INFLUENCE OF FOREST FRAGMENTATION ON TREE SPECIES RICHNESS AND ABUNDANCE IN THE FRAGMENTS OF KAKAMEGA FOREST, KAKAMEGA COUNTY, KENYA.

BY

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DECLARATION

Declaration by Candidate

I hereby declare that this Thesis is my original work and that it has never been presented for award of any degree in any other University.

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ABSTRACT

Forest fragmentation occurs when large continuous forests are perforated by small holes or broken up into edges and smaller patches to form a non-perforated matrix of open spaces. Global researches have shown that primary attributes of the remnant forest fragment that may influence patterns of species richness include: fragment area, fragment isolation, fragment edge to interior ratio, and the fragment shape complexity. In Sub Saharan Africa, for example, high human population densities resulting from rapid increase of population has led to numerous anthropogenic activities with negative impacts on forest fragments, consequently, affecting the tree species richness. Various studies on Kakamega forest have generally revealed effects of fragmentation and habitat loss emanating from anthropogenic activities. Few studies have analyzed the influence of forest fragmentation attributes such as total edge length, edge density on tree species richness and tree species relative abundance. The theoretical approach guiding this study was based on the Island Biogeography Theory. The purpose of this study was to assess the influence of forest fragmentation on tree species richness in the fragments of Kakamega forest, Kakamega County. The specific objectives of this study were to: determine the influence of total edge length of forest fragments on tree species richness in the detached fragments of the Kakamega forest; establish the influence of the edge density of the forest fragments on tree species richness; and assess the influence of edge density and total edge length on tree species relative abundance. The study adopted a cross-sectional correlational research design. Proportionate random sampling was used. A sample of 30 plots each measuring 2m by 2m was established randomly in the fragments (0-200m from the edge towards the interior);Malava: Kisere: Ikuywa in that order for field sampling and measurements. Data was collected using tools such as measuring tapes,metre rule,GPS 64s Garmain and suunto inclinometer. A total of 39 species of trees were recorded from the three fragments with *Funtumia africana* being recorded as the most abundant species. The results show that 96%, 95%, and 96% variation of tree species richness in. Malava (r^2 = 0.96), Kisere (r^2 = 0.95) and Ikuywa (r^2 = 0.96) in that order can be explained by the total edge length of the fragments. Moreover, 83%, 85%, and 92% variation of tree species richness in. Malava (r^2 = 0.83), Kisere (r^2 = 0.85) and Ikuywa (r^2 = 0.92) in that order can be explained by the edge density of the fragments. The 92%, 83% and 92% variation of tree species relative abundance in Malava (r^2 = 0.92), Kisere (r^2 = 0.83) and Ikuywa (r^2 = 0.92) in that order can be explained by the total edge length of the fragments. The edge density also explained 87%, 94% and 94% variation of tree species relative abundance in Malava (r^2 = 0.87), Kisere (r^2 = 0.94) and Ikuywa (r^2 = 0.94) in that order. It was concluded that tree species richness and tree species abundance in the detached portions of Kakamega forest were dominantly influenced by forest fragment total edge length and fragment edge density. For us to conserve more tree species we recommend maintenance of the total edge length of the fragments above 15km with edge density (3.413.79m\m^2) in order to maintain high tree species richness and tree species relative abundance.

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LIST OF ABBREVIATIONS AND ACRONYMS

B.D.T.F.F.P – Biological Dynamics of Tropical Rainforest Fragmentation Project
C.B.D - Convention of Biological Diversity
D.B.H - Diameter of Breast Height
F.I.A - Forest Inventory and Analysis
GIS - Geographical Information system
IBT- Island Biogeography Theory
D.R.S.R.S - Department of Remote Sensing and Resource Surveys
K.I.F.C.O.N- Kenya Indigenous Forest Conservation Program.
KWS - Kenya Wildlife Service
UNEP - United Nation Environmental Policy
UN - United Nations
UNFC- United Nation Framework Convention.

WORKING DEFINITION OF TERMS

Forest fragmentation- Is a form of habitat fragmentation occurring when forest is cut down in a manner that leaves relatively small, isolated patches of forest known as forest remnants. In this research it entails a part of the whole forest such as Malava and Kisereand also **a quasi-fragment** ;that which has not been wholly detached from the main forest block such as Ikuywa fragment that has been influenced by external factors resulting to separation of this part or a section of it from the main forest. It was measured by calculating the forest edge length and edge density; which will assist in giving the percentage proportion of the fragmented area.

Relative abundance – This is the percentage composition of an organism of a particular species relative to total number of other species in a given area.

Species diversity – Refers to the number of different species that are represented in a given community. It consists of two components, namely, Species richness and relative abundance.

Species evenness – Refers to how close in number each species in an environment is. It is a measure of biodiversity which quantifies how equal the community is numerically.

Species richness – This is the simple count of species. In this research it entails simple count of tree species which was identified by plucking the different species leaves, comparing then classifying them accordingly. It was given in whole numbers.

Edge length-. An edge is an interface between two different types of environments or ecosystems, arising between two different landscape forms or habitats - like a border between a spruce forest and a barley field. In this research edge length entails the perimeter of the part of the forest that has been separated from the original forest size. It also entails measuring the size of the quasi-fragment which entails the part of the fragment which is not in contact with part of the forest that has been fragmented. It was measured in kilometers.

Edge Density-This is the proportion of forested area within each $1km^2$ of the detached fragments of the forest. In this research it represents the total edge length of all the edges between forested and non-forested region of the detached fragments of the forest within a $1km^2$ analysis unit. It was measured in square kilometers.

Forest edge- This is the outer band of a forest patch; an area that may vary in width depending on parameters considered. The edge of a forest patch is influenced by environmental conditions adjacent to the patch and is thereby different from the forest interior. It was measured using edge length and edge density.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Forest fragmentation involves continuous reduction of a forest habitat into smaller isolated forest patches (Laurance *et al.*, 1998). The reduction in the forest habitat and continued isolation may lead to reduced populations, composition and distribution of species of various organisms in the resulting patches (Laurance *et al*., 2000). The newly created edges (patches) expose trees to other biotic and abiotic factors, thus increasing tree mortality (Honnay *et al.*, 2002). Forest fragmentation occurs in many forests across the world and has been reported to be a threat to various species of plants and animals (Foley *et al.*, 2005). Tropical forests world over have been subjected to massive anthropogenic activities consequently resulting into extensive fragmentation with newly created edges (Lung and Schaab 2006).

The process of habitat loss and fragmentation is widely considered to be one of the primary threats to global biodiversity (Laurance *et al.*, 2007). For instance, South America is unique in having large fragments isolated from forest disturbance and hence massive forest biodiversity loss (Reinmann *et al*., 2017). When habitat fragmentation occurs, the perimeter of a habitat increases, creating new borders and increasing edge effects (Taubert *et al*., 2018). These studies focused on general forest biodiversity loss on the forest fragments as a whole. However, the influence of forest fragmentation parameters such as edge length and edge density on tree species richness and abundance has not been done extensively in the tropical forests.

Global researches have shown that primary attributes of the remnant forest fragment that may influence patterns of species richness include: fragment area, fragment isolation, fragment edge to interiorratio, and the fragment shape complexity (Keppel *et al*., 2010). Area and isolation have been widely used as important attributes for analyzing effects of forest fragmentation on species richness and composition (Laurance *et al.*, 2011). Effect of habitat fragmentation on various species world over has been studied although much more needs to be studied with regard to total edge length and edge density of the fragments (Miller-Rushing, *et al*., 2019). In relation to the total forest land area and fragment isolation, not much has been done to elucidate on how the interaction between the two phenomena can be used in assessing the edge density of the fragments and how it influences the tree species richness and abundance in the forest. Edge phenomena in the forest ecosystem may have direct effects on the forest species, however, it is not known how the total edge length and edge density of the forest fragments influence tree species richness and abundance.

In Africa few research studies have been reported about fragmentation and tree species richness and diversity (Fashing and Cord 2000). In Sub Saharan Africa, for example, high human population densities resulting from rapid increase of population has led to numerous anthropogenic activities with negative impacts on forest fragments, consequently, affecting the tree species richness (Peres 2001). The rise in population coupled with extreme poverty situations has led to indiscriminate activities in the forest that in turn leads to loss of forests and the forest land (FAO 2001). The effects on biodiversity at the Uluguru forest block in Tanzania which is a highly regarded global biodiversity hotspot are extreme at the forest edges (Burgess *et al.*, (2002). Harcourt and Doherty (2005) established that many studies in Africa showed weaker relations between forest size and tree species richness. Intensity of fragmentation has been reported to be dependent on physical factors such as land elevation and land use (Echeverría *et al*., 2006; Burgess *et al*., 2007). Structural complexity is positively related to resource and shelter availability for both habitat patches and the matrix, and ultimately affects species distribution (Driscoll *et al.*, 2013). In their study, Brinck *et al.* (2017) quantified increasing fragmentation of tropical forests over time, using spatial metrics such as fragment size, distribution and distance to forest edge. Thus, primary forests taken as a subset of the modelled forest fragments in Africa such as East Guiana shield which is the largest tropical forest fragment exhibit largely the same relationship as that of the whole fragment with regard to tree species richness and abundance (Fahriga *et al.,* 2019). These studies have substantially focused on how population pressure has influenced land elevation and land use and its impacts on the forest fragments. However, the studies failed to analyze other attributes such as edge length and edge density with respect to how they influence tree species abundance in the studied fragments. Hence, there was need to understand the influence of edge density and total edge length on tree species abundance and tree species richness.

In Kenya, larger forests have borne the brunt of fragmentation as a result of various anthropogenic activities such as logging and pit-sawing and (Brooks *et al.*, 1999). This implies that there will be future declines of tree species and increased tree species extinctions, over the coming years (Mammides *et al.*, 2009). Forest fragmentation in Kenya can be inferred from as far as coastal forest region (Maeda *et al.*, 2010) and throughout the country in forested areas such as the Mau forest and the Kakamega forest blocks. Reduced fragment area, increased isolation and increased edge, initiate changes in the forest ecosystems which can have unpredictable outcomes with regard to fragmentation (Olson *et al*., 2014). Edge areas have biotic and abiotic conditions that are different from both the matrix patch core region, with either positive or negative effects on species (Haddad *et al*. 2015). These studies focused more on how anthropogenic activities have increased forest fragmentation resulting to reduced fragment area. However, few studies have been reported regarding how tree species richness and tree species abundance have been influenced by total edge length and edge density of the fragments.

Kakamega forest is the only tropical rainforest in Kenya and it has undergone massive fragmentation resulting into quite a number of small fragments since it was first gazetted in 1933 leading to different ecological pressures (Brooks *et al.*, 1999).Studies done on Kakamega forest have generally revealed effects of fragmentation and habitat loss emanating from anthropogenic activities(Maina and Jackson 2003). For example, an irregularly shaped fragment is likely to have longer edge length thereby increasing isolation which in turn inhibits species movement and interaction between the fragments (Laurance *et al.*, 2006,). These variations are indicators for selective logging over a long period of time and a higher degree of forest disturbance (Lawes *et al.,* 2007). The fragments of Malava, Kisere, Yala, Ikuywa(quasi-fragment) and Kaimosi depicts how fragments vary in shape and in distance to the main forest as well as in distance to each other and in age (Botzat *et al*. 2013). The boundary between the forest and the matrices (usually of human use) create edge effects which vary by the species and the type of matrix (Taubert *et al*., 2018). Edge effects which can be biological (e.g. predation) or abiotic (e.g. temperature), decrease the effective available area for species growth and thus influence tree species richness (Mitchard *et al*. 2018). However, these studies have not helped us to understand the effects of forest fragmentation attributes on tree species richness and abundance. Thus, there was need to assess how the edge density and total edge length influenced tree species abundance in the tropical areas.

1.2Statement of the problem

The encroachment of forests by human activities threatens the survival of unique indigenous flora and fauna species. Although studies have been carried out to demonstrate general forest fragmentation as well as the threatened survival of indigenous flora, focus has to be directed towards the influence of spatial metrics of forest fragments on tree species richness and abundance in Kakamega tropical rainforest. When habitat fragmentation occurs, the perimeter of a habitat increases, creating new borders and increasing edge effects.Edge length is regarded to be an important attribute affecting species richness globally due to its direct influence on tree mortality at the edge.An irregularly shaped fragment is likely to have longer edge length and a low edge density thereby increasing isolation which in turn inhibits species movement and interaction between the fragments. Effects of habitat fragmentation on various species world over has been studied although much more needs to be studied with regard to total edge length and edge density of the fragments so as to find out the influence of forest fragmentation on tree species richness and abundance in the detached fragments of Kakamega forest in Kakamega County.

