linked to *Piper capensis,* ferns and *Ribes* spp. which made the gaps to act as closed canopy despite the disturbances. These pioneer species were rampant in medium and large gap sizes due to high light intensity impairing light penetration to the forest floor (Velázquez & Wiegand, 2020). The species resulted into less light reaching the soil floor due to interceptions and reflection (Matsushita *et al.*, 2022).

Additionally, the uniform canopy distribution of these invasive species in medium and large gap sizes created a layer which allowed for uniform light distribution on the canopy (Kovács *et al.,* 2018). This inhibited direct solar radiation except sun flecks to penetrate to the forest floor similar to the results of Lu *et al.* (2019). Also, small gap sizes exhibited a low canopy openings due to shading from the surrounding trees (Kovács *et al.*, 2020), necessitating, less light intensity even without canopy cover from the invasive species. This result, therefore, concurred with the findings by Kovács *et al.* (2018) that uniform canopy cover from the invasive species do not allow for light penetration. As a result, there was no significant difference in light intensity in the three gap sizes.

5.3 Influence of canopy gap size on woody vegetation population parameters in SW Mau Forest reserve

5.3.1 Influence of canopy gap size on regeneration of woody species in SW Mau Forest reserve

In this study, small gap sizes recorded the highest seedling density followed by medium and lastly large gap sizes. This suggested that small gap sizes were more crucial for regeneration than the other two gap sizes. This could be explained by canopy cover in medium and large gap sizes caused by *Piper capensis* which could have influenced species-specific pattern of regeneration due to resource variations (Velázquez & Wiegand, 2020). However, this study was different from that reported earlier by Guo *et al.* (2019) who recorded higher species regeneration in medium gap sizes.

Previous studies report that canopy openings create consistency among species due to niche partitioning (Hammond *et al*., 2020). This could explain why medium and large gap sizes were invaded by *Piper capensis,* a light demanding species (Devagiri *et al.,* 2016). Also, canopy openings have been associated with increased seed germination (Zhang & Yi, 2021) due to influence on microsite conditions, such as sunlight (Velázquez & Wiegand, 2020; Zhang *et al.,* 2018). As a result, gap size influence species regeneration as reported by Zhang and Yi (2021). However, this study revealed a contrary result that only small gap sizes provided important environment for species regeneration.

This study also recorded some species regenerating in one gap size while missing in the other gap size. This concurred with other findings that canopy opening size plays an integral role in determining which species fit in a gap size based on its requirements (Hammond *et al*., 2020). This was revealed by reporting for example, *Macaranga kilimandscharica* to be common in more disturbed sites with large gap sizes (Lu *et al.*, 2019) due to light availability as reported by Zhang *et al.* (2018); especially in Ndoinet block following reclamation. It is an example of pioneer species whose presence is favoured by increased light availability (Velázquez & Wiegand, 2020).

Large gap sizes recorded regeneration of species especially sun plants (invasive species) attributed to higher light intensity (Lu *et al.*, 2019) used in photosynthesis leading to their prolific growth (Zhang & Yi, 2021). This could explain the reason why the two gap sizes recorded lesser species regeneration due to closed canopy (Zhang *et al*., 2018). Moreover, apart from shadowing species in the gaps, invasive species also consumed a lot of moisture from the soil; consequently leaving the floor surface drier and which cannot support seed germination (Su & Shangguan, 2019).

However, the general results from the study were contrary to other studies which reported that medium and large gap sizes create more conditions which increases species regeneration (Guo *et al.,* 2019; Zhang & Yi, 2021). On the contrary, small gap sizes favoured many species regenerations compared with medium and large gap sizes. This could be attributed to shade intolerant species which invaded and closed the other gap sizes (Velázquez & Wiegand, 2020) intercepting most resources from reaching the forest floor.

With slight variations in microsite conditions in the gap sizes; large and medium gap sizes did not favour germination and establishment of shade tolerant species (Zhang & Yi, 2021). This could be explained by *Piper capensis* which dominated such gap sizes necessitating resources deficit (Su & Shangguan, 2019). Nevertheless, medium and large gap sizes negatively affected growth and development of shade tolerant species (Lu *et al.*, 2019). Therefore, forest canopy gaps influence regeneration by affecting micro-environmental conditions (Zhang & Yi, 2021; Zhang *et al.*, 2018). Again, it was confirmed that gap size is a strong predictor to determine forest species composition and regeneration due to changing 'Ecological Shade Tolerance (EST) status'(Hammond *et al.*, 2020). This could be explained by the presence of some species, such as *Dovyalis abyssinica* and *Pittosporum viridiflorum* in large gap sizes with more closed canopy by *Piper capensis* but absent in small gap sizes with exposer.

The non-significant difference in regeneration among the three gap sizes was caused by canopy cover from invasive species (Prévost & Raymond, 2012). Because of the prolificacy of the invasive species, they failed to let resources (light) reach forest floor in the gap sizes. Moreover, they utilized the available soil moisture, thus drained the germinating seeds of moisture (Hammond *et al.*, 2020). This could be the reason for less regenerating species in medium and large gap sizes weighed against small gap sizes.

5.3.2 Influence of canopy gap size on forest growth and structure in SW Mau Forest reserve

Small gap sizes recorded the highest number of undergrowth (seedlings and saplings) while large gap sizes recorded the least. Small gaps fostered positive growth response to seedlings and saplings that were already established in the understorey. Depending on individual species mechanism, the study revealed a difference in the forest physiognomic appearance (tree height and dbh) similar to the findings by Fotis *et al.* (2018). Small gap sizes were characterized by more seedlings followed by saplings then other growth levels. This could be due to 'sky view' visibility permitting light penetration to the forest floor (Kovács *et al.,* 2020) compared with the other gap sizes (Velázquez & Wiegand, 2020).

Large and medium gap sizes on the other hand exhibited increased tree height and dbh compared with small gap sizes. This could be attributed to higher light intensity (Zhang & Yi, 2021) and temperature which could have facilitated the development of the tree species. On the contrary, tree height and dbh were recorded low in small gap sizes due to shorter lighting span causing slow growth in the trees, thus corroborating with more recent results by Velázquez and Wiegand (2020).

Structural complexity was higher in small gap sizes compared with medium and large gap sizes. This could be related to low stem and height densities in small gap sizes which availed resources to the bordering trees, hence slight light interception to the forest floor. This study was, therefore, similar to the one reported by Zhang *et al.* (2018). Moreover, small gap sizes could have allowed for already established species to develop competing for the available resources, consequently, more complex structure (Fotis *et al.*, 2018). Small gap sizes could be filled by lateral branch ingrowth (Kovács *et al.*, 2018), therefore, favouring only the earlier established individuals, thereby increasing the canopy cover. Because of lateral branch expansions in these small gap sizes, the neighbouring tree species could have expanded more towards the gap centre; thus, covering the canopy hole and allowing only fast growing species to reach the top, hence canopy roughness (Fotis *et al*., 2018).

Even though there was no significant difference in forest structure in the three gap sizes, large gap sizes reported a higher mean tree dbh and height compared with medium and small gap sizes. The results tallied with those reported by Fotis *et al.* (2018) that large gaps promotes tree development. The reason for this could be attributed to less competition for light in large gap sizes which enabled trees to invest resources in both vertical and horizontal development. The results from this study concurred with earlier findings by Fotis *et al.* (2018) that forest complexity is driven by the community composition and stem size within the forest. The study revealed this in the small gap sizes which had a higher Holdridge's Complexity Index compared with medium and large gap sizes. This could be explained by increased species composition in small gap sizes compared with the other gap sizes.

The cause of differences in species composition in the gap sizes is determined by canopy heights, empty crown spaces as well as spatial leaf arrangements (Fotis *et al.*, 2018). Medium and large gap sizes were highly invaded by pioneer species (Zhang & Yi, 2021) which were shorter in height with somehow intact canopy with a levelled crown cover. This could have contributed to low canopy complexity due to inhibited light penetration, hence similar to the study by Kovács *et al.* (2018).

5.3.3 Influence of canopy gap size on species diversity in SW Mau Forest reserve

Small gap sizes recorded the highest number of species followed by large then medium gap sizes. This study was, however, contrary to the report by Devagiri *et al.* (2016) who demonstrated high species diversity with increase in gap size. Types of species that colonize a particular forest gap size help in assessing long-term variations in floristic composition and diversity as well as forest structure (Fotis *et al*., 2018). Therefore, distribution of species in the gap sizes is determined by light variations in the gap sizes (Lu *et al*., 2019). This could be expounded more by the presence of some specific species in given gap sizes, hence agreeing with the demonstration by Zhang and Yi (2021).

In SW Mau Forest reserve, some species failed to appear in specific gap sizes due to resource gradient, hence similar to the results by Devagiri *et al.* (2016). Being able to examine the occurrence of some rare species within gap sizes help in foretelling the functions to be offered by that particular forest ecosystem (Fotis *et al*., 2018). For example, in small gap sizes, it was reported a higher number of species compared with medium and large gap sizes. This could be related to high soil moisture content in the gap size and moderate mean light intensity which favoured shade tolerant species emergence (Lu *et al.*, 2019). However, in the medium and large gap sizes, pioneer species colonized fast; competing with germinating tree species for resources, thus affecting seedling sprouting (Zhang & Yi, 2021). This could have resulted into low species diversity in highly invaded gap sizes.

Large gap sizes portrayed the presence of many light-demanding woody tree species, such as *Macaranga kilimandscharica*, *Dombeya torrida*, *Psydrax shimperiana* due to more light. The results were congruent to those reported by Lu *et al.* (2019) and Hammond *et al.* (2020). This study also corroborated with the findings by Velázquez and Wiegand (2020) and Zhang and Yi (2021) which reported that gaps avail light which attract rare species that demand more light. This could also explain the reason for *Piper capensis* large invasion in medium and large gap sizes. It was, therefore, hypothesized that small gap sizes did not provide enough light for *Piper capensis* to germinate, corroborating with previous studies by Fotis *et al.* (2018).

The presence of higher number of species in small gap sizes compared with medium and large gap sizes could be linked to less seed interception from seed dispersal; for example, seed rains, dispersal by wind, birds and animals (Tinya *et al.*, 2019) among other agents which drive species colonization (Fotis *et al.*, 2018). Small gap sizes were also more exposed compared with the other invaded gap sizes, hence presence of direct light reaching forest floor (Velázquez & Wiegand, 2020). The study, also, concurred with that by Tinya *et al.* (2019), who reported that the presence of light demanding species in large gap sizes compete with shade tolerant species for resources, therefore, could not allow for species diversity.

There were less species in medium gap sizes contrary to the findings by Lu *et al*. (2019) that medium gap sizes multiply species diversity. Nevertheless, the study concurred with other results that species diversity decrease with increase in gap sizes (Lu *et al.*, 2019). This could be explained by unexposed forest floor by invasive species which deprived understorey species the required conditions for growth.

Shannon-Weiner's Diversity Index and dominance were, however, recorded high in large gap sizes compared with the other two gap sizes. These results agreed with those demonstrated by Devagiri *et al.* (2016) that species diversity is necessitated by increase in gap size. This could be attributed to site conditions which influence species establishment as reported by other researchers (Lu *et al.*, 2019; Zhang & Yi, 2021).

5.4 Comparing microsite conditions and vegetation population parameters between disturbed and undisturbed sites of SW Mau Forest reserve

5.4.1 Comparing soil moisture in disturbed and undisturbed sites of SW Mau Forest reserve

In this study, mean soil moisture was higher in undisturbed sites compared with the disturbed sites. The result was contrary to the finding by Guo *et al.* (2019) who reported reduced soil moisture in closed canopy. However, the results were similar to those reported by Kovács *et al.* (2020) and Ni *et al.* (2019) that soil moisture increases under closed canopy. The difference could be attributed to more sun heat reaching the ground in disturbed sites which could have resulted into increased moisture loss through evaporation among other processes (Fischer *et al.*, 2022). Closed canopy forests are known to create an ameliorated, stable and unique microclimates which differ from open canopy forests (Kovács *et al.*, 2020). Moreover, it is expected that mean of soil moisture in such forests should be lower compared with the open forests (De Frenne *et al.*, 2019).

The study was again contrary to that found by Kovács *et al.* (2018) who demonstrated that soil moisture increases with canopy openness due to decrease in transpiration rates. Difference in this study was attributed to shallow rooted invasive species which invaded disturbed sites, thus utilizing soil moisture on the soil surface (Su & Shangguan, 2019). Also, other blocks experienced incessant human disturbances exposing the ground, hence generally low soil moisture in disturbed sites.

However, the non-significant difference in soil moisture between disturbed and undisturbed sites was attributed to the invasive species which covered canopy openings in disturbed sites reducing moisture losses through evaporation (Su & Shangguan, 2019); thus, reporting the same findings as Fischer *et al.* (2022) and Ni *et al.* (2019). This was because there was no difference between disturbed and undisturbed sites in terms of canopy cover.

5.4.2 Comparing soil temperature in disturbed and undisturbed sites of SW Mau Forest reserve

This study recorded a higher mean soil temperature in disturbed sites compared with undisturbed sites. This could be explained by wider 'sky view' in disturbed sites which favoured light penetration, therefore, increased incoming solar radiation warming the soil (Kovács *et al.,* 2020). Light intensity influence soil moisture through evaporation in the forest due to radiations which affects the within temperature (Zhang & Yi, 2021). This was exhibited through increase in soil temperature in relation to increase in light intensity in the gaps. However, soil temperature was low in undisturbed sites attributed to less sunlight penetration. This could be due to shielding of the forest floor by foliage from the closed canopy which could have reduced radiations to the forest floor, hence slightly low temperature in undisturbed sites. A report by Kovács *et al.* (2018) mentioned that closed canopy in undisturbed sites insulate the forest by lowering long waves resulting into low soil temperature.

According to the findings demonstrated by Kovács *et al.* (2018), open canopy in disturbed sites results into increased air temperature in forests. The authors also reported a higher difference in air temperature in such open and closed canopies. This explained a direct influence of solar radiation and air temperature on soil temperature. Therefore, increased soil temperature in disturbed sites could be attributed to the two factors. The mean difference in soil temperature between disturbed and undisturbed sites were in support to the report by Kovács *et al.* (2020).

However, the non-significant difference in soil temperature between disturbed and undisturbed sites could still be attributed to invasive species which created a micro-climate in disturbed sites similar to undisturbed sites in relation to canopy cover, ergo, similar to Kovács *et al.* (2020) demonstration. Nevertheless, canopy cover in SW Mau Forest reserve buffered against both the high and low microclimate in disturbed and undisturbed sites causing a generally equal temperature in the two sites (De Frenne *et al.,* 2019).

5.4.3 Comparing light intensity in disturbed and undisturbed sites of SW Mau Forest reserve

This study reported high mean light intensity in disturbed sites than in undisturbed sites. The result was similar to that reported by Kovács *et al.* (2020) that disturbed sites do receive a lot of light intensity compared with undisturbed sites. This is because disturbed sites have canopy openings which allow for light penetrations (De Frenne *et al.,* 2019). The invasive species in disturbed sites also modified canopy closure which allowed for uniform sun fleck penetration as opposed to multi-storey canopy cover in undisturbed sites. This corroborated with the findings by Kovács *et al.* (2020). The study was also congruent with the previous findings by Kovács *et al.* (2018) that light intensity depends on canopy openings, therefore, disturbed sites recorded higher light intensity compared with the undisturbed sites. This is because disturbed sites provide a more illuminated environment than a closed canopy.

Furthermore, light intensity in canopy gaps is dictated by tree heights and vertical light spread. It varies horizontally and vertically, thus tree height is one of the factors that determine resource partitioning as a location function in forest gap sizes (Zhang & Yi, 2021). This could have resulted in low light intensity in undisturbed sites due to canopy cover from multi-storey canopies (Matsushita *et al.,* 2022).

There was a significant difference in light intensity between disturbed and undisturbed sites of SW Mau Forest reserve. This was linked to an observed decrease in mean light intensity between disturbed and undisturbed sites of the forest, hence similar to previous studies (Matsushita *et al.,* 2022). This was again attributed to attenuation of light by the multi-storey canopy cover in undisturbed sites which could not allow for sun flecks penetration. Additionally, invasive species in disturbed sites created a generally uniform canopy layer which permeated a lot of sun flecks to the forest floor, thus higher light intensity (Khan *et al.,* 2020).

5.4.4 Comparing regeneration in disturbed and undisturbed sites of SW Mau Forest reserve

Disturbed sites recorded higher number of regenerating species compared with undisturbed sites. Moreover, some species failed to regenerate in some sites and this could be related to resource gradient (Berdugo & Dovciak, 2019). Therefore, this study revealed a difference in mean regeneration between disturbed and undisturbed sites of SW Mau Forest reserve corroborating with Zhang and Yi (2021) results. Forest gaps are known to improve seedling growth rate compared with closed canopy, hence important for forest regeneration in every forest type. Paradoxically, higher number of seedling germination do not imply that all of them are to be established (Zhang & Yi, 2021). This was witnesses in some sites whereby the emerged seedlings and saplings were withering and dying due to severe competition for growth resources; such as light, soil moisture, nutrients and space.