1.3 Objective of the study

The general objective was to assess the influence of forest fragmentation on tree species richness and abundance in the detached fragments of Kakamega forest, Kakamega County.

Specific objectives

1. To determine the influence of total edge length of forest fragments on tree species richness in the detached fragments of the Kakamega forest.
2. To establish the relationship between the edge density of the forest fragments and the tree species richness in the detached fragments of Kakamega forest.
3. To determine the influence of edge density and total edge length on tree species abundance in the detached fragments of Kakamega forest.

1.4 Research questions.

i. What is the influence of total edge length of forest fragments on tree species richness in the detached fragments of the Kakamega forest?

ii. What is the relationship between the edge density of the forest fragments and the tree species richness in the detached fragments of the Kakamega Forest?

iii. What is the influence of edge density and total edge length on tree species abundance in the detached fragments of Kakamega forest?

1.5 Significance of the study

A reduction of species may occur in fragments that are too small to support their original flora and fauna because forest destruction and degradation threaten thousands of tree species with extinction (Echeverria et al., 2007). This study focused in Kakamega forest because it is the only tropical rainforest in Kenya. Although studies have been carried out to demonstrate general forest fragmentation as well as the threatened survival of indigenous flora, specifically, studies have not clarified how the total edge length of the forest fragments influence the tree species richness and abundance. Primary forests taken as a subset of the modelled forest fragments in Africa such as East Guiana shield which is the largest tropical forest fragment exhibit largely the same relationship as that of the whole fragment with regard to tree species richness and abundance. In the same measure, there are six fragments of Kakamega forest although this study's focus was on three fragments because they all have similar attributes. Understanding the influence of forest fragmentation on tree species richness and abundance in the detached fragments of Kakamega Forest would help the local community to formulate conservation measures of forests. Assessment of how total edge length and edge density influence tree species richness and abundance would help local community and the scientific community in understanding the causes of forest tree species loss in Kakamega rain forests fragments. The data on spatial factors of forest fragmentation will also be useful to the individual researcher in assessing the influence of forest fragmentation on tree species richness and abundance in the forest of other regions.

1.6 Scope and limitations of the study

Fragmentation has occurred in a wider section of Kakamega forest resulting to over six small fragments, however, due to time and financial constrains the study was limited to only three fragments namely Malava, Kisere and Ikuywa(a quasi-fragment). The variables considered in the study include the total edge length, edge density, tree species richness, and tree species abundance. Moreover, the study was limited to trees and not shrubs and lianas because trees are greatly targeted for most of the anthropogenic activities. The limitation of this study was inaccessibility of some areas within the fragments due to excessive thickness of the forest with limited accessibility pathways. This limitation was overcome by sourcing for assistance from the research assistants who assisted in maneuvering through the forest to collect the data.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter discussed the various literature related to the effects of forest fragmentation on tree species richness which was analyzed according to the objectives of the study and a conceptual framework which will give a summary of the variables studied. The documented reports were reviewed and a close critique of the used methodologies given.

2.2 Fragmentation, Edge Length and Tree Species Richness.

Global researches have shown that edge length is a primary attribute of a remnant of forest fragments that may influence patterns of species richness (Haddad *et al*., 2015). Other studies have revealed that fragments of old secondary succession stages have similar species richness like disturbed forest fragments (Wekesa *et al*., 2016). Edge length is regarded to be an important attribute affecting species richness globally due to its direct influence on tree mortality at the edge as explained by various past studies (Mitchard *et al*., 2018). It is evident that most of these studies dwelt on patterns of species richness; however, these studies did not analyze influence of edge length on fragmentation thereby necessitating the need for this research. Forest destruction and degradation threaten thousands of tree species with extinction all over the world (Ewers and Didham 2006b). It is vastly known that the forest area in England and in the whole of the UK such as the

Sherwood Forest in Nottinghamshire is low, and comprises mainly small, isolated fragments (Glenday 2006).

Approximately 40% to 75 % of the forest area in England is edge-influenced in terms of microclimate, which will in turn have an effect on ecosystem processes, such as soil fauna activity (Tsvuura *et al*. 2012) and litter decomposition (Tsvuura *et al*. 2012). A reduction of species may occur in fragments that are too small to support their original flora and fauna (Saunders *et al.,* 2019). These studies focused on the interaction between forest fragments and anthropogenic activities while less focus was put on the influence of edge length on tree species richness. While the reduction in tree species may result directly from a decrease in forest area, it is more likely due to the increased perimeter: area ratio that results from fragmentation and the modification of abiotic and biotic factors at the forest edge. Hence the need to study the influence of total edge length on tree species richness.

Despite global studies documenting various analyses of tropical forests fragmentation edge attributes such as edge length on various species richness these studies are still limited in Africa Debinski(1999). In Africa, where there's high human population growth rates and poverty thus edge length attribute is likely to be affected due to constant interaction between the forest edge and anthropogenic activities resulting into high level of forest loss along the edge (FAO 2001). Within the East African region, few studies have been carried out in Uganda mainly in Kibale forest complex in western region of Uganda (Fairgrieve and Muhumuza 2003). These studies primarily focused on the determination of the types of species that are most susceptible to habitat disturbance and which types of disturbed habitats can support particular species. However, less was quantified with regard to determining the relationship between the various sizes of the fragments (edge length) and the number of tree species in the patches which have been influenced by fragmentation. This prompted the need to study how the perimeter of the fragments in Kakamega forest influences the number of the tree species available in a given fragment.

Burgess *et al. (*2007b) argues that fragment size, shape and edge 'penetration distance' are likely to affect the amount of core area where native flora and fauna are able to persist. Creation of settlements at the edges of the forests results in cleared lands encircling remnants of forest islands (Mumbi *et al.,* 2008). In such cases, the forest edges are in contact with continuous disturbance of human activities, consequently these edges can no longer support the initial flora and fauna populations thus the result of this invasion is the destruction of sessile organisms and migration of mobile organisms (Miller-Rushing, *et al*., 2019).These studies focused on the effects of having settlements at the fragment edges however analysis of this aspect in relation to Kenyan forests fragments and the total edge length is minimal. Thus, there was need for studying the relationship between edge lengths of forest fragments and the tree species richness.

For majority of fauna and flora, the encroachment and destruction of habitats poses the greatest threat to their survival. Erosion of genetic diversity and the extinction of species are high in tropical forests (Fischer 2004). Clearing of natural vegetation for human activities has resulted in forest fragmentation in major forest ecosystems; natural habitats that were once incessant have become carved up into separate fragments (FAO, 2006). Kenya is one of the countries endowed with tropical rainforest cover (FAO, 2006). Just like other tropical biomes of the world, the Kenyan tropical forests have been encroached and fragmented by human activities (Ewers and Didham 2006a) hence becoming a hot spot of threatened biodiversity, (Miller-Rushing *et al*., 2019). These studies focused on the extinction of tree species on the general forest while minimum was done in relation to how fragmentation and forest edges have specifically affected the tree species at the edges of the fragments.

Evidence of aspect effects on vegetation includes variation in exotic species cover and abundance, species richness, and tree species distribution (Gould, 2000).Because edge effects undoubtedly vary with habitat type, geographical location, and forest structure, it is important to add case studies to the existing body of knowledge (Fahrig 2003) Previous studies have been limited by replicacation and inconsistencies in sampling at several points from edge to centre of the fragment, and a lack of consideration of the potential interactions among variables in the responses of microclimate and vegetation in the edge environment (Laurance *et al.,* 2007). A large sample of studies may allow for broad conclusions to be drawn where there are currently inconsistencies (Haddad *et al*., 2015). For the case of Kakamega forests analysis have indicated that forest cover decreased by almost 40% from around independence to early2000, with a reduction in ‘core forest’ >1 km from a non-forest edge of almost 80% (Wekesa *et al*., 2018).Edge effects due to fragmentation typically affect an area several times larger than the forest destruction itself, increasing exposure to damaging winds, fire frequency and access for livestock, other non-forest animals and hunters (Hansen *et al*., 2018). To assess the impact of tropical deforestation on biological diversity, not only the area deforested, but also the isolation of forest patches and the area of edge habitat must be determined (Fahriga *et al* 2019). These studies do not sample into the forest fragment to reach the threshold point at which certain variables no longer vary with distance from the edge, however with more analysis on the total fragment edge lengths, a lot of insight into this was sought out in this study.

In Kakamega forest, studies explored effects of fragmentation on various flora and fauna. However, they mainly focused on species/area relationships such as (Fjeldså, 1999) while others were focused on edge and disturbance relationships such as (Griffiths*et al.*,2000). However, evidence of forest regeneration in Kenya has been seen (Millington *et al.,* 2003). Thus, the forest classes include virtually all-natural forest habitats upon which 90% of East Africa's fauna depends (Millington *et al*., 2003). A study on the influence of fragmentation on the tropical forests of Kenya in general showed that as the result of extensive fragmentation and the limited areas of the remaining patches, a large number of tropical forest ecosystems are threatened, especially since these are highly disturbed (Freund, 2005). Forest fragment types with modified matrices have most likely been exposed to new edge effects that changed abiotic factors such as canopy cover and light regimes (Mammides *et al.* 2009). Whereas this was possibly caused by other forms of human impact: road formation, selective logging or excessive bark harvesting of big indigenous interior tree species leading to the introduction of invasive species the effects of landscape attributes on fauna have been extensively studied for birds (Peters *et al.* 2009).However, few studies have outlined the relationship between the edge attributes and the species and functional groups of plants in forest remnants, yet there are minimal studies considering the variability of ecosystem descriptors.

Most of the studies have focused on plots within large, well conserved areas for example in the scarp-forest fragments in KwaZulu-Natal, South Africa. (Fletcher*et al.*, 2018). Rarely is the relationship between landscape and plant diversity studied within highly fragmented areas, where the forest cover and patch size are reduced, and where isolation and edge effects are more severe (Fahriga *et al*., 2019). These natural remnants are not necessarily a lost cause, however, although their ability to contribute to conservation and to provide environmental services will depend on their structural integrity and biodiversity (Grogan *et al*., 2019). These researches concentrated on few forest fragments samples of similar age and history. However, much sampling into the forest fragment to reach the threshold point was not adequately done. Hence, there was need to address this concern by analyzing data from three different forest fragments to get precise information on how the forest fragmentation influence tree species richness.

2.3 Influence Edge density and Tree Species Abundance

Globally, tree communities in Atlantic tropical forest in Brazil have demonstrated that tree species richness of the forest fragments appeared to be similar among patches of different sizes (Geldenhuys, 1997). Similarly, tree species richness in the Highlands of Chiapas Mexico, is not related to patch size and to any other spatial attribute (Laurence *et al*., 1998). However, it is important to mention that in this research the lowest richness of tree species (between one and three tree species per 500 square meters plot) was recorded in the smallest fragments. In the Mata Atlantic tropical forests, forest connectivity and the complexity of the matrix may be more important than fragment area and isolation in explaining variation in tree species richness and functional group richness (Gould 2000). However, patch size appears to have a significant relationship with shade-tolerant species in tropical forests. Conversely, a previous study conducted in the montane Atlantic forests of south-eastern Brazil, fragment size was found to be the major determinant of changes in woody plant composition and guild structure (Ochoa-Gaona *et al.,* 2004). Edge effects have been reported to play a critical role in determining impacts of richness, composition and abundances (Ries *et al.,* 2004). In some cases, species have been reported to decline with increasing edge density (Ewers and Didham, 2007). To assess the impact of fragmentation on forest abundance Wekesa *et al*., (2018) considered the area of the fragment in relation to the edge length which is related to the extent of isolation of the fragment in question from the rest of the fragments and the forest block. These researches mainly focused on forest area connectivity, area matrix and the similarity of tree species richness in the patches, however minimal was studied in relation to the distribution of tree species with reference to edge density at the fragments. This necessitated the need to carry out this research so that the relationship between fragment edge density and tree species abundance can be ascertained.

A reduction of patch size by fragmentation was related to a decline in the edge density of the fragments. The highest values of edge densities were found in large fragments of old-growth forest, where large trees of shade-tolerant species occur. Similar to this result, high basal areas are also associated with old-growth forests in Western Ghats, India (Haddad *et al*., 2015) and with larger fragments in south-eastern Madagascar such as in Ankafobe (Haddad *et al* 2015). A reduction of edge density in the study landscape represented a modification of the forest structure in which the forest returned to an earlier successional stage. This has also been described in the Klamath-Siskiyou forests, Pacific North-west USA (Staus *et al*., 2017), where the forest stands have become younger and more fragmented in response to logging of the larger (and older) trees. The current analysis of forest structure distribution by patch size revealed that most of the mid-successional forests or secondary forests were concentrated in the smallest classes of fragment size. These forests contain the lowest basal areas recorded, as a result of a simpler forest structure characterized by a high abundance of saplings and young trees. These changes in forest structure may have negative consequences on some species dependent on particular characteristics of forest structure (Spasojevic *et al.*, 2019). These studies at the global level such as studies done in Ankafobe forest reserve in Madagascar primarily majored on fragment are connectivity and the fragment structure influencing species patterns. Less was discussed on the edge density of trees on the patches of these forests thus forming a basis for research in this study.

Studies done at the Uluguru forest block in Tanzania showed that Species abundance of some tree species declined with an increase in patch area, while others decreased (Shirima *et al*., 2011) Furthermore, species abundance varied significantly, which could be attributed to changes in soil in both intact and fragmented areas (Shirima *et al*., 2011). Areas characterized by low edge density were not well placed to support high species abundance due to the wide extent of fragmentation; low species abundance was prevalent in fragmented areas associated with low values of nitrogen, carbon, potassium and phosphorus in the Uluguru North (Rashid *et a*l., 2013). This is attributed to increased anthropogenic activities in the area (Rashid *et a*l., 2013). This confirms a similar study finding which associated high species abundance with intact areas attributed to less human disturbances (Saikia, et *al*., 2013). Other related studies established less species in sites exposed to predation (Keenan *et al*., 2015). These studies strongly majored on the association between tree species abundance and anthropogenic factors in relation to the availability of rich-soil contents at the forests; less was covered in relation to the influence of edge density on tree species abundance.

In the deciduous forest patches of the East Guinea studied by Nackoney *et al*., (2014), forest edges typically contained more pioneer and xeric plant species than the interior, higher densities of shrubs and herbaceous ground layer vegetation for several meters into the forest, and higher species richness than the interior. Higher species richness in forest edges may often be due to the invasion of exotic plant species such as the *Acacieae* (Reinmann 2017). Edge orientation also influenced species composition: south- and west-facing edges contained more xeric plant species than did north- and east-facing edges (Reinmann., 2017) due to variation in light and moisture conditions. Most of these regional studies concentrated on analysis of species abundance and anthropogenic influences. These studies put less focus on the abundance of tree species after the invasion at the forest patches.

Freund *et al*. (2006) and Mammides (2009) cautioned the dangers of *S. mauritianum* weed if it found its way into the ecosystem. Similar concerns were expressed by Shirima *et al.* (2011) in a study in Mau forests in Kenya. Increase in density of individual species and overall density can be attributed to stable regeneration regimes and recruitment. However, it is yet to be established whether*S. ellipticum* and *C. mildbraedii* which increased drastically in 2006 could be some of those species that appeared spasmodically through the succession but with their first prominence at 66 years. Although some studies have been stated on the processes influencing the structure and composition of the forests in different tropical forests of the world (Ribeiro *et al.*, 2019), not much is on record about the impacts of fragmentation on the tree species composition in Kakamega forest fragments. In addition, the relevant studies within Kakamega forest zone have focused on single species of an organism such as abundance of *Funtumia africana* and abundance of some animals such as baboons not necessarily in all types of trees in totality in a single fragment.

Certain findings to date from experimental studies of fragmentation such as predation rate, mortality rate indicate that the Tropical forest fragments have experienced a wide array of ecological change (Republic of Kenya, 2013). Edge effects have been a dominant driver of fragment dynamics, strongly affecting forest microclimate, tree mortality, carbon storage, fauna, and other aspects of fragment ecology (Laurance *et al* 2017). However, edge-effect intensity varies markedly in space and time, and is influenced by factors such as edge age, the number of nearby edges, and the adjoining matrix of modified vegetation surrounding fragments (Fahrig, 2017). Rare weather events, especially windstorms and droughts, have further altered fragment ecology (Wekesa 2018). These studies show that not much has been documented on effects of edge density on tree species diversity. Related reports have been largely about other attributes such as fragment ecology attributes.

Studies have revealed that while the interiors of small fragments had marginally higher species richness to the interiors of the larger fragments, the community structure remained similar (Ewers and Didham, 2006). The fragment edges however had lower functional evenness compared to the interiors of the forest (Echeverría et *al.*, 2007). This is a clear indication of change in both abundance and dominance of functional traits, with negative impacts of human activities (Fahrig *et al*., 2019). With a greater focus being on the functional evenness of the forestless was studied with regard to species diversity on the forest edges at the

Kakamega forest. Hence the need to establish how it was impacted by the edge density of the forest fragments.

The resulting height and crown cover disturbances usually extend beyond the original edge boundaries (Mumbi, 2008). The creation of roads leads to the creation of microclimates at the edges hence new plant species colonize the regions interfering with the original plant cover (Saatchi 2008). Edge effects, as a consequence of creating roads through tropical forests, lead to high erosion of species biodiversity (Mumbi, 2008). Whereas the estimates of tropical forest cover from remote sensing, for instance, give information in forest alterations, they crucially shed no light on how these estimates relate to the biodiversity within the forest (May *et al.,* 2019). This gap was richly discussed in this study as it focused more on how species diversity had been influenced at the forest fragments with reference to the edge density.

The methodology used in the study of the analysis to establish the relationship between interior and peripheral forest environments entailed incorporating sample effects in the study area and use of regression models for analysis (Fahrig, 2017). Given the rarity of some of the tree species many species may be absent from fragments not because their populations have vanished, but because they were simply not present at the time of fragment creation—a phenomenon termed the 'sample effect' (Reinmann 2017). Such sample effects are the hypothesized explanation for the absence of many rare understory species from fragments (Wekesa *et al*., 2018). Most of these studies have cited that smaller fragments are often unable to support viable populations and deleterious edge effects. Ecological changes associated with the abrupt, artificial edges of forest fragments can also rise sharply in intensity. This study established the relationship between edge density of the forest fragments and the tree species diversity through sampling of the tree species and the analysis done using simple linear regression.

2.4 Influence of edge density and total edge length on tree species abundance.

Forest fragmentation leads to changes and reduction to spatial structure and size which in turn affect the tree community composition within the resulting fragments (Fjeldså, 1999). Forests structure world over have been affected by human activities leading to reduction in their original sizes (Fjeldså, 1999). In Mediterranean ecosystems of southern Spain, grazing has caused an alteration of the spatial organization of browse-sensitive species and a decline in the richness of some plants, particularly in the most heavily browsed sites (Martínez *et al.*, 2004).Most of these studies focused on how tree species on the browsed sites have been influenced by human activities , however, less was concentrated on this localities basing on how the forest edge length and density have influenced tree species composition. In the Amazonian forest of Brazil, less is, however, known about the impacts of continued reduction of fragment sizes on the stand structure of forest communities' species. When a forest edge is newly created it is open to fluxes of wind, heat, and light, creating sharp edge-interior gradients in forest microclimate that stress or kill many rainforest trees (Martinez et *al*., 2004).

As the edge ages, however, proliferating vines and lateral branch growth tend to 'seal' the edge, making it less permeable to microclimatic changes (Freund *et al*., 2005). Tree death from microclimatic stress is likely to decline over the first few years after edge creation (Drinnan 2005) because the edge becomes less permeable, because many drought-sensitive individuals die immediately, and because surviving trees may acclimate to drier, hotter conditions near the edge (Laurance *et al*., 2007). Tree mortality from wind turbulence, however, probably increases as the edge ages and becomes more closed edge (Mvavu *et al.,* 2007). Regrowth forest adjoining fragment edges can also lessen edge effect intensity (Laurance 2007). In central and southern Sweden and north-eastern Germany regions around the Baltic Sea, studies showed that habitat area and edge length describe different qualities of landscape configuration but they are interrelated (Fletcher*et al*., 2007).At landscape level, the relationship between forest edge length and forest area is humped with maximum edge length in landscapes with intermediate forest cover (Fahrig 2017). When comparing landscapes with similar total forest area, longer forest edge indicates that forests have more irregular margins and\or that forest patches are similar.

In Madagascar, the spatial pattern analysis of forest structure showed that levels of basal area were associated with accessibility to the fragments (Magnago *et al*., 2015). In these studies, the significant decrease of forest canopy cover and increase of stumps in small fragments confirm that these small fragments are being seriously disturbed by logging. In particular, logging for fuel wood has caused a severe deterioration of the remnant forest, especially of those forests situated near urban centers (Reinmann *et al*., 2017). Thus, globally this studies mainly focused on the openness and closeness of the forest edges, with less attention being directed towards the relationship between edge length and edge density of these fragments as this are the primary attributes of tree species abundance in the forest fragments.

East African tropical rainforests suffer large over-exploitation by humans and belong to the most threatened and least explored ecosystems on Earth (Mitchel 2004). Only about 0.1 % of the estimated 10 million km² of tropical rainforest in the world occur in Eastern Africa, which is about 10.000 km². Unlike the vast West and Central African forests, the forests of Eastern Africa are highly fragmented - discrete islands surrounded by comparatively arid woodland (Lovett *et al.*, 2006). Selective logging leads to gap formation that is the principal site for spontaneous forest rejuvenation whereby a mature tree, often senescent, releases a site for occupation of new individuals (Magnago 2015). Tropical forests are highly threatened by logging, agriculture and an increasing human population. Remaining forests are mainly degraded and often highly fragmented (Otuoma., *et al* 2016). Reported effects of tree species density on the understory community are less consistent, as both increases and decreases in understory density with increasing tree species richness having been observed, as well as absence of any relationship (Wekesa et *al.* 2016). Edges have also been observed to have differing environmental factors from edges such as greater canopy openness and altered forest microclimate with hotter and drier conditions near the edge (Fahriga 2017). These studies focused on the edge effects in relation to micro climatic conditions and how it influences canopy openness, however analysis based on tree species abundance at the fragments and the association with fragment edge length and edge density was studied in this research.

Fragmentation of Kakamega forest had been reported to be modifying the species richness or community composition in the past (Laurance *et al.,* 2011). The methodology used entailed field-based measurements, allometry, and mixed models to investigate the effects of proximity to the forest edge on species richness and community composition in Ikuywa quasi-fragment, Kisere and Malava forest fragments in Kakamega forest (Otuoma, 2016). It was evaluated whether fragment size or connectivity with surrounding forests altered these edge effects. Land-use change is the main driver of global tree species loss, but its relative impact on species turnover across multiple spatial scales remains unclear (Wekesa *et al*., 2018). These studies mainly focused on the use of allometry and mixed models in the analysis of proximity of the forest edge to species richness, less has been studied using simple linear regression in the analysis of determining the influence of edge density and total edge length on tree species abundance which shows the relationship between the forest edge attributes using scatter plots.

Studies done in Kakamega forest showed that plant communities in fragmented rain forests can undergo declines (floristic homogenization) or increases (floristic differentiation) in species turnover (FAO 2001). These phenomena may primarily be attributed to compensatory effects of small trees at the forest edge; however, it is due in some cases to the retention of large trees at forest edges, likely a result of forest management (Mitchell 2004). Most tropical and subtropical tree species depend on pollination and seed dispersal by animals to permit seed production, seedling recruitment and consequently forest regeneration (Laurance *et al*. 2007). These processes may, however, be altered by both fragmentation and matrix effects (Saatchi *et al*, 2008). Selective logging may change the original species composition of trees via the removal of large trees and the subsequent recruitment of early successional tree species (Qie *et al*., 2017). However, it is still unknown whether the combination of logging and edge effects may result in the slow recovery rates of fragmented forests (Brancalion *et al*, 2019). This research concentrated on the effects of habitat fragmentation on tree species density and interactions among species on the forest edges. Based on data collected and analyzed using the land cover maps showing greater canopy openness in the fragment edges, few studies have been done with respect to edge effect on tree dynamics, hence this research was meant at addressing this by analyzing the effects of edge length and edge density attributes on tree species abundance.

2.5 Theoretical framework

Tree species richness expresses the number of species in a given community or study site, according to the equilibrium theory of island biogeography developed by Mac Arthur and Wilson 1963, the rate of extinction rises as the number of species on the island rises. If the island is larger there was no more room for many viable populations of species than if the island is small. Fragmentation depicts loss of humid tropical forests as large fragments that experience continually greater pressures of conversion; posing a threat to maintenance of biodiversity within this biome (Fahriga *et al*., 2019) When habitat fragmentation occurs, the edge length of a habitat increases, creating new borders and increasing edge effects (Regolin et al., 2020).The rate of extinction of species on a small island was higher than the rate of extinction for the same number of species on a larger island. Hence with regard to this study; fragments are smaller than the initial forest size hence rate of extinction of the tree species is high on the fragments while the regeneration rate is low. This is due to the fact that fragments have a high perimeter (edge length) hence fewer tree species which influence the richness and abundance of the trees especially on the edges of the fragments. The end result is destruction of natural habitats explaining the increasing effect of forest fragmentation on edge density and edge length of the fragments. It is important to adopt the IBT in order understand how edge length and density influence tree species richness and tree species abundance. IBT presumes that both edge density and edge length dominantly influence tree species richness and abundance. The smaller the fragment the greater the influence of external factors and edge effects which affect the edge length and edge density of the fragments. Edge effects are more complicated as they alter growing conditions within the interior of forests through drastic changes in temperature, moisture, light and wind. A distinct focus on the edge length and edge density of the fragments as key variables in studying the influence of forest fragmentation on tree species abundance and richness will give clear explanation on edge effects at the different forest patches in line with the IBT.