Therefore, seedling establishment was also determined by the environmental factors (physical, biological and chemical) which determined seedling mortality and survival (Zhang & Yi, 2021). Apart from other factors, biological factors were the most common in such disturbed sites, whereby, animals were trampling on the sprouting seedlings, hence similar to the findings by Ronoh *et al.* (2018). *Urtica dioica* (stinging nettle) was a biological disturbance in Ndoinet block which killed most of *Psydrax schimperiana* saplings. This could be testified by low number of saplings in the invaded sites compared with seedling population sites, consequently, hindering regeneration of other species.

However, in gaps within disturbed sites, it was witnessed that frequency of regeneration was higher. This could be attributed to influence on microsite conditions by the disturbances (Devagiri *et al.,* 2016; Przepióra *et al.,* 2020). Activities, such as grazing in the forest enriched the forest soil with manure from cattle dung which could have promoted growth of tree species. Additionally, other microsite conditions, such as sunlight were availed to the seeds from soil seedbank and dispersal which facilitated species regeneration in disturbed sites similar to other studies (Ronoh *et al*., 2018).

High regeneration in disturbed sites could be related to more light penetration to forest floor for photosynthesis which could have facilitated seedling germination, growth and establishment (Berdugo & Dovciak, 2019). The results, therefore, concurred with those reported by Zhang and Yi (2021). However, it was contrary to the findings by Tinya *et al.* (2019) who reported a low regeneration in clear cut areas due to harsh conditions of increased temperatures with low moisture. The canopy gaps in disturbed sites, therefore, mediated a vigorous growth in seedlings improving forest regeneration by attracting diversity of species in such openings (Przepióra *et al.*, 2020). Additionally, findings by Tinya *et al.* (2019) added that despite the presence of a lot of seeds in undisturbed sites from the mother plants, regeneration can still be low or even zero. This can be due to unfavourable microsite conditions in such sites (Devagiri *et al.,* 2016).

Findings from this study were, however, not similar to demonstrations by Tinya *et al*. (2019) who reported that gap areas have scanty regeneration due to environmental hostility; such as extreme temperatures, low soil moisture, high light intensity and shading as similarly described by Hitimana *et al*. (2004). On the contrary, disturbed sites recorded the highest number of regeneration than in undisturbed sites. This could be explained by the availability of resources in optimal level (Zhang & Yi, 2021).

When testing for inferential statistics, the study revealed a non-significant difference in regeneration between disturbed and undisturbed sites of SW Mau Forest reserve. This could be because, most of the species found regenerating in disturbed sites were also present in undisturbed sites except for the invasive species. This was similar to the results given by Tinya *et al.* (2019). Non-significant difference in regeneration between the two sites were also related to uniformity in light intensity, soil moisture and soil temperature due to canopy cover which influenced transitions within the forest (Zhang & Yi, 2021).

5.4.5 Comparing forest growth and structure in disturbed and undisturbed sites of SW Mau Forest reserve

Disturbed sites recorded a higher seedling mean followed by sapling mean compared with undisturbed sites. A study carried out by Tinya *et al.* (2019) report that in forest structure, seedling and sapling population is higher in disturbed sites than in undisturbed sites. This could explain why there was a reduction in population from seedling level to emergent layer. Moreover, other authors record a reduction in the growth levels with time due to invasion by shade intolerant species which suppress the growth of seedlings and saplings of shade tolerant species (Huang *et al.*, 2003). This study agreed with the findings considering high number of seedlings and saplings in the disturbed sites.

Undisturbed sites, however, showed higher stem and height densities of main and emergent trees layers, hence exhibiting a more packed canopy. This could not easily allow for seedling establishment underneath, thus agreeing with other studies (Tinya *et al.*, 2019). This in turn could have influenced microsite conditions, such as light intensity, temperature and moisture through interceptions and reflection (Fotis *et al*., 2018). The study revealed that in undisturbed sites where human disturbances are less common, tree species invest more in height development with less crown development due to competition for light. This could be the reason for huge tall trees found in undisturbed sites, therefore, concurring with the study by Fotis *et al*. (2018).

However, areas with more canopy gaps (disturbed plots) reported low stem and height densities similar to the findings of Fotis *et al.* (2018). This could be due to low competition for the available resources, such as light. Therefore, trees invested more in lateral branch development rather than vertical growth. In undisturbed sites, survival of species, height and dbh development were low due to closed canopy which prompted less light penetration (Tinya *et al.*, 2019). This could have been the reason for less undergrowth in closed canopy.

A research done by Bagaram *et al*. (2018) discovered that forest structure is being affected by canopy openings in disturbed sites. The researchers state that elliptical gap shapes allow for more light penetration to the forest floor which trigger fast growth of seedlings and saplings. Additionally, it is reported that regular gap shapes contribute to diameter growth, hence more structural complexity. The SW Mau Forest reserve study agreed with these findings on increased undergrowth in canopy gaps (Bagaram *et al.*, 2018). However, this study was contrary to other previous findings that diameter growth is high in disturbed sites (Tinya *et al.*, 2019). Undisturbed sites reported the highest mean diameter density compared with disturbed sites. This could be explained by increased natural disturbances mostly wind which targeted huge trees (emergent layer) in the forest, consequently creating an almost uniform tree height.

Structural complexity was recorded high in disturbed sites compared with undisturbed sites. These results were similar to those reported by Huang *et al.* (2003) who demonstrated variations in resource availability between the two sites, thus differences in tree growth and development in disturbed sites, resulting into structural complexity. Forest structure was treated as the vertical stratification which resulted into layering in disturbed and undisturbed sites of the forest (Tinya *et al.*, 2019). The different layers of the forest, therefore, were vegetation layers of different heights and species. This was used to classify the forest structure into emergent, main canopy and understorey layers (Hitimana *et al*., 2004).

There was a significant difference in forest structure in the two sites. The reason for this significant difference could be attributed to the invasive species which colonized all gaps in disturbed sites, consequently utilizing resources which could have otherwise been used by woody species (Huang *et al.*, 2003). Again, the invasive species could have created a rough canopy which could have not allowed for uniform light distribution in disturbed sites (Kovács *et al.*, 2018). However, undisturbed sites received equal light amount without interceptions, hence improved vertical and horizontal increment. These findings were, however, contrary to those reported by Tinya *et al.* (2019) who reported an insignificant difference in forest structure between disturbed and undisturbed sites.

5.4.6 Comparing species diversity in disturbed and undisturbed sites of SW Mau Forest reserve

The current study reported a higher species number in disturbed than in undisturbed sites. The results were similar to the findings by Kovács *et al*. (2020) who reported high species diversity in gap areas due to resource availability. However, low species diversity in undisturbed sites of SW Mau Forest reserve were attributed to low regeneration of species. This could be due to a lot of debris from trees in form of leaf litter as well as shading by tall trees which influenced light penetration and seed settlement (Fischer *et al.*, 2022) from the mother trees (Huang *et al.*, 2003). This could be due to accumulation of thick layer litters which could have hindered germination in the closed canopy.

Species diversity was again higher in disturbed sites due to less dense canopy cover which allowed for diverse species to colonize the sites (Kovács *et al*., 2020). By contrast, undisturbed sites presented a fairly closed canopy which could not allow for light penetration among other resources. This resulted into less species whereby inheritance was only by few species which were mostly climax species. Therefore, it was possible to conclude that canopy gaps in disturbed sites increase species diversity (Bagaram *et al*., 2018). Again, gaps in disturbed sites could have allowed for easy seed dispersal, such as through seed rain by heavy seeds. This could have been the reason for the presence of more seedlings under mother trees (Tinya *et al.*, 2019). However, some species neither surrounding the gaps nor in close proximity to the sites could still be spotted. This could be due to light seeded species being dispersed by other agents, such as wind, birds and animals, increasing species diversity in disturbed sites (César *et al*., 2018). These findings were in accordance to those reported by Tinya *et al.* (2019).

Shannon-Weiner's Diversity Index and Simpson's Dominance Index were recorded high in disturbed sites compared with undisturbed sites. Similar results were given by Heidrich *et al.* (2020) who explained that species richness is caused by heterogeneity in environmental conditions. Disturbed sites recorded high mean soil temperature, low moisture and high light intensity which could have resulted into niche partitioning for resources, necessitating species diversification (Heidrich *et al.*, 2020).

However, the study revealed a non-significant difference in species diversity between disturbed and undisturbed sites of the forest. The reason for this could be related to shading by invasive species in disturbed sites (Huang *et al.*, 2003) which, therefore, provided a generally uniform canopy cover. This could only allow for colonization by shade tolerant species (Zhang & Yi, 2021). In addition, more recent studies by Johnson *et al*. (2021) report that presence of herbaceous plants reduce colonization by woody plants, thus affecting species diversity. This could be well explained by *Piper capensis, Ribes* spp. and ferns in gaps within disturbed sites which recorded low number of regenerating woody species (Huang *et al.*, 2003). Species diversity in forests is caused by interplay of biotic and abiotic interactions. The factors, such as sunlight tend to filter species and their coexistence to colonize a particular forest depending on the resources available. Light among other resources help in achieving a mixture of species for economic and ecologic purposes (Johnson *et al*., 2021).