2.6 Conceptual framework

Fragmentation and edge effects change forest structure and above ground biomass. As a result, mortality increases among sensitive tree species which results to changes in the forest edge density, forest edge length and the tree species richness and density of forest as a whole. Consequently, tree populations face local, regional and global extinction as attested by the IBT. Increase in the forest edge length and forest edge density lead to the increase in the general decrease of the percentage of the forest cover with respect to the initial forest size or area with reference to fig 2.1. As forest edge density increases, the extent of the fragments increases leading to a decrease in tree species richness and abundance. As the fragmented forest edge length increases, the number of tree species affected by fragmentation increase in number

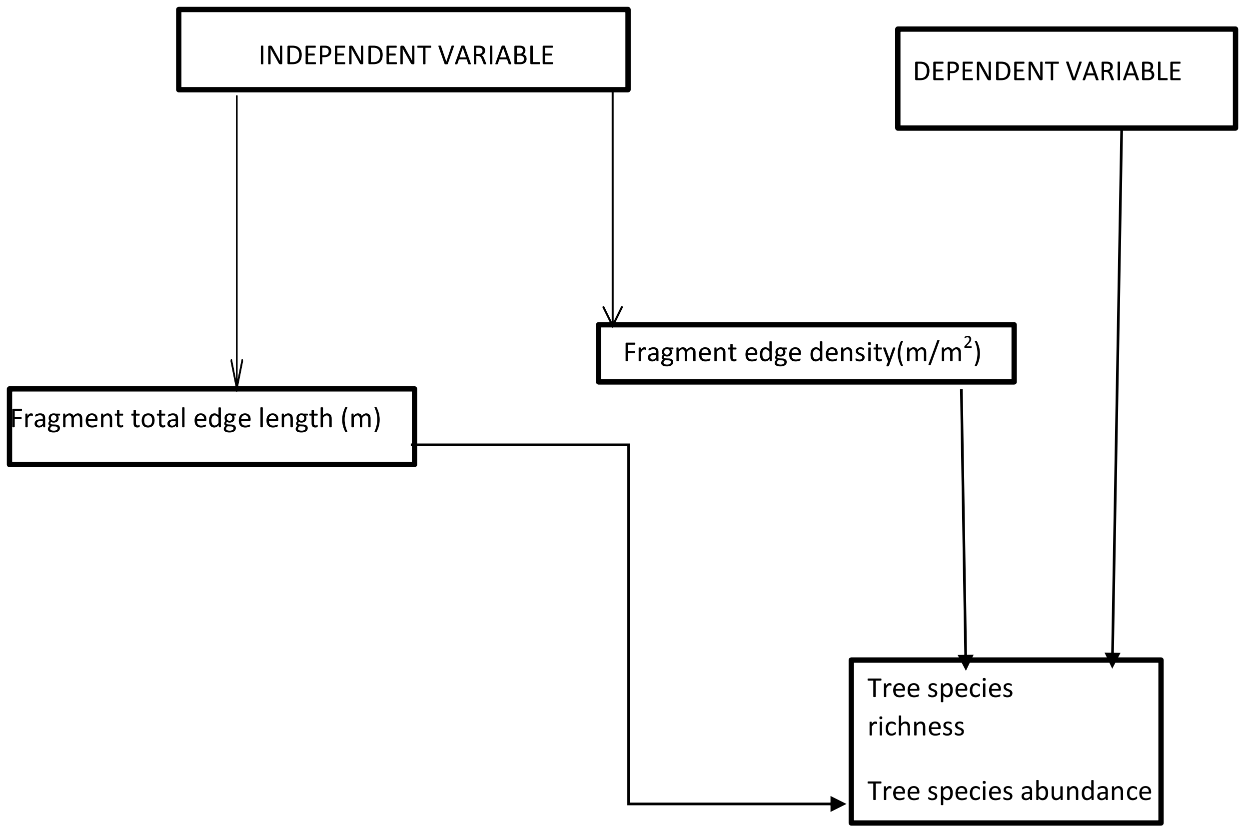

Figure 2.1: Effects of fragment attributes (Edge length and Edge density) on tree species richness, abundance.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

The study was based in Kakamega tropical rainforest and its fragments. Thus, this chapter focuses on research area and study population, research design, sampling procedures, data collection methods, data analysis and results presentation, reliability, validity and data collection and analysis from the forest's fragments.

3.2 Study area.

Kakamega forest is located in Kakamega East Sub-County in Kakamega County, Western Kenya. It lies between longitudes 34^0 40' and 34^0 57' 30" East and 0^0 15" South (Figure3.1). The entire population of Kakamega East Sub-county was projected at 167,641 by 2019, according to 2019 population census (KNBS 2019). The forest has a varied topography with altitudes ranging from 1250 to 2000 m above sea level and has a mean daily temperature of 11°C with a range of 5-26°C. A majority of the tree species show positive correlations between monthly and seasonal precipitation and moisture index during the periods of short and long rainy seasons. Data from the Kenya meteorological station at Isecheno Forest Station shows that the forest has a warm and wet climate and experiences two rainy seasons: the long rains which start in March and end in June; and the shorterrains which begin in July and end in October with a peak in August. Annual rainfall averages between 1500 – 2000 mm which is sufficient for tree species increase as the saplings are able to mature faster and as a result there will be vast tree species abundance in the forest. Habitats within the established boundaries include indigenous forest, swamp and riverine forest, colonizing forest, disturbed forest, forestry plantations, and natural grass glades. Closed canopy indigenous forest covers about 30% of the official area and is dominated by evergreen hardwood trees (Kokwaro, 1988).

The area surrounding the forest is intensively used forhuman activities. The primary contemporary drivers of tropical forest biodiversity loss include direct effects of human activities such as habitat destruction and fragmentation (land use change that influences fragment edge length and edge density). There is widespread dependence on the forest by the local people who obtain their livelihood by mainly harvesting firewood, thatch grass and medicinal plants (Wekesa *et al.*,2018). There are incidences of illegal logging, grazing, debarking, charcoal burning and hunting of small mammals in the forest.

Kakamega forest is the headwaters for the County's two rivers and is an important watershed for the Lake Victoria basin (Geldenhuys *et al.* 1997). Soils throughout the area are composed largely of volcanic clays and clay loams classified as ferralo-chromic or humic cabrisoils (Kokwaro 1998). In order to increase tree species richness and abundance the total inorganic carbon in soils must be increased so that the edge length of the fragment from the main forest block can be reduced hence reducing the extinction rates of tree species in accordance to the IBT(Mammides *et al.,* 2009). The main forest block is located about 7.5 km from Kakamega town. The present study was conducted in three of its detached fragments namely Malava, Kisere and Ikuywa. The fragments vary in shape, in distance to the main forest as well as in distance to each other and in age (Kawawa, 2016).

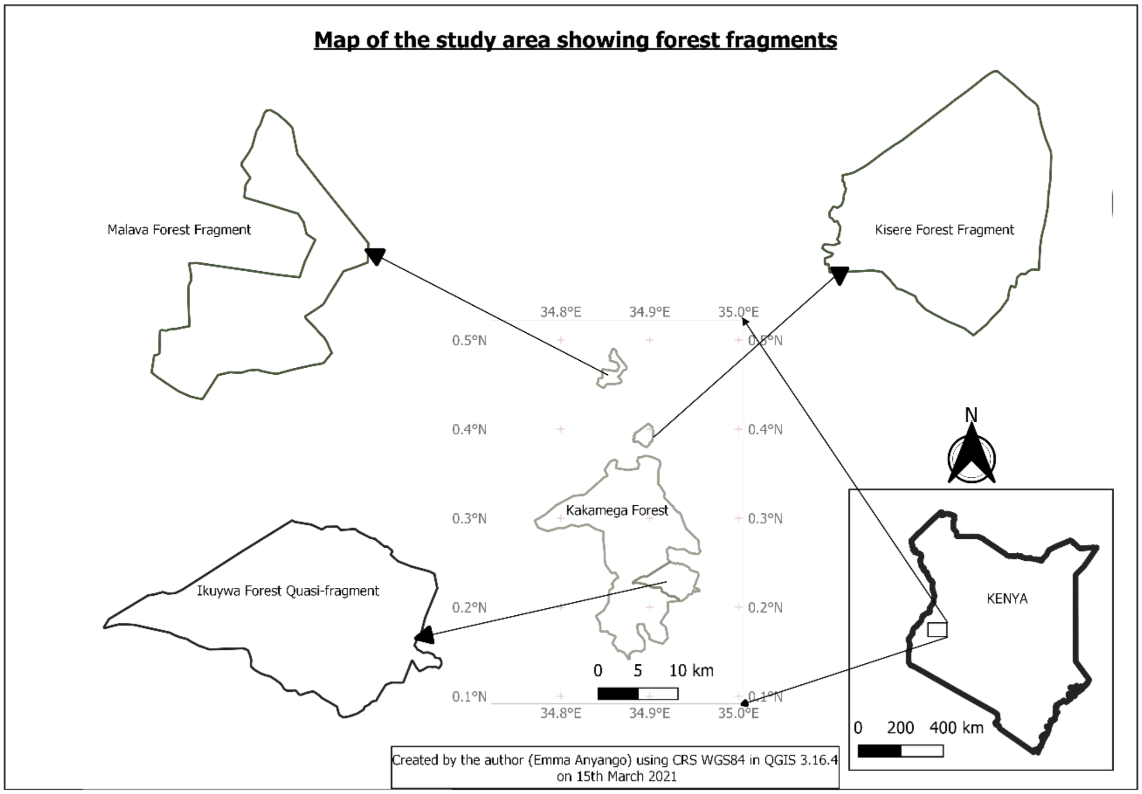

Figure 3.1 Map of Kakamega Forest showing the three fragments (Ikuywa- quasi-fragment, Malava and Kisere)

The area surrounding the forest is intensively used for farming. There is widespread dependence on the forest by the local people who obtain their livelihood by mainly harvesting firewood, thatch grass and medicinal plants (Resende *et al.*, 2018). There are incidences of illegal logging, charcoal burning and hunting of small mammals in the forest (Regolin *et al*., 2020). The fragments are characterized by closed canopy indigenous forest covers about 30% of the official area (Wekesa. 2018), and is dominated by evergreen hardwood trees.

3.3 Study sites

The present study was conducted at three different sites in Kakamega Forest, namely, Kisere, Malava and Ikuywa fragments. The approximate sizes of the fragments in hectares are 1,370, 400 and 100 for Ikuywa, Kisere and Malava in that order, while the main Kakamega forest block measure is about 8500 hectares. Kisere fragment is located to the north of the main forest block. This location is within the small-scaled agricultural land. The surrounding fragments of the fragment have, therefore, been converted to agricultural land (Lung and Schaab 2006). It lies about 1.6 Km from the main forest block. Its original gazette size as of 1933 was 458 ha (Fischer 2004). The current sizes of the fragments under study are as per Table 3.1.

Table 3.1: Forest fragments of Kakamega forest and their sizes

Fragment	**Sizes (hectares)**
Ikuywa	1,370
Kisere	400
Malava	100
Main block	8,500

Source: KFS.

Malava fragment is located to the north east side of Kisere fragment along Kakamega - Webuye highway. Its surrounding is dotted with settlements suggests possibility of anthropogenic activities. The fragment lies about 9.8 Km away from the forest block.

Ikuywa fragment is located adjacent to the main forest block and is documented as having been part of the main forest block as of 1933. Hence forming a quasi-fragment because it is not wholly detached from the main fragment. It is about 1,370 ha currently and lies about 1.5 Km from the main forest block (Fischer 2004).

3.3 Research design

The study adopted a correlational research design because it aimed at determining the influence of forest fragmentation variables (total edge length and edge density) on tree species richness and tree species abundance in the forest fragments. Cross-sectional study was used because forest fragmentation has already taken place and data could be obtained over a short period of time. Hence, the data was collected within four weeks. The units of analysis were the three forest fragments and tree species. The reason for this selection of units was based on the fact that in assessing forest fragmentation, total length of boundary of the forest fragment was used to determine the forest edge length, the total edge length divided by the forest land area was used to determine the edge density of the forest fragments. The focus of the research was conditional which entails exploring the current state of the forest fragment.

3.4 Study population and sampling

The study population was three forest fragments in Kakamega forest. Proportionate random sampling was used to select tree strata in the three forest fragments. In total sample of 30 plots each measuring 20m by 20m were established randomly in the three fragments, Malava,Kisere and Ikuywa.

In each plot, all trees with diameter at breast height (DBH) ≥ 10 cm measured at 1.3 m above the ground were counted and identified this was done to avoid counting the saplings. The identification was done with the help of an expert from the Kenya forest Service.

The total number of species in a plot was established using the species/area relationship curve:

$$S=cAz$$

(Where S is species number, A is area of forest, and c and z are constants), (Brooks *et al,* 1999).

3.5 Data Collection Methods

Primary data collection methods used were observation, measurement, counting and recording. Primary data that was obtained from the field includes simple count of tree species near the fragment edges, area of the sampled forest edge and total edge length of the forest fragment. It also included the size of the forest fragments sampled. Data used in this study were obtained between November, 2018 and January, 2019. These methods were appropriate for the data collection because the data to be collected could be obtained by measurement (sample plots 2m by 2m each, height of trees to be counted), counting (number of tree species) and observation (the edge density – closeness or openness). Data on tree Species abundance was collected by identifying a specific tree species within the sampled area and counting them in the whole of the sampled areas in all the three fragments to get the abundance of each of the tree species in the fragments.

Independent variable is forest fragmentation attributes e.g. forest fragment edge length and forest fragment edge density. The dependent variables were tree species richness and tree species abundance. The instruments for data collection included 1M ruler,30M diameter tape,50m measuring tape for demarcating the plot sizes. String was used to demarcate the quadrants. Global Positioning System (GPS 64s Garmain) was used for identification of the sample sites. Suunto Inclinometer for estimating the DBH of the trees. Data was collected within the randomly selected 30 study sites within the forest fragments. The study sites were based on their location in the forest fragments. The plots were established from the forest edge adjacent to the interior of the forest. To assess the effects of forest fragmentation on tree species richness in the detached fragments of Kakamega forest, the number of individuals of all trees was counted and recorded in the sampled areas of the fragments. Secondary data was appropriate in sourcing for the maps of the fragments as well as previous measurements of Kakamega forest as a whole and the fragments.

3.5.1 Effect of total edge length of forest fragments on the tree species richness

The total length of boundary of the forest fragments, Ikuywa, Kisere and Malava, were measured using a tape measure and the values tabulated. The values were used as a representation for the forest fragment edge length. Different tree species along the boundary (0-200m) were identified, counted and the total number of every identified species recorded per fragment. The Relative abundance of every species in every fragment was calculated and recorded (appendix D).

3.4.2 Edge density of the forest fragments and tree species richness

Once the total edge length of the forest fragment was measured, the area of the sampled edges was used to determine the edge density. Briefly, the edge density was calculated by obtaining the ratio of total fragment area to the total edge length. These measurements were used in asserting the relationship between the proximity to the forest edge and tree species richness.

3.4.3 Total edge length and tree species relative abundance

The total length of boundary of the forest fragment was measured using a tape measure and the values tabulated. The values were used as a representation for the forest fragment edge length. The tree species relative abundance was calculated by dividing the total number of each tree species in each of the fragments by the total number of individual species in each of the three fragments (Malava, Kisere and Ikuywa).

3.5 Data analyses and results presentation

Simple linear regression was used to predict tree species relative abundance and tree species richness from total fragment edge length and edge density of the three fragments. And the outcome represented inform of scatter plots. Linear regression equation was used for analysis:

$$Y=a+bx$$

Where Y is the dependent variable {the variable that goes on the Y axis- species richness and species abundance); x is the independent \predictor variable [it is plotted on the x axis- total edge length and edge density]; b is the slope of the line and a is the y-intercept. The coefficient of determination [r^2] was analyzed to show how the percentage variation in y is accounted for by x. The scatterplots were used to present the results at significance level, $p \leq 0.05$.

3.6 Reliability and validity of data

Lung (2006) states that the reliability of a test refers to the ability of that test to consistently yield the same results when repeated measurements are taken of the same individual under the same conditions. Basically, reliability is concerned with consistency in the production of the results and refers to the requirement that, at least in principle, another researcher, or the same researcher on another occasion, should be able to replicate the original piece of researcher and achieve comparable evidence orresults, with similar or same study population.

This research embraced test-retest method of ascertaining reliability as shown below:

$$N = \frac{n_1 * n_2}{m^2}$$

where n_1 is the number of individuals observed by sampler 1, n_2 is the number of individuals observed by sampler 2 and m^2 is the square of the number of individuals observed by both of the observers. N cannot be less than 1 neither can it be negative. The closer is to 1 the more reliable the data is; the upper limit is infinite.

On the other hand, predictive validity which entails the extent to which a score on a scale or test predicts scores on some criterion measure was used. In this research the extent of the loss of tree species predicts the rate of fragmentation in the forest. Validity of the data collection instruments and results were also verified by the professionals in the department, primarily supervisors of the thesis.

3.7. Ethical consideration.

The researcher observed the ethical issues as far as the proposal writing and proposal approval by the school of graduate studies was concerned. The researcher also observed ethical issues as far as the letter given by the dean of graduate studies and also getting a research license from The National Commission for Science, Technology and Innovation (NACOSTI) authorizing data collection from the field. The researcher further observed the ethics of data collection process that involved first seeking permission from Kakamega forest ecosystem conservator, the forester and other officers from the Kenya forest service department. Information regarding the expected duration of data collection, purpose of the research and the benefits of the study to the forest was also communicated. The researcher also observed ethics during data analysis and compilation of the thesis. Relevant citations were used in acknowledgement of the research work.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents results of the analyzed data. It begins by giving the effects of total edge length of forest fragments on tree species richness, then results for the edge density and tree species richness and, lastly, results for Influence on edge density and total edge length on tree species abundance.

4.2 Influence of total edge length of forest fragments on the tree species richness

Ikuywa which was the largest fragment of the three studied fragments with an estimated edge length of 14.7 Km had a total of 560 individual trees accounting for 47% of the total tree species identified from a sampled edge length of 896.25m(Appendix A). The most abundant species were *Funtumia africana* with a total of 117 stems contributing 21% of the total number of species in this fragment (Appendix E). The influence of total edge length of Ikuywa forest fragment was determined and the results are presented in Figure 4.1.

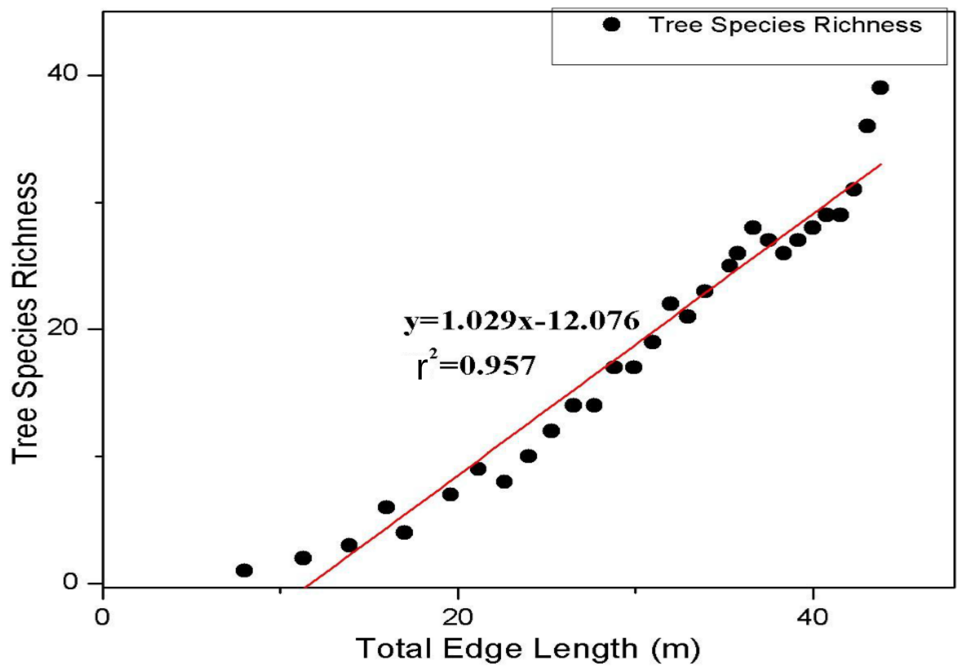

Figure 4.1: The scatter plot of simple linear regression result showing the influence of total edge length on tree species richness in Ikuywa forest fragment.

Figure 4.1 shows that 96% of the variation of tree species richness in Ikuywa forest fragment can be explained by the total edge length. This implies that total edge length is the dominant factor influencing tree species richness in Ikuywa. The remaining 4% of the variation can be explained by other environmental factors which were not considered in this study.

Kisere which was the second largest fragment studied had estimated area of 4.2 Km^2 and total edge length of 8.2 Km, it had a total of 397 individual trees representing 33.5% of the total tree species identified from a sample edge length of 896.25m. The most abundant species from this fragment again were *Funtumia africana* with a total of 100 individual trees contributing 25% of the total number of species in this fragment (Appendix E).

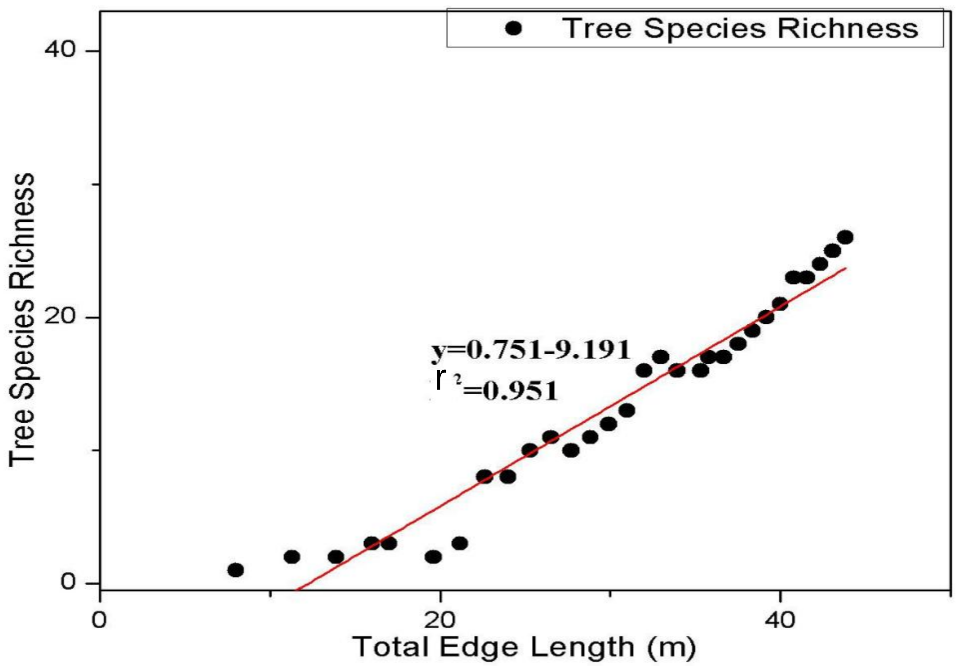

Figure 4.2: The scatter plot of simple linear regression result showing the influence of total edge length of Kisere forest fragment on tree species richness.

Figure 4.2 shows that 95% of the variation of tree species richness in Kisere forest fragment can be explained by the total edge length. This implies that total edge length is the dominant factor influencing tree species richness in Kisere. The remaining 5% of the variation can be explained by other environmental factors which were not considered in this study.

Malava fragment which had the lowest estimated edge length of 4 Km and was the smallest of the three fragments in terms of area (1km^2). From the sampled size of about, it had a total of 278 individual trees making up for only 23.5% of the total tree species identified from the three fragments. The most abundant species were still the *Funtumia africana* with a total of 55 individual trees which represent 25% of the total number of species identified in the fragment. Figure 4.3 shows that 96% of the variation of tree species richness in Malava forest fragment can be explained by the total edge length. This implies that total edge length is the dominant factor influencing tree species richness in Malava. The remaining 4% of the variation can be explained by other environmental factors which were not considered in this study.