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

i. The SW Mau Forest reserve records three gap sizes; small, medium and large. The three gap sizes are determined by the number of trees removed/dead/broken. Every block within the forest exhibits different gap sizes depending on the common disturbances. Therefore, most of the medium and large gap sizes are as a result of natural disturbances commonly wind snapping and uprooting while small gap sizes are mostly due to human disturbances, such as selective logging and debranching. Gap size influence on microsite conditions; soil moisture and light intensity was not significant in SW Mau Forest reserve. This is because the reserve is highly invaded by shade intolerant species (*Piper capensis*, *Ribes* spp. and Ferns) which engulf medium and large gap sizes providing shade.

ii. Species regeneration, forest structure and species diversity are directly related to the availability of resources which are among the conditions necessary for seed germination. Regeneration and species diversity were higher in small gap sizes due to exposure to the sky compared with the shaded medium and large gap sizes. This necessitated the forest to operate contrary to how it has been known with gap sizes. A lot of seedling and sapling populations were recorded in small gap sizes. This was explained by availability of soil moisture and favourable soil temperature in the gap size which facilitated growth rate. Small gap sizes, therefore, provided a multi-storey structure spanning from undergrowth to emergent layers.

iii. Disturbed sites recorded the highest species regeneration and diversity. This can be linked to the availability of microsite conditions that are high in open canopies than in closed canopies. Canopy gaps, therefore, avail moisture, soil temperature and sunlight that are necessary for plant germination, growth and development. In addition, variations in resource availability are dictated by vertical and horizontal development in most tree species, hence, result in structural complexity in disturbed sites of SW Mau Forest reserve. This was seen in the various layers of canopy structure from the ground to the upper most layer in disturbed sites. On the contrary, undisturbed sites provide a somehow smooth canopy without multiple layers. Disturbed sites on the other hand provide a mixed texture in structure due to resource availability which promotes understory growth as well as crown and stem enlargement. Disturbed sites are diverse in species which exhibit differences in resource utilization, thus different growth rates.

6.2 Recommendations

i. Forest gaps should be allowed to transpire naturally and without artificial interventions so that other processes may occur naturally. Therefore, non-destructive utilization of the forest resources is recommended to sort out the issue of artificial disturbances for biodiversity conservation.

ii. There is need to ensure continuity of SW Mau Forest reserve by availing environmental conditions to the regenerating species. Therefore, this study calls for coming up with strategies to clear off the invasive species (*Piper capensis*) in the affected gaps to allow for the forest regeneration.

iii. Enrichment planting is recommended in the invaded gaps within the disturbed sites to save biodiversity in SW Mau Forest reserve. This can be done through considering the requirements of indigenous species of interest to be planted by critically examining the favourable gap size.

iv. The government should come up with strategies of sharing benefits that accrue from indigenous forests, such as carbon credit with the neighbouring communities for better forest protection and conservation to avoid destructive utilization of the forest.

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APPENDICES

Appendix I: Forest gap sizes and microsite conditions in disturbed sites of blocks

Descriptive statistic on microsite conditions in Itare block

Gap size	Count	Mean gap area	Mean soil moisture	Mean soil temperature	Mean light intensity
Large	3	469.0	20.7	19.0	989.0
Medium	7	163.0	22.1	17.6	759.0
Small	3	31.4	22.3	17.3	767.0
Grand total	**13**	**663.4**	**65.1**	**53.9**	**2515.0**

Descriptive statistics on microsite conditions in Maramara block

Gap size	Count	Mean gap area	Mean soil moisture	Mean soil temperature	Mean light intensity
Large	3	376.0	22.0	17.7	650.0
Medium	2	228.0	24.0	17.5	668.0
Small	6	51.2	26.2	17.5	648.0
Grand total	**11**	**655.2**	**72.2**	**52.7**	**1966.0**

Descriptive statistics on microsite conditions in Ndoinet block

Gap size	Count	Mean gap area	Mean soil moisture	Mean soil temperature	Mean light intensity
Large	1	387.0	20.0	18.0	933.0
Medium	2	177.0	21.5	18.0	930.0
Small	14	39.5	24.6	16.4	719.0
Grand total	**17**	**603.5**	**66.1**	**52.4**	**2582**

Appendix II: Woody vegetation population parameters in disturbed sites of blocks

Regeneration in the blocks

Descriptive statistics on regeneration in Itare block

Species	% Count
Albizia gummifera	6.96
Allophylus abyssinica	4.30
Dracaena steudneri	1.93
Ehretia cymosa	1.19
Ekebergia capensis	0.15
Macaranga kilimandascharica	3.85
Millettia dura	0.44
Neoboutonia macrocalyx	12.00
Prunus africana	0.15
Psydrax schimperiana	14.52
Schefflera abyssinica	0.44
Syzygium guineense	2.67
Tabernaemontana stapfiana	39.56
Teclea nobilis	0.15
Trichilia emetica	5.93
Trichocladus ellipticus	0.59
Xymalos monospora	1.33
Zanthoxyllum gilletii	3.85
18	**100.00**

Descriptive statistics on regeneration in Maramara block

Species	% Count
Albizia gummifera	9.68
Allophylus abyssinica	2.76
Dovyalis abyssinica	0.23
Ehretia cymosa	1.15
Macaranga kilimandscharica	5.53
Maytenus rotudos	6.68
Millettia dura	3.92

Neoboutonia macrocalyx	10.14
Pittosporum viridiflorum	0.92
Prunus africana	1.61
Psydrax schimperiana	5.99
Schefflera volkensii	0.69
Syzygium guineense	15.44
Tabernaemontana stapfiana	16.59
Trichilia emitica	13.36
Xymalos monospora	0.92
Zanthoxyllum gilletii	4.38
17	**100.00**

Descriptive statistics on regeneration in Ndoinet block

Species	**% Count**
Acacia lahai	0.11
Acacia mearnsii	2.62
Allophylus abyssinicus	0.55
Others	1.20
Dovyalis abyssinica	0.22
Macaranga kilimandscharica	29.73
Morella salicifora	1.64
Neoboutonia macrocalyx	0.33
Podocarpus latifolius	7.10
Polyscias capensis	0.22
Psydrax schimperiana	33.22
Rapanea melanophloess	3.72
Syzygium guineense	19.23
Trichilia emitica	0.11
14	**100.00**

Descriptive statistics on species diversity in Itare block

Woody Species	**% Count**
Albizia gummifera	5.77
Allophylus abyssinicus	2.56
Dracaena steudneri	1.28
Ehretia cymosa	1.28
Ekebergia capensis	0.64
Macaranga kilimandscharica	12.18
Millettia dura	1.28
Neoboutonia macrocalyx	16.03
Polyscias fulva	0.64
Prunus africana	1.28
Psydrax schimperiana	6.41
Rhamnus prinoides	1.28
Schefflera abyssinicas	0.64
Syzygium guineense	4.49
Tabernaemontana stapfiana	26.92
Teclea nobilis	1.28
Trichilia emetica	5.77
Trichocladus ellipticus	1.28
Xymalos monospora	1.92
Zanthoxyllum gilletii	7.05
20	**100.00**

Descriptive statistics on species diversity in Maramara block

Woody Species	**% Count**
Albizia gummifera	5.88
Allophylus abyssinicus	2.61
Dovyalis abyssinica	0.65
Ehretia cymosa	1.96
Macaranga kilimandscharica	7.84
Maytenus ovatus	0.65
Maytenus rotudos	7.19

Millettia dura	2.61
Neoboutonia macrocalyx	12.42
Pittosporum viridiflorum	0.65
Polyscias capensis	2.61
Prunus africana	1.96
Psydrax schimperiana	6.54
Schefflera volkensii	1.31
Syzygium guineense	7.84
Tabernaemontana stapfiana	11.11
Trichilia emitica	15.03
Xymalos monospora	1.31
Zanthoxyllum gillettii	9.80
19	**100.00**

Descriptive statistics on species diversity in Ndoinet block

Woody species	% Count
Acacia lahai	1.66
Acacia mearnsii	0.55
Allophylus abyssinicus	1.10
Others	2.76
Diospyros abyssinica	0.55
Dombeya torrida	1.10
Dovyalis abyssinica	0.55
Ekebergia capensis	1.10
Macaranga kilimandascharica	45.86
Morella salicifora	8.29
Neoboutonia macrocalyx	0.55
Podocarpus latifolius	6.08
Polyscias capensis	1.66
Psydrax schimperiana	11.60
Rapanea melanophloes	6.63
Syzygium guineense	9.39
Trichilia emiticas	0.55
17	**100.00**