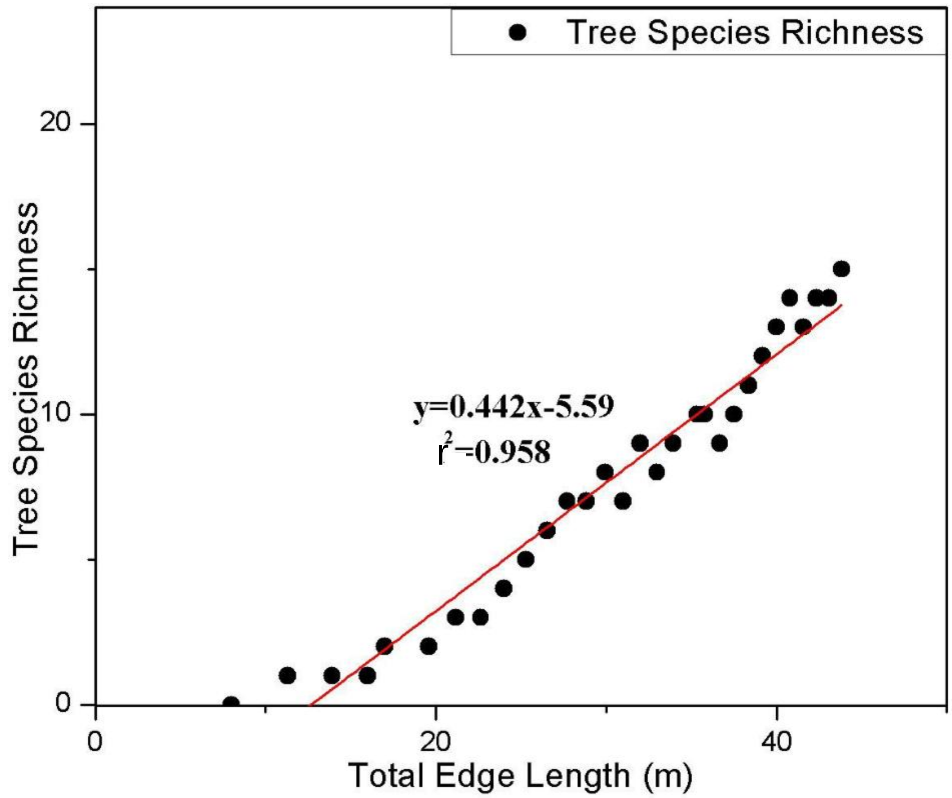

Figure 4.3: The scatter plot of simple linear regression result showing the influence of total edge length of Malava forest fragment on tree species richness.

The findings (Figure 4.1, 4.2, 4.3) of this study revealed that total edge length was the dominant factor forest fragment attribute influencing tree species richness. Moreover, the relationship between total edge length of the fragments and tree species richness was quantified to be linear as evidenced by the residual plots Appendix 4(i). The scatter plots represent tree species identified in each of the 30 plots. A study by Seibold (2017) also established that tree species was significantly related to size of the forest fragment which is consistent with this study.

Furthermore, Harcourt and Dohetry (2005) concluded that in tropical forests, the abundance of tree species has been found to be significantly related to changes in forest fragment size. The tropical rainforest such as Kakamega are known to be rich in tree species as they are located within the region of high rainfall and habitat heterogeneity (Echeverría *et al.*, 2007).

Higher species numbers were observed in the fragments which were more disturbed such as Ikuywa. However, some other studies have revealed that fragments of old secondary succession stages have similar species richness like disturbed forest fragments (Wekesa *et al*., 2016). The findings are in line with those of Mitchell (2004), whose results showed that high species numbers therefore cannot be said to be strictly correlated with high level of disturbance or with draconic conservation strategies. Some of the most observable disturbance aspects in the forest fragment in general include creation of footpaths, charcoal burning, harvesting of grass, tree, medicinal plants and grazing of livestock.

In Ikuywa for example which was part of the main forest in which now the connecting part is nearly destroyed after clear-felling, *Celtis mildbraedii* was very abundant and *Funtumia africana* was limited in its individual numbers, (Haddad *et al*., 2015). Ikuywa has been characterized mainly by *Funtumia africana* as per the results of this study(Appendix E). Although various species were selectively logged in high numbers the stand structure of the trees in the upper canopy has not changed much (Wekesa *et al*., 2018). They are still the characteristic species in this fragment. Although the human disturbances in terms of selective logging or clear-felling took place, the tree species composition is not only influenced by the past or recent logging history. Abiotic factors like soil, climate or topographic are suggested to play a role in development of the species composition, too (Taubert *et al*., 2018). Malava fragment nowadays is a plantation of indigenous and exotic tree species. The natural species composition is not maintained today. Indigenous species like *Cordia africana*, *Prunusafricana* and *O*. *capensis* were planted beside exotic species like *Khaya anthotheca* and *Bischoffia javanica* (Appendix E). This species composition was found again in the analyses. Past result of the analyses of Malava indicates that the forest was heavily logged and replanted (Grogan*et al*., 2019).

In the last decades' human disturbance in Kisere forest was comparably low, except for pit sawing. Pit sawing preferred species such as Olea *capensis* which would probably explain its low numbers. However, the study was still able to record a few of them especially in Malava fragment (Appendix E). The now most abundant tree species *Funtumia Africana* (Appendix E)were cut in later decades than e.g. *Olea capensis* or *Prunus africana* in each area (Reinmann *et al*., 2017). Perhaps, the valuable, favored tree species were less abundant after selective logging and new trees were chosen for the timber industry. Therefore, the species became more abundant due to the new possibilities to grow there. On the other hand, these species possibly could have been always abundant there, but were of lower interest, until *O*. *capensis* and *P*. *africana* were overexploited (Saunders*et al*., 2019). This study has answered the research question effectively on the influence of total edge length of forest fragments on tree species richness in the detached fragments of Kakamega forest. The findings that total edge length is a dominant factor influencing tree species richness; a lower edge length will result to less tree species richness in a given fragment as ascertained above.

4.3 Edge density of the forest fragments and tree species richness

The relationship between edge density and tree species richness in Ikuywa was significant (r^2= 0.9236, p<0.05) and the slope coefficient (y= -1.0477x+1.8252) (figure. 4.4).

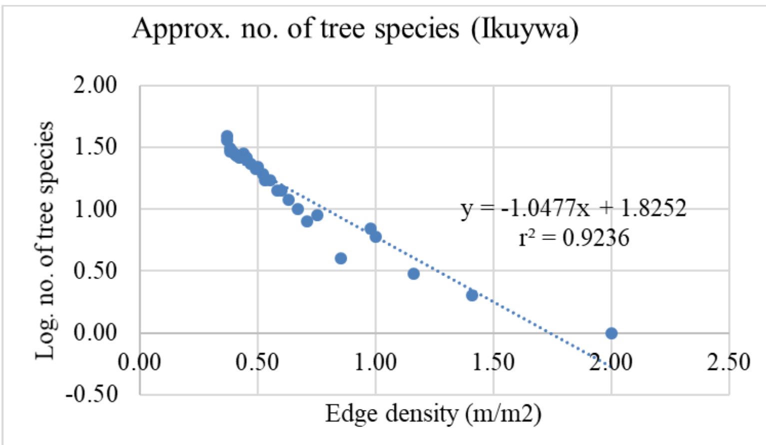

Figure 4.4: The scatter plot showing log-linear regression result on the influence of edge density on Tree species richness in Ikuywa forest fragment.

Figure 4.4 shows that for every 1% increase in edge density, there is (-1.0477/100) decrease in the tree species. Moreover, there is a corresponding coefficient92% of the variation of tree species in Ikuywa forest fragment can be explained by the edge density. This implies that edge density is the dominant factor influencing tree species richness in Ikuywa. The remaining 8% of the variation can be explained by other environmental factors which were not considered in this study.

In Kisere forest fragment the result shows that there was a significant relationship (r^2=0.8492, p < 0.05) between the species richness and the edge density, the slope coefficient(y=-1.0246x+1.6519).

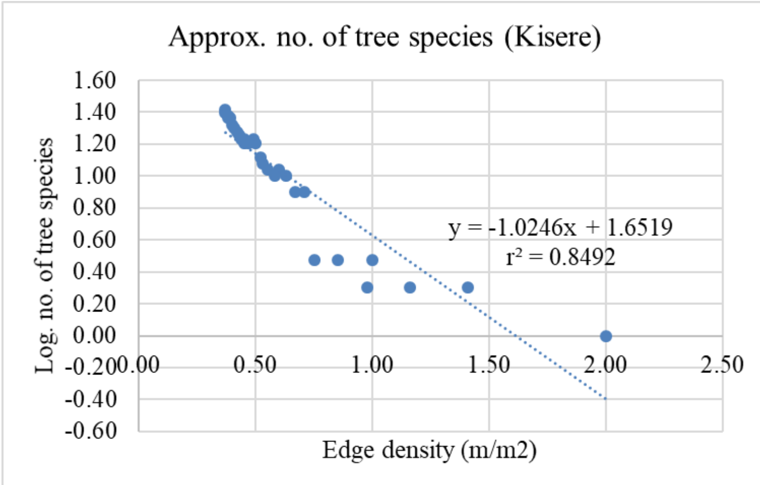

Figure 4.5: The scatter plot showing simple linear regression result on the influence of edge density on Tree species richness in Kisere forest fragment.

Figure 4.4 shows that for every 1% increase in edge density, there is (-1.0246/100) decrease in the tree species. Moreover, there is a corresponding coefficient 85% of the variation of tree species in Kisere forest fragment can be explained by the edge density. The remaining 17% of the variation can be explained by other environmental factors which were not considered in this study such as climate, soils and topography.

Moreover, Malava forest fragment shows that there was a significant relationship (r^2=0.8251, $p < 0.05$) between the species richness and the edge density, the slope coefficient (y= -0.9276x-1.3666) (Figure 4.6).

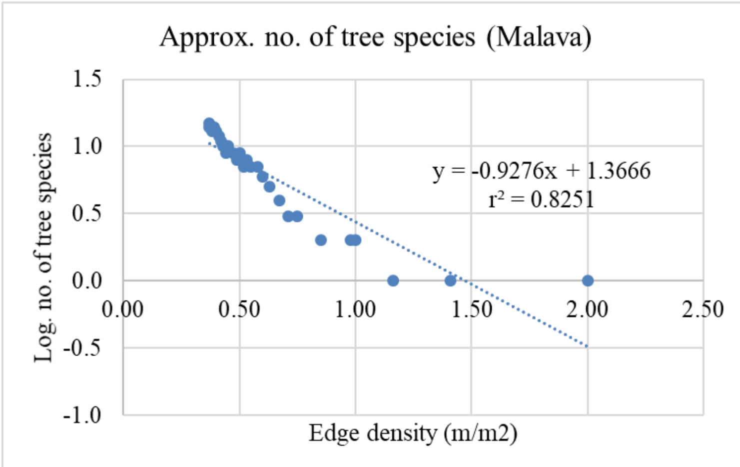

Figure 4.6: The scatter plot showing simple linear regression result on the influence of edge density on Tree species richness in Malava forest fragment.

Figure 4.6 shows that for every 1% increase in edge density, there is (-0.927/100) decrease in the tree species. Moreover, there is a corresponding coefficient 83% of the variation of tree species in Malava forest fragment can be explained by the edge density. This implies that edge density is the dominant factor influencing tree species richness in Malava.

In terms of relationship between the edge density and the tree species richness, there was a significant relationship for all the fragments ($P \leq 0.05$).The scatter plots represent tree species identified in each of the quadrats in the 30 plots. Edge density in the three fragments increased along the gradient from the edge of the forest to the interior. Similar to Kisere which was highly influenced, Malava and Kisere's edge density varied significantly. The overall tree species richness varied significantly among the three fragments sampled (19.92m/$m^2$with $P \leq 0.05$) The fragment area proportional forest loss was linearly related to the fragment edge density ranging from mean density of 3.41 (at Kisere) to 3.79 (at Malava) with an overall average of 3.6 in all the three fragments as evidenced by the residual plots in appendix 4(ii). This is because the dependent variable (data on tree species richness) was transformed to base 10 to bring out the log-linear regression results. The residual plots which show differences between the observed values and the predicted values, have clearly supported the good performance of the regression models in Appendix 4 (ii),with residuals distributed around null (falling close to zero values) in all the three fragments. The closer the values are to the horizontal line the better the model as evidenced in appendix4 (ii).

Species richness increases the number and thus potentially the complexity of species interaction as discussed in the findings of Jan.M. Baert (2017). The log-linear extension presented by these residual plots increases the flexibility of transformation methods. This demonstrates that log-linear relationships between edge density and tree species richness are likely to occur in biodiversity experiments. In line with the findings of this research. De Laender*et al*., (2016) also found out in their studies that biodiversity experiments related to edge density of fragments are often designed with equal initial functional contributions among species. Indeed, species interactions can change functional contributions and biodiversity effects over time. The significant variation of trees at the edges could be attributed to the fact that Kakamega forest is adjacent to cultivated farmlands where agro forestry is practiced. Analysis of tree species richness in relation to fragment edge density has revealed significant relationship to similar studies in the past (Fletcher*et al.*, 2018). For example, in relation to the findings of this study, secondary forests have been mostly associated with smaller fragments which have a lower edge density (Pardini *et al.*, 2005). The changes in species composition lead to negative consequences such as high extinction rates or low regeneration rates on certain tree species that may be dependent on the density of the forest and its composition (Regolin *et al.,* 2020). With increased fragmentation, there is likelihood of changes in forest composition in terms of composition of the various species and the microclimate which significantly influences tree species richness at the fragment edges (Laurance *et al*., 2007) which is in line with the IBT. From the present study, the mean densities displayed an increasing trend with increase in fragment tree species towards the interior of the forest., which suggest that increasing the fragment size could have increased the species richness observed in each fragment.