Appendix III: Woody vegetation parameters in the gap sizes

Descriptive statistics on regeneration in the three gap sizes

Variable	Woody species	Regeneration (%)
Small gap size	*Acacia lahai*	0.10
	Acacia mearnsii	2.50
	Albizia gummifera	3.44
	Allophylus abyssinicus	0.94
	Dovyalis abyssinica	0.21
	Macaranga kilimandscharica	20.75
	Maytenus rotudos	1.56
	Millettia dura	0.73
	Morella salicifora	1.56
	Neoboutonia macrocalyx	2.71
	Others	0.94
	Podocarpus latifolius	4.28
	Polyscias capensis	0.10
	Prunus africana	1.36
	Psydrax schimperiana	22.73
	Rapanea melanophloes	3.13
	Schefflera volkensii	0.31
	Syzygium guineense	20.33
	Tabernaemontana stapfiana	8.24
	Trichilia emitica	2.82
	Xymalos monospora	0.31
	Zanthoxyllum gilletii	0.94
	22	**100.00**
Medium gap sizes		
	Albizia gummifera	6.78
	Allophylus abyssinicus	4.37
	Dovyalis abyssinicar	0.15
	Dracaena steudneri	1.66
	Ehretia cymosa	0.60

	Macaranga kilimandscharica	6.33
	Millettia dura	0.15
	Neoboutonia macrocalyx	10.54
	Pittosporum viridiflorum	0.60
	Podocarpus latifolius	3.16
	Prunus africana	0.45
	Psydrax schimperiana	23.34
	Rapanea melanophloes	0.45
	Syzygium guineense	3.77
	Tabernaemontana stapfiana	22.44
	Trichilia emitica	10.09
	Trichocladus ellipticus	0.60
	Xymalos monospora	0.30
	Zanthoxyllum gilletii	4.22
	19	**100.00**
Large gaps		
	Acacia lahai	0.24
	Albizia gummifera	2.67
	Allophylus abyssinicus	1.94
	Others	0.49
	Dracaena steudneri	0.49
	Ehretia cymosa	2.18
	Ekebergia capensis	0.24
	Macaranga kilimandscharica	19.66
	Maytenus rotudos	3.40
	Millettia dura	2.91
	Neoboutonia macrocalyx	7.77
	Podocarpus latifolius	0.73
	Polyscias capensis	0.24
	Prunus africana	0.49
	Psydrax schimperiana	13.35
	Rapanea melanophloes	0.24
	Schefflera abyssinica	0.73

Syzygium guineense	9.95
Tabernaemontana stapfiana	26.94
Teclea nobilis	0.24
Trichilia emitica	1.21
Xymalos monospora	1.94
Zanthoxyllum gilletii	1.94
23	**100.00**

Shannon-Weiner's Diversity Index in small gap size

Shannon Weiner's Diversity Index					
Species	**Count**	**pi**	**lnpi**	**pilnpi**	**H`**
Acacia lahai	2	0.008475	-4.77068	-0.04043	
Acacia mearnsii	1	0.004237	-5.46383	-0.02315	2.57963
Albizia gummifera	4	0.016949	-4.07754	-0.06911	**HE**
Allophylus abyssinicus	3	0.012712	-4.36522	-0.05549	0.774151
Others	4	0.016949	-4.07754	-0.06911	
Diospyros abyssinica	1	0.004237	-5.46383	-0.02315	
Dombeya torrida	1	0.004237	-5.46383	-0.02315	
Dovyalis abyssinica	1	0.004237	-5.46383	-0.02315	
Ehretia cymosa	1	0.004237	-5.46383	-0.02315	
Ekebergia capensis	2	0.008475	-4.77068	-0.04043	
Macaranga kilimandscharica	70	0.29661	-1.21534	-0.36048	
Neoboutonia macrocalyx	11	0.04661	-3.06594	-0.1429	
Maytenus ovatus	1	0.004237	-5.46383	-0.02315	
Maytenus rotudos	9	0.038136	-3.26661	-0.12457	
Millettia dura	3	0.012712	-4.36522	-0.05549	
Morella salicifora	11	0.04661	-3.06594	-0.1429	
Podocarpus latifolius	9	0.038136	-3.26661	-0.12457	
Polyscias capensis	4	0.016949	-4.07754	-0.06911	
Prunus africana	1	0.004237	-5.46383	-0.02315	
Psydrax schimperiana	22	0.09322	-2.37279	-0.22119	
Rapanea	9	0.038136	-3.26661	-0.12457	

melanophloes				
Schefflera volkensii	1	0.004237	-5.46383	-0.02315
Syzygium guineense	24	0.101695	-2.28578	-0.23245
Tabernaemontana stapfiana	17	0.072034	-2.63062	-0.18949
Trichilia emitica	15	0.063559	-2.75578	-0.17516
Xymalos monospora	2	0.008475	-4.77068	-0.04043
Zanthoxyllum gilletii	6	0.025424	-3.67207	-0.09336
Teclea nobilis	1	0.004237	-5.46383	-0.02315
	236			

Simpson's Dominance Index in small Gap Size

Simpson's Dominance Index			
Species	**n**	**n-1**	**n(n-1)**
Acacia lahai	2	1	2
Acacia mearnsii	1	0	0
Albizia gummifera	4	3	12
Allophylus abyssinicus	3	2	6
Others	4	3	12
Diospyros abyssinica	1	0	0
Dombeya torrida	1	0	0
Dovyalis abyssinica	1	0	0
Ehretia cymosa	1	0	0
Ekebergia capensis	2	1	2
Macaranga kilimandscharica	70	69	4830
Neoboutonia macrocalyx	11	10	110
Maytenus ovatus	1	0	0
Maytenus rotudos	9	8	72
Millettia dura	3	2	6
Morella salicifora	11	10	110
Podocarpus latifolius	9	8	72
Polyscias capensis	4	3	12
Prunus africana	1	0	0
Psydrax schimperiana	22	21	462

Rapanea melanophloes	9	8	72	*Shannon Weiner Diversity Index in medium gap sizes*
Schefflera volkensii	1	0	0	
Syzygium guineense	24	23	552	
Tabernaemontana stapfiana	17	16	272	
Trichilia emitica	15	14	210	
Xymalos monospora	2	1	2	
Zanthoxyllum gilletii	6	5	30	
Teclea nobilis	1	0	0	
N	**236**		**6846**	
N-1	235	**D**	**0.87656**	
N(N-1)	55460			

Shannon Weiner's Diversity Index

Species	Count	pi	lnpi	pilnpi	H`
Albizia gummifera	10	0.071429	-2.63906	-0.1885	
Allophylus abyss	4	0.028571	-3.55535	-0.10158	2.59957
Dombeya torrida	1	0.007143	-4.94164	-0.0353	**HE**
Dovyalis macrocalyx	1	0.007143	-4.94164	-0.0353	0.80760
Dracaena steudneri	1	0.007143	-4.94164	-0.0353	
Ehretia cymosa	1	0.007143	-4.94164	-0.0353	
Macaranga kilimandscharica	20	0.142857	-1.94591	-0.27799	
Neoboutonia macrocalyx	20	0.142857	-1.94591	-0.27799	
Millettia dura	1	0.007143	-4.94164	-0.0353	
Morella salicifora	2	0.014286	-4.2485	-0.06069	
Pittosporum viridiflorum	1	0.007143	-4.94164	-0.0353	
Podocarpus latifolius	1	0.007143	-4.94164	-0.0353	
Polyscias capensis	1	0.007143	-4.94164	-0.0353	
Polyscias fulva	1	0.007143	-4.94164	-0.0353	
Prunus africana	2	0.014286	-4.2485	-0.06069	
Psydrax schimperiana	12	0.085714	-2.45674	-0.21058	
Rapanea melanophloes	2	0.014286	-4.2485	-0.06069	
Rhamnus prinoides	2	0.014286	-4.2485	-0.06069	
Schefflera volkensii	1	0.007143	-4.94164	-0.0353	

Syzygium guineense	7	0.05	-2.99573	-0.14979
Tabernaemontana stapfiana	24	0.171429	-1.76359	-0.30233
Trichilia emitica	10	0.071429	-2.63906	-0.1885
Trichocladus ellipticus	2	0.014286	-4.2485	-0.06069
Xymalos monospora	1	0.007143	-4.94164	-0.0353
Zanthoxyllum gilletii	12	0.085714	-2.45674	-0.21058
	140			

Simpson's Dominance Index in medium gap sizes

Simpson's Dominance Index			
Species	**n**	**n-1**	**n(n-1)**
Albizia gummifera	10	9	90
Allophylus abyss	4	3	12
Dombeya torrida	1	0	0
Dovyalis macrocalyx	1	0	0
Dracaena steudneri	1	0	0
Ehretia cymosa	1	0	0
Macaranga kilimandscharica	20	19	380
Neoboutonia macrocalyx	20	19	380
Millettia dura	1	0	0
Morella salicifora	2	1	2
Pittosporum viridiflorum	1	0	0
Podocarpus latifolius	1	0	0
Polyscias capensis	1	0	0
Polyscias fulva	1	0	0
Prunus africana	2	1	2
Psydrax schimperiana	12	11	132
Rapanea melanophloes	2	1	2
Rhamnus prinoides	2	1	2
Schefflera volkensii	1	0	0
Syzygium guineense	7	6	42
Tabernaemontana stapfiana	24	23	552
Trichilia emitica	10	9	90

Trichocladus ellipticus	2	1	2
Xymalos monospora	1	0	0
Zanthoxyllum gilletii	12	11	132
N	**140**		
N-1	139		1820
N(N-1)	19460	**D**	**0.906475**

Shannon-Weiner's Diversity Index in large gap sizes

Shannon Weiner's Diversity Index					
Species	**Counts**	**pi**	**lnpi**	**pilnpi**	**H`**
Acacia lahai	1	0.008772	-4.7362	-0.04155	
Albizia gummifera	4	0.035088	-3.3499	-0.11754	2.6253
Allophylus abyssinicus	3	0.026316	-3.63759	-0.09573	**HE**
Other	1	0.008772	-4.7362	-0.04155	0.8261
Dracaena steudneri	1	0.008772	-4.7362	-0.04155	
Ehretia cymosa	3	0.026316	-3.63759	-0.09573	
Ekebergia capensis	1	0.008772	-4.7362	-0.04155	
Macaranga kilimandscharica	24	0.210526	-1.55814	-0.32803	
Neoboutonia macrocalyx	14	0.122807	-2.09714	-0.25754	
Maytenus rotudos	2	0.017544	-4.04305	-0.07093	
Millettia dura	2	0.017544	-4.04305	-0.07093	
Morella salicifora	2	0.017544	-4.04305	-0.07093	
Podocarpus latifolius	1	0.008772	-4.7362	-0.04155	
Polyscias capensis	2	0.017544	-4.04305	-0.07093	
Prunus africana	2	0.017544	-4.04305	-0.07093	
Psydrax schimperiana	7	0.061404	-2.79029	-0.17133	
Rapanea melanophloes	1	0.008772	-4.7362	-0.04155	
Schefflera volkensii	1	0.008772	-4.7362	-0.04155	
Syzygium guineense	5	0.04386	-3.12676	-0.13714	
Tabernaemontana stapfiana	18	0.157895	-1.84583	-0.29145	
Trichilia emitica	8	0.070175	-2.65676	-0.18644	
Xymalos monospora	2	0.017544	-4.04305	-0.07093	

Zanthoxyllum gilletii	8	0.070175	-2.65676	-0.18644
Teclea nobilis	1	0.008772	-4.7362	-0.04155
24	**114**			

Simpson's Dominance Index in large gap sizes

Simpson's Dominance Index			
Species	**n**	**n-1**	**n(n-1)**
Acacia lahai	1	0	0
Albizia gummifera	4	3	12
Allophylus abyssinicus	3	2	6
Others	1	0	0
Dracaena steudneri	1	0	0
Ehretia cymosa	3	2	6
Ekebergia capensis	1	0	0
Macaranga kilimandscharica	24	23	552
Neoboutonia macrocalyx	14	13	182
Maytenus rotudos	2	1	2
Millettia dura	2	1	2
Morella salicifora	2	1	2
Podocarpus latifolius	1	0	0
Polyscias capensis	2	1	2
Prunus africana	2	1	2
Psydrax schimperiana	7	6	42
Rapanea melanophloes	1	0	0
Schefflera volkensii	1	0	0
Syzygium guineense	5	4	20
Tabernaemontana stapfiana	18	17	306
Trichilia emitica	8	7	56
Xymalos monospora	2	1	2
Zanthoxyllum gilletii	8	7	56
Teclea nobilis	1	0	0
N	**114**		**1250**
N-1	113		
N(N-1)	**12882**	D	0.902965

Appendix IV: Vegetation parameters in disturbed and undisturbed sites of SW Mau Forest reserve

Species regeneration in disturbed sites

Variable	Species	% Regeneration
Disturbed site	*Acacia lahai*	0.10
	Acacia mearnsii	1.18
	Albizia gummifera	4.37
	Allophylus abyssinicus	2.26
	Dovyalis abyssinicar	0.15
	Dracaena steudneri	0.64
	Ehretia cymosa	0.64
	Ekebergia capensis	0.05
	Macaranga kilimandscharica	15.82
	Maytenus rotudos	1.43
	Millettia dura	0.98
	Morella salicifora	0.74
	Neoboutonia macrocalyx	6.29
	Others	0.54
	Pittosporum viridiflorum	0.20
	Podocarpus latifolius	3.19
	Polyscias capensis	0.10
	Prunus africana	0.88
	Psydrax schimperiana	21.03
	Rapanea melanophloes	1.67
	Schefflera abyssinican	0.15
	Schefflera volkesii	0.15
	Syzygium guineense	12.83
	Tabernaemontana stapfiana	16.66
	Teclea nobilis	0.05
	Trichilia emitica	4.86
	Trichocladus ellipticus	0.20
	Xymalos monospora	0.64
	Zanthoxyllum gilletii	2.21

	29	**100.00**

Species regeneration in undisturbed sites

Variable	Woody species	% Regeneration
Undisturbed site	*Acacia mearnsii*	2.06
	Albizia gummifera	3.10
	Allophylus abyssinicus	12.98
	Others	1.72
	Dombeya torrida	0.09
	Dovyalis abyssinica	0.09
	Dracaena steudneri	0.09
	Ehretia cymosa	1.81
	Macaranga kilimandscharica	14.70
	Maytenus ovatus	0.17
	Maytenus undata	0.43
	Millettia dura	0.26
	Morella salicifolia	0.77
	Neoboutonia macrocalyx	1.46
	Podocarpus latifolius	1.03
	Polyscias fulva	0.34
	Psydrax schimperiana	20.03
	Rapanea melanophloes	3.87
	Syzygium guineense	5.50
	Tabernaemontana stapfiana	14.19
	Teclea nobilis	0.60
	Trichilia emetica	12.81
	Vangueria madagascariensis	0.43
	Xymalos monospora	0.86
	Zanthoxyllum gillettii	0.60
	25	**100.00**

Shannon-Weiner's Diversity Index in disturbed sites

Shannon Weiner's Diversity Index						
Variable	**Species**	**Count**	**pi**	**lnpi**	**pilnpi**	**H`**
Disturbed sites	*Acacia lahai*	2	0.00409	-5.49922	-0.02249	
	Acacia mearnsii	1	0.002045	-6.19236	-0.01266	2.71
	Albizia gummifera	18	0.03681	-3.30199	-0.12155	
	Allophylus abyssinicus	10	0.02045	-3.88978	-0.07955	**HE**
	Diospyros abyssinica	1	0.002045	-6.19236	-0.01266	0.77
	Dombeya torrida	2	0.00409	-5.49922	-0.02249	
	Dovyalis abyssinica	1	0.002045	-6.19236	-0.01266	
	Dovyalis macroca	1	0.002045	-6.19236	-0.01266	
	Dracaena steudneri	2	0.00409	-5.49922	-0.02249	
	Ehretia cymosa	5	0.010225	-4.58292	-0.04686	
	Ekebergia capensis	3	0.006135	-5.09375	-0.03125	
	Macaranga kilimandscharica	114	0.233129	-1.45616	-0.33947	
	Maytenus ovatus	1	0.002045	-6.19236	-0.01266	
	Maytenus rotudos	11	0.022495	-3.79447	-0.08536	
	Millettia dura	6	0.01227	-4.4006	-0.054	
	Morella saliciforum	15	0.030675	-3.48431	-0.10688	
	Neoboutonia macrocalyx	45	0.092025	-2.3857	-0.21954	
	Others	5	0.010225	-4.58292	-0.04686	
	Pittosporum viridiflorum	1	0.002045	-6.19236	-0.01266	
	Podocarpus latifolius	11	0.022495	-3.79447	-0.08536	
	Polyscias capensis	7	0.014315	-4.24645	-0.06079	
	Polyscias fulva	1	0.002045	-6.19236	-0.01266	
	Prunus africana	5	0.010225	-4.58292	-0.04686	
	Psydrax schimperiana	41	0.083845	-2.47879	-0.20783	
	Rapanea melanophloes	12	0.02454	-3.70746	-0.09098	
	Rhamnus prinoides	2	0.00409	-5.49922	-0.02249	

Schefflera volkensii	3	0.006135	-5.09375	-0.03125
Syzygium guineense	36	0.07362	-2.60884	-0.19206
Tabaenamontana stapfiana	59	0.120654	-2.11483	-0.25516
Teclea nobilis	2	0.00409	-5.49922	-0.02249
Trichilia emitica	33	0.067485	-2.69585	-0.18193
Trichocladus ellipticus	2	0.00409	-5.49922	-0.02249
Xymalos monospora	5	0.010225	-4.58292	-0.04686
Zanthoxyllum gilletii	26	0.05317	-2.93427	-0.15601
	489.00			