This is due to the fact that a larger forest area is likely to be more heterogeneous because of the high edge density and therefore has a higher possibility of having many tree species (Driscoll *et al.,* 2013). This finding provides an indication that Kisere fragment is rich and has a high recruitment rate per unit area than Malava and Ikuywa, which did not differ markedly. The observation can possibly be linked to anthropogenic disturbances synonymous with Kakamega forests fragments (Lung and Schaab, 2006). The higher the degree of disturbance (fragmentation), the more stems could be recorded, which indicate a direct influence of the forest edge density (Mitchell 2004). The more disturbances took place in the past, the smaller and younger the trees are in a given area as a result of regeneration (Omoro *et al.,* 2010) in line with the IBT guiding this research.

The findings indicate that a high stem density is therefore an evidence for former disturbance. Due to fragmentation, changes in microclimatic conditions along the edges could favor the introduction of new species (Keenan *et al.,* 2015). This may also lead to changes in pattern of growth, mortality and survival of the existing species hence affecting the edge density of forest fragments which has a direct influence on tree species richness (Wekesa *et al.*,2018). Higher species richness can increase the resistance and\or the resilience to disturbances and stresses and hence have a positive impact on the forest edge density. This is in line with the above findings which indicate that the larger the sample the more species would be found which as a result indicate a denser forest fragment. More number of species indicate more species richness hence a stable ecosystem. Consistent with these findings are those done by Regolin*et al, (*2020) which indicate that more species richness contributes to increase in the forest edge density which in turn increases biodiversity.

4.4 Influence of forest fragment edge density and forest fragment total edge length on tree species abundance

I compared tree species relative abundance in the three forest fragments varying in sizes. Species abundance ranged from 0.04 to 22.95 (Appendix D). Species abundance was significantly affected by forest-fragment type, just like species richness, increased significantly with the increase in the fragment size according to the regression slopes for every fragment which were not substantially different (Figure 4.5, 4.6 and 4.7). For example, the linear regression equation for the relationship between Species Relative abundance and Total edge length for Malava fragment shows the coefficient indicating that the relative abundance increases with increase in total edge length. The coefficient is 2.192 and the r^2

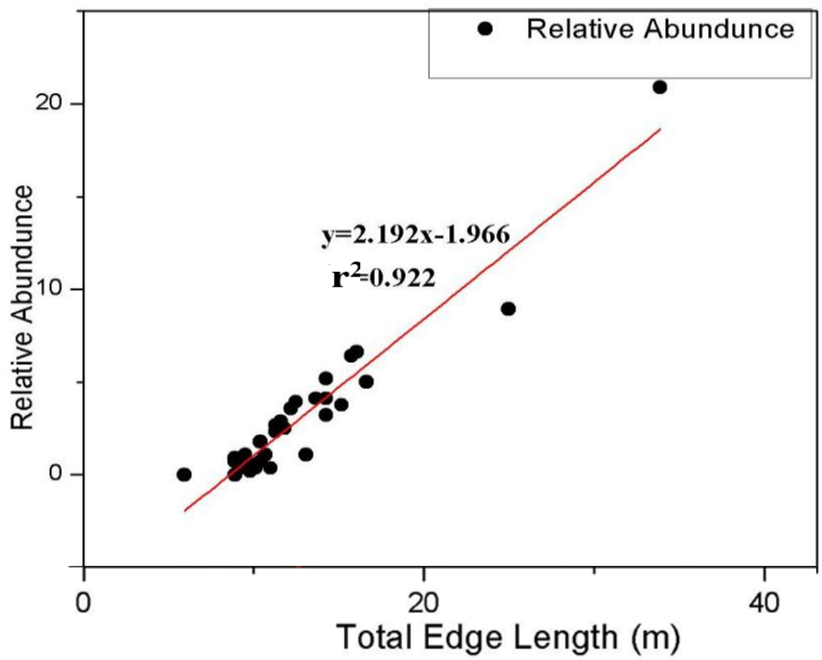

Figure 4.7: The scatter plot of simple linear regression showing the influence of Total Edge Length on tree species relative abundance in Malava forest fragment.

Figure 4.7 shows that 92% of the variation of tree species relative abundance in Malava forest fragment can be explained by the total edge length. This implies that total edge length is the dominant factor influencing tree species relative abundance in Malava. Similarly, the relationship between tree species relative abundance and edge density in Malava forest fragment increases with increase with the edge density towards the interior of the forest. This implies that the number of tree species is less at the edges creating a lot of edge openness but towards the interior of the fragment the number of tree species increases thereby species closeness evidenced by edge density also increases. This is also in line with the IBT from which the research results that the extinction rates of tree species at the edges is high. The coefficient was 0.841 and the r^2 values being 0.865 indicating a very strong relationship between variables (Figure 4.8).

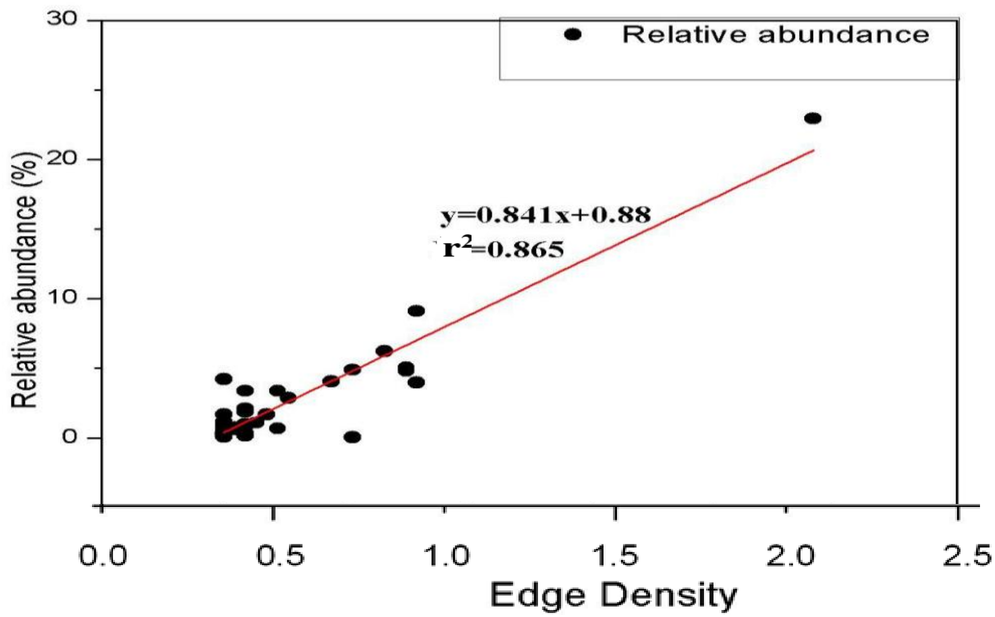

Figure 4.8: The scatter plot of simple linear regression showing the influence of Edge density on tree species relative abundance in Malava forest fragment.

Figure 4.8 shows that 87% of the variation of tree species relative abundance in Malava forest fragment can be explained by the edge density. This implies that edge density is also a dominant forest fragment factor influencing tree species relative abundance in Malava. The relationship between total edge length and tree species relative abundance was significant (r^2= 0.832, p<0.0001) and the slope coefficient was 2.443 (Figure 4.9).

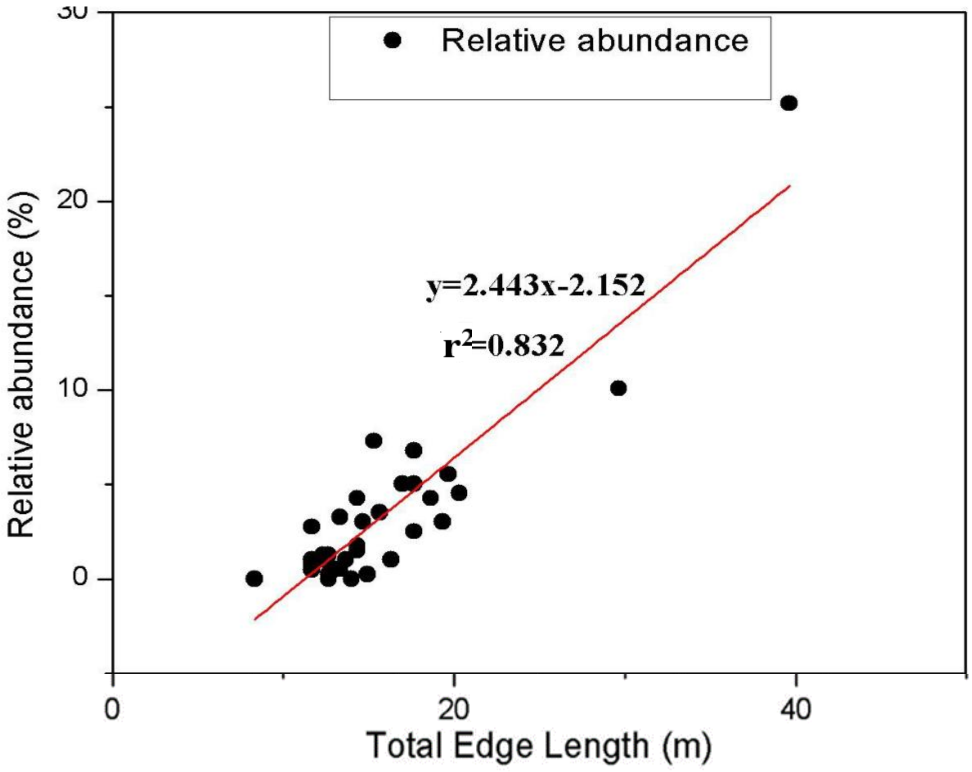

Figure 4.9: The scatter plot of simple linear regression showing the influence of Total Edge length on tree species relative abundance in Kisere forest fragment.

Figure 4.9 shows that 83% of the variation of tree species relative abundance in Kisere forest fragment can be explained by the total edge length. This implies that total edge length is a dominant forest fragment attribute influencing tree species relative abundance in Kisere forest fragment. The remaining 17% of the variation can be explained by other environmental factors which were not considered in this study. The relationship between edge density and tree species relative abundance was significant (r^2= 0.939, p<0.0001) and the slope coefficient was 0.882 (Figure 4.10).

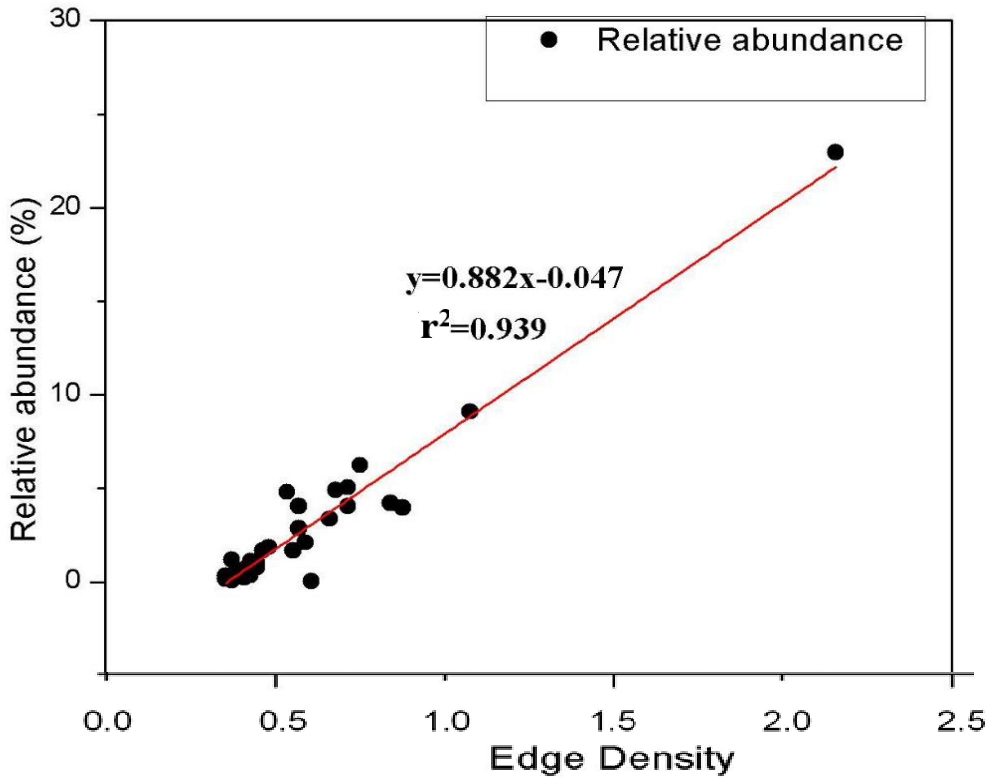

Figure 4.10: The scatter plot of simple linear regression showing the influence of Edge density on tree species relative abundance in Kisere forest fragment.

Figure 4.10 shows that 94% of the variation of tree species relative abundance in Kisere forest fragment can be explained by the edge density. This implies that edge density is also a dominant forest fragment attribute influencing tree species relative abundance in Kisere forest fragment. The regression slopes for Ikuywa fragment similarly showed species abundance along the edge being significantly related to fragment edge density (r^2=0.944, p<0.0001). The species abundance increased with increase in slope, with a slope coefficient at 1.036 (Figure 4.11)

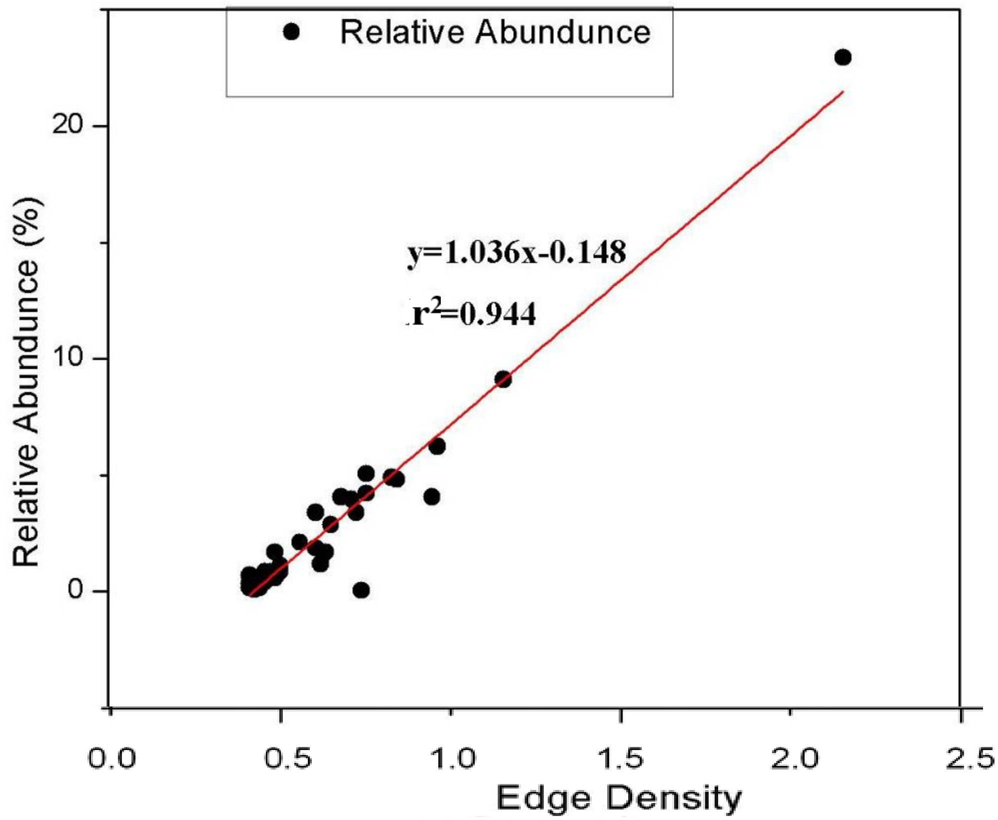

Figure 4.11: The scatter plot of simple linear regression showing the influence of Edge density on tree species relative abundance in Ikuywa forest fragment.

Figure 4.11 shows that 94% of the variation of tree species relative abundance in Ikuywa forest fragment can be explained by the edge density. This implies that edge density is also a dominant forest fragment attribute influencing tree species relative abundance in Ikuywa forest fragment. The remaining 6% of the variation can be explained by other environmental factors which were not considered in this study. The relationship between total edge length and tree species relative abundance was significant (**r^2**= 0.922, p<0.0001) and the slope coefficient was 2.192 (Figure 4.12).

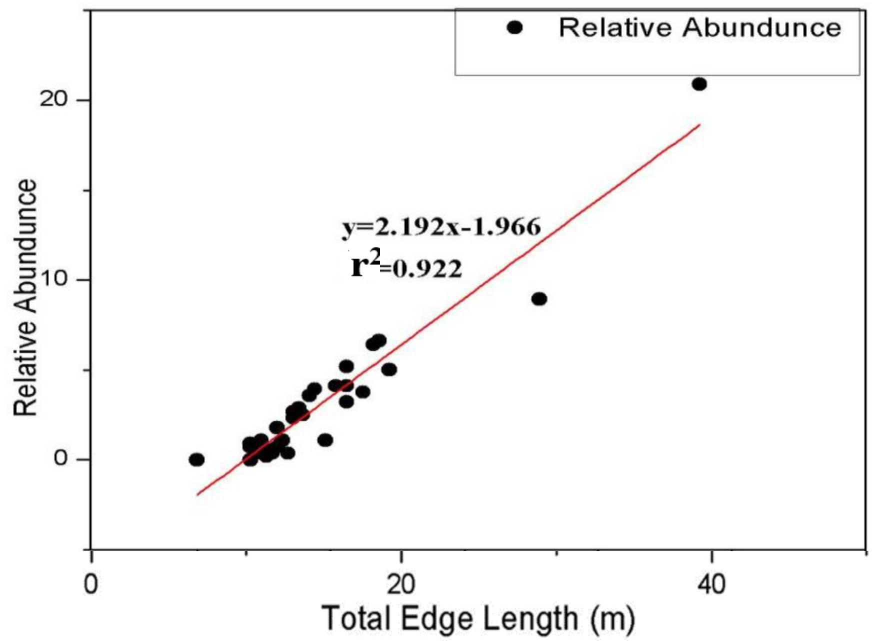

Figure 4.12: The scatter plot of simple linear regression showing the influence of total edge length on tree species relative abundance in Ikuywa forest fragment.

Figure 4.10 shows that 92% of the variation of tree species relative abundance in Ikuywa forest fragment can be explained by the total edge length. This implies that total edge length is also a dominant forest fragment attribute influencing tree species relative abundance in Ikuywa forest fragment. The scatter plots represent tree species identified in each of the quadrats in the 30 plots.

Generally, tree species relative abundance varied significantly between fragment types. The tree species relative abundance was significantly higher in Ikuywa than in the other two fragments (Appendix E). Moreover, the relationship between the edge density, total edge length and tree species abundance was quantified to be linear as evidenced by the residual plots (Appendix 4(iii). Similar to these findings, (Mwavu 2007) also found out that tree species relative abundance was only slightly influenced by differences in the fragment's attributes. The influence was more pronounced in relation to fragment edge length showing a clear decline in species abundance in small fragments compared to larger fragments. Declined tree species abundance in forest fragments is well, documented in the literature (Martı´nez *et al.,* 2004) and has been attributed to alterations of abiotic or biotic conditions in modified forests (Regolin *et al*., 2020). In consistence with the findings of this study, these studies revealed that while the interiors of small fragments had marginally higher species richness to the interiors of the larger fragments, the community structure remained similar in both cases (Driscoll *et al*., 2013).

The fragment edges however had lower functional evenness compared to the interiors of the forest (Ewers and Didham 2006). This is a clear indication of change in both abundance and dominance of functional traits, with negative impacts of human activities (Magnago *et al.,* 2015). Total edge length and the fragment edge density have been a dominant driver of fragment dynamics, strongly affecting forest microclimate, tree mortality, carbon storage, fauna, and other aspects of fragment ecology (Peters *et al.*, 2009). However, Pardini *et al.,*(2005),results contradicted the above findings by indicating edge-effect intensity varies markedly in space and time, and is influenced by factors such as edge age, the number of nearby edges, and the adjoining matrix of modified vegetation surrounding fragments .These findings are also true but the functionality of the above factors depends largely on the edge density and fragment total edge length of the forest fragments so as to give more satisfactory results as indicated on the above findings in this research. Rare weather events, especially windstorms and droughts, have further altered fragment ecology (Laurance *et al* 2017).

The presence of less tree species, richness, and abundance at the Ikuywa can be linked to higher levels of anthropogenic activities including fetching for their basic needs like firewood, charcoal, building poles, and traditional medicines along the edges (Burgess *et al*,2013). This is because these factors lead to the reduction of fragment total edge length which in turn decreases the relative abundance of tree species. Another possible contributing factor to low edge density is the action of sporadic winds which will subsequently affect the composition and abundance of the species at the fragment edges (Shirima et al, 2011) forming a basis for further research in this area.

Similar to the findings of this study, the general low tree abundance at some fragments such as Malava may also be the result of the interplay of other factors as reduction of seedling establishments due to abiotic and biotic interactions which affect the edge density of the tree species (Bruzzone and Prieto 2001). Some activities related to edge effects that could have contributed to low tree abundance on the edge habitats of the fragments include; reduction in recruitment of the seedlings at the edges perhaps because of uprooting and breakage due to abiotic factors such as wind (Laurance, 2007) and damage to the seedlings as a result of falling off of items such as debris and litter along the edges (Buermann *et al.*, 2008). The ease of accessibility of the edges by human and livestock may also be a contributing factor (Lovett *et al.*, 2006).

This study has revealed that three fragments of Kisere, Malava and Ikuywa have slightly different species composition from one another. The negligible differences can be attributed to fragmentation which has in turn opened up the edges to increased anthropogenic activities as well as other abiotic factors even in Ikuywa which is a quasi-fragmnet. For a forest ecosystem, it is assumed that the tree species ability to be persistent in a given environment and even disperse is crucial towards more complex species diversity (Brancalion *et. al.*, 2019). Therefore, a new realization in this study is that both total edge length and edge density directly influence tree species abundance; as total edge length and edge density increases the tree species abundance also increases at the fragments.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter of the thesis presents summary of the findings of the study, gives conclusions, recommendations and suggests areas that need further research.

5.2 Summary of findings

High variation of tree species richness Malava (r^2 = 0.958), Kisere (r^2 = 0.951) and Ikuywa (r^2 = 0.957) can be explained by the total edge length of the fragments whereby edge length is the dominant factor which can influence relative abundance in the three fragments

Moreover, in the analysis of the influence of edge density on tree species richness high variation of tree species richness Malava (r^2 = 0.8251), Kisere (r^2 = 0.8492) and Ikuywa (r^2 = 0.9236) can be explained by the edge density of the fragments whereby edge density is the dominant factor which can influence tree species richness in the three fragments. The remaining percentage variation can be explained by other environmental factors which were not considered in the analyses.

Assessment of the influence of edge density and edge length on tree species abundance on the three fragments showed that both factors have a higher percentage of the variation on the relative abundance whereby they are the dominant factors which can influence relative abundance. The edge length dominantly influenced relative abundance in the three fragments as follows; Malava (r^2 = 0.922), Kisere (r^2 = 0.832) and Ikuywa(r^2 = 0.922). Similarly edge density also dominantly influenced relative abundance in the three fragments as stipulated, Malava (r^2 = 0.865), Kisere (r^2 = 0.0.939) and Ikuywa(r^2 = 0.944).

5.3 Conclusions

The study concludes that tree species richness, tree species abundance and diversity in the fragments of Kakamega forest could be dominantly influenced by forest fragment edge length and fragment edge density.

For us to conserve more tree species richness and tree species abundance in the forest we need to maintain minimum total forest fragment edge length of 2.69km. Moreover, a minimum of variation of edge density (3.41- 3.79m\m^2) is also required to maintain a higher tree relative abundance.

Generally, edge density varied significantly in the three fragments influencing the tree species abundance at the forest edges. Forest interior exhibited a marginally higher edge density while at the forest exterior it was of lower density hence resulting to significant variation in tree species abundance at the fragment edges. Additionally, in accordance to the findings and the IBT used in this research, the findings indicate an urgent need for conservation and restoration measures to improve landscape connectivity which will reduce extinction rates and assist maintain ecosystem services. The findings help us to understand the need of necessitating increase in the total edge length and density of fragments so that tree species richness can be on the higher side to reduce fragmentation rates in the forests.

5.4 Recommendations

For conservation of more tree species the study recommends maintenance of the total edge length of the fragments with a high edge density of the trees so that fragmentation effects are reduced remarkably and this will increase species relative abundance and tree species richness. Furthermore, this