Simpson's Dominance Index in disturbed sites

Simpson's Dominance Index			
Species	**n**	**n-1**	**n(n-1)**
Acacia lahai	2	1	2
Acacia mearnsii	1	0	0
Albizia gummifera	18	17	306
Allophylus abyssinicus	10	9	90
Diospyros abyssinica	1	0	0
Dombeya torrida	2	1	2
Dovyalis abyssinica	1	0	0
Dovyalis macrocalyx	1	0	0
Dracaena steudneri	2	1	2
Ehretia cymosa	5	4	20
Ekebergia capensis	3	2	6
Macaranga kilimandscharica	114	113	12882
Maytenus ovatus	1	0	0
Maytenus rotudos	11	10	110
Millettia dura	6	5	30
Morella salicifora	15	14	210
Neoboutonia macrocalyx	45	44	1980
Others	5	4	20
Pittosporum viridiflorum	1	0	0
Podocarpus latifolius	11	10	110

Polyscias capensis	7	6	42
Polyscias fulva	1	0	0
Prunus africana	5	4	20
Psydrax schimperiana	41	40	1640
Rapanea melanophloes	12	11	132
Rhamnus prinoides	2	1	2
Schefflera volkensiis	3	2	6
Syzygium guineense	36	35	1260
Tabernaemontana stapfiana	59	58	3422
Teclea nobilis	2	1	2
Trichilia emitica	33	32	1056
Trichocladus ellipticus	2	1	2
Xymalos monospora	5	4	20
Zanthoxyllum gilletii	26	25	650
N	**489**		24024
N-1	488		
N(N-1)	**238632**	**D**	**0.899326**

Shannon-Weiner's Diversity Index in undisturbed sites

Shannon Weiner's Diversity Index						
Variable	**Species**	**Count**	**pi**	**lnpi**	**pilnpi**	***H`***
Undist.	*Acacia mearnsii*	2	0.005181	-5.26269	-0.02727	
Sites	*Albizia gummifera*	16	0.041451	-3.18325	-0.13195	2.546861
	Allophylus abyssinicus	14	0.036269	-3.31678	-0.1203	**HE**
	Cassipourea malo	1	0.002591	-5.95584	-0.01543	0.772751
	Dombeya torrida	1	0.002591	-5.95584	-0.01543	
	Dovyalis abyssinica	1	0.002591	-5.95584	-0.01543	
	Dracaena steudnere	1	0.002591	-5.95584	-0.01543	
	Others	6	0.015544	-4.16408	-0.06473	
	Ehretia cymosa	12	0.031088	-3.47093	-0.1079	

Macaranga kilimandscharica	110	0.284974	-1.25536	-0.35774
Neoboutonia macrocalyx	18	0.046632	-3.06547	-0.14295
Maytenus ovatus	8	0.020725	-3.8764	-0.08034
Maytenus undata	1	0.002591	-5.95584	-0.01543
Millettia dura	3	0.007772	-4.85723	-0.03775
Morella salicifora	27	0.069948	-2.66	-0.18606
Olea capensis	2	0.005181	-5.26269	-0.02727
Podocarpus latifolius	3	0.007772	-4.85723	-0.03775
Polyscias fulva	5	0.012953	-4.3464	-0.0563
Psydrax schimperiana	21	0.054404	-2.91131	-0.15839
Rapanea melanophloes	7	0.018135	-4.00993	-0.07272
Syzygium guineense	18	0.046632	-3.06547	-0.14295
T. stapfiana	61	0.158031	-1.84496	-0.29156
Trichilia emitica	23	0.059585	-2.82034	-0.16805
Vangueria madaga	6	0.015544	-4.16408	-0.06473
Xymalos monospora	4	0.010363	-4.56954	-0.04735
Teclea nobilis	3	0.007772	-4.85723	-0.03775
Zanthoxyllum gilletii	12	0.031088	-3.47093	-0.1079
27	**386**			

Simpson's Dominance Index in undisturbed sites

Simpson's Dominance Index			
Species	**n**	**n-1**	**n(n-1)**
Acacia mearnsii	2	1	2
Albizia gummifera	16	15	240

Allophylus abyssinicus	14	13	182
Cassipourea malosana	1	0	0
Dombeya torrida	1	0	0
Dovyalis abyssinica	1	0	0
Dracaena steudneri	1	0	0
Others	6	5	30
Ehretia cymosa	12	11	132
Macaranga kilimandscharica	110	109	11990
Neoboutonia macrocalyx	18	17	306
Maytenus ovatus	8	7	56
Maytenus undata	1	0	0
Millettia dura	3	2	6
Morella salicifora	27	26	702
Olea capensis	2	1	2
Podocarpus latifolius	3	2	6
Polyscias fulva	5	4	20
Psydrax schimperiana	21	20	420
Rapanea melanophloes	7	6	42
Syzygium guineense	18	17	306
Tabernaemontana stapfiana	61	60	3660
Trichilia emitica	23	22	506
Vangueria madagascariensis	6	5	30
Xymalos monospora	4	3	12
Teclea nobilis	3	2	6
Zanthoxyllum gilletii	12	11	132
27	**386**		**18788**
N=386			
N-1	**385**		**D=0.873675**
N(N-1)	**148610**		

Appendix V: Forest inventory score sheet

Sampling site (1) Maramara (2) Itare (3) Ndoinet

Description of the site Disturbed/Undisturbed

Plot Number-------------------------------------- Plot size --------------------------------

Plot GPS coordinates Longitude --------------------------- Latitude----------------------------

Gap/Id No.	Woody species	Tree parameters			Growth Stage (No.)	
		dbh	Height	Crown class	saplings	seedlings

D = Dominant, C = Co-Dominant, I = Intermediate, and S = Suppressed

Appendix VI: Forest microsite conditions

Sampling site (1) Maramara (2) Itare (3) Ndoinet

Description of the site Disturbed/Undisturbed

Plot Number--------------------------- Plot size ---

Plot G PS coordinates Longitude --------------------------- Latitude----------------------------------

Gap Metrics			Microsite Conditions		
GNo.	Gap/sub-plot area (m^2)	GPS coordinates	Soil moisture (%)	Soil temperature (^0C)	Light intensity (Cd)

Appendix VII: List of my publications

Open Access Research Journal of
Science and Technology
Journals home page: https://oarjst.com/
ISSN: 2782-9960 (Online)

OARJ OPEN ACCESS RESEARCH JOURNALS

(RESEARCH ARTICLE)

Check for updates

Determining the influence of gap size on three selected microsite conditions in Southwestern Mau Forest reserve, Kenya

Jemimah Achieng Ocholla *, Shadrack Kinyua Inoti and Gilbert Obati Obwoyere

Department of Natural Resources, Faculty of Environment and Resource Development, P.O Box 536-20115, Egerton University-Kenya.

Open Access Research Journal of Science and Technology, 2022, 05(01), 059–069

Publication history: Received on 16 June 2022; revised on 24 July 2022; accepted on 26 July 2022

Article DOI: https://doi.org/10.53022/oarjst.2022.5.1.0054

Abstract

South-Western (SW) Mau is experiencing anthropogenic and natural disturbances; creating canopy gaps influencing microclimate in the forest. This study determined the influence of canopy gap size on three microsite conditions (soil temperature, soil moisture and light intensity) in SW. The study utilized Ecological Survey Research Design; plots of 500 m by 500 m were laid in disturbed and undisturbed sites of Itare, Maramara and Ndoinet blocks. In the sampled gaps within the plots in disturbed sites; soil moisture and temperature were measured using Kensizer soil tester (3-in-1 moisture/light/pH). Light intensity was measured using the Luxmeter (model HTC LX-104). In undisturbed sites, 500 m by 500 m plots were laid and 30 m by 20 m quadrats randomly nested 19 times within. Four measurements were taken for every Microsite condition per sub-plot. Data was analysed using R and Microsoft excel. Descriptive statistics were given and Kruskal-Wallis test employed to determine differences in microsite conditions among the gap sizes. Wilcoxon rank sum test was used to compare microsite conditions between disturbed and undisturbed sites. The study revealed that there was significant difference in soil temperature (Kruskal-Wallis chi-squared=19.00, df=3, p-value=0.0002732) in the gaps. Additionally, there was significant difference in light intensity between disturbed and undisturbed sites (W=555, p-value=0.01). Non-significant results of some microsite conditions were attributed to *Piper capensis* and *Ribes spp.* which invaded medium and large canopy openings. It was concluded that canopy cover influences microsite conditions in forests. Gaps should be allowed to occur naturally for biodiversity conservation.

Keywords: Canopy gaps; Disturbances; Disturbed sites; *Piper capensis;* Undisturbed sites

Asian Journal of Environment & Ecology

19(3): 20-31, 2022; Article no.AJEE.92726
ISSN: 2456-690X

Influence of Gap Size on Regeneration, Structure and Species Diversity of Woody Vegetation in a Secondary Montane Forest Reserve, Kenya

Jemimah Achieng Ocholla [a*], Gilbert Obati Obwoyere [a] and Shadrack Kinyua Inoti [a]

[a] *Department of Natural Resources, Faculty of Environment and Resource Development, Egerton University, P.O.Box 536-20115, Kenya.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJEE/2022/v19i3410

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/92726

Original Research Article

Received 19 August 2022
Accepted 20 October 2022
Published 28 October 2022

ABSTRACT

South-Western (SW) Mau forest reserve has been experiencing anthropogenic and natural disturbances creating canopy openings in the forest. The objective of this study was to determine how these canopy openings influence regeneration, forest structure and species diversity. The study employed nested sampling design in disturbed sites of the forest reserve. Plots of 500 by 500 m were laid once at 100 m inwards from the forest edge in the three blocks of SW Mau; Ndoinet, Maramara and Itare. Gaps were randomly identified in the plots and gap area calculated using Ellipse Method (EM). Gap sizes were categorized based on area (m^2). Woody species surrounding the gaps were identified and names inventoried. To determine regeneration, two quadrats of 5 by 5 m and 1 by 1 m were randomly delineated in every gap size four times and eight times for saplings (1-3 m high) and seedlings (<1 m high), respectively. Tree heights surrounding the gaps were measured using suunto clinometer. Diameter at breast height (dbh) was measured using diameter calliper (65 cm for small trees) and diameter tape for large trees (dbh> 65 cm). A total of 41 gaps were identified with small gap sizes dominating (23). Kruskal-Wallis rank sum test indicated non-significant differences in regeneration, forest structure and species diversity in the three gap sizes. This was attributed to *Piper capensis* which invaded medium and large gap sizes creating a closed canopy. It was, therefore, concluded that canopy cover from the invasive species influenced woody vegetation parameters in the gap sizes. It is, therefore, recommended to clear the dense ground cover to allow better natural regeneration and also enrichment planting in the gaps.

Keywords: Canopy cover; canopy openings; disturbed sites; ellipse method; piper capensis; vegetation parameters.

Asian Journal of Research in Agriculture and Forestry

Volume 9, Issue 1, Page 38-48, 2023; Article no.AJRAF.95923
ISSN: 2581-7418

Comparative Assessment of Regeneration, Structure and Species Diversity of Woody Vegetation in Disturbed and Undisturbed Sites of a Secondary Montane Forest, Kenya

Jemimah Achieng Ocholla[a*], Shadrack Kinyua Inoti[a] and Gilbert Obati Obwoyere[a]

[a]Department of Natural Resources, Faculty of Environment and Resources Development, Egerton University, P. O. Box 536-20115, Kenya.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJRAF/2023/v9i1196

Open Peer Review History: This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc. are available here: https://www.sdiarticle5.com/review-history/95923

Original Research Article

Received: 25/11/2022
Accepted: 30/01/2023
Published: 07/02/2023

ABSTRACT

Secondary montane forest is created by either natural or artificial disturbances resulting in open canopies. It is an important resource in relation to economic and ecological values, however, it faces over-exploitation. The objective of this study was to compare regeneration, forest structure and species diversity of woody vegetation between disturbed and undisturbed sites of the South-Western (SW) Mau forest reserve in Kenya. A nested research sampling design was used, whereby, plots of 500 by 500 m were demarcated in Itare, Maramara and Ndoinet blocks. In disturbed sites, canopy openings were randomly selected to constitute the sample units. In undisturbed sites, sample plots of 30 by 20 m were randomly nested. Regeneration, forest structure and species diversity were then determined per sample unit. Wilcoxon rank sum test with continuity correction was then used to compare the three parameters in disturbed and undisturbed sites of the forest. A total of 41 gaps were selected (7 large, 11 medium and 23 small gap sizes) in disturbed sites while a total of 19 sub-plots (Itare 5, Maramara 6 and Ndoinet 8 times) were laid in undisturbed sites. There was a significant difference in forest structure between disturbed and undisturbed sites of the forest (P = 0.01, P value *adjustment method: BH*). The forest was invaded by *Piper capensis*, *Ribes spp.* and ferns in disturbed sites which affected the three woody vegetation population parameters. Therefore, enrichment planting was recommended in disturbed sites to conserve biodiversity within the forest.

Keywords: Canopy openings; disturbances; gaps; Piper capensis; Ribes spp.; vegetation population.

Appendix VIII: Egerton University ethical clearance

EGERTON UNIVERSITY

TEL: (051) 2217808
FAX: 051-2217942

P. O. BOX 536
EGERTON

EGERTON UNIVERSITY RESEARCH ETHICS COMMITTEE

EU/RE/DVC/009
Approval No. EUREC/APP/151/2021

1st December, 2021

Ochollla A. Jemimah
P.O Box 536-20115,
Egerton Njoro, Nakuru-Kenya
Telephone: +254743354660
E-mail: jemmy achieng@gmail.com

Dear Jemimah,

RE: ETHICAL APPROVAL: INFLUENCE OF GAP SIZE ON REGENERATION STRUCTURE AND SPECIES DIVERISTY OF WOODY VEGETATION IN SOUTH-WESTERN MAU FOREST RESERVE, KENYA

This is to inform you that *Egerton University Research Ethics Committee* has reviewed and approved your above research proposal. Your application approval number is *EUREC/APP/151/2021*. The approval period is *1st December, 2021 – 2nd December, 2022*.

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. You are required to adhere Institutional Experimental Animals use and Care policy.
iii. All changes including (amendments, deviations, and violations) are submitted for review and approval by *Egerton University Research Ethics Committee*.
iv. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to *Egerton University Research Ethics Committee* within 72 hours of notification
v. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to *Egerton University Research Ethics Committee* within 72 hours
vi. Clearance for Material Transfer of biological specimens must be obtained from relevant institutions.
vii. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.

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viii. Submission of an executive summary report within 90 days upon completion of the study to *Egerton University Research Ethics Committee*.

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely,

EGERTON UNIVERSITY
Date: 1/12/2021

Prof. R. Ngure
CHAIRMAN, EGERTON UNIVERSITY RESEARCH ETHICS CTTEE
RMN/BK/

Appendix IX: KFS clearance letter

KENYA
Forest Service

Kenya Forest Service Hqs
Karura, Off Kiambu Rd
P.O. Box 30513 - 00100
Nairobi, Kenya

Ref: No......RESEA/1/KFS/VOL..VII/28

Date:..22nd..April.2022....

Prof. Gilbert O. Obwoyere,
Associate Professor – Landscape Ecology and Ecosystem Health
Egerton University
P. O. Box 536
EGERTON.

Dear Prof. Obwoyere,

RE: PERMISSION TO CARRY OUT MSC THESIS RESEARCH IN SOUTH WEST MAU FOREST RESERVE (NDOINET, MARAMARA AND ITARE FOREST STATION).

Reference is made to your letter dated 9th March 2022, requesting access to South West Mau forest reserve for Ms. Jemimah Achieng Ocholla to undertake research. Your request is hereby approved.

The following conditions shall apply;

I. No sample shall be collected in such a way that will threaten or be detrimental to the supply of that material in the wild.

II. No information detrimental or of a confidential manner shall be shared publicly without written permission from Kenya Forest Service.

III. Intellectual property rights arising from the study of the materials will be jointly shared by the Kenya Forest Service and yourself.

IV. You shall acknowledge the Kenya Forest Service in all and any publications, patents or presentations involving the use of the information.

V. You shall indemnify and keep the Kenya Forest Service and the State harmless from any claim, action and damage or cost deriving from or in connection with the use of the information.

VI. No commercialization shall take place without clearance from Kenya Forest Service.

Trees for better lives

Tel: (254)020-3754904/5/6, (254)020-2014663, (254)020-2020285, Fax: (254)020-2385374
Email: info@kenyaforestservice.org. Web: www.kenyaforestservice.org

Appendix X: NACOSTI permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: 889922

Date of Issue: 10/March/2022

RESEARCH LICENSE

This is to Certify that Ms.. Jemimah Achieng Ochollo of .Egerton University, has been licensed to conduct research in Bomet, Kericho, Nakuru on the topic: DETERMINING THE INFLUENCE OF GAP SIZE ON REGENERATION, STRUCTURE AND SPECIES DIVERISTY OF WOODY VEGETATION IN SOUTH-WESTERN MAU FOREST, KENYA for the period ending : 10/March/2023.

License No: NACOSTI/P/22/16095

889922

Applicant Identification Number

Director General

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

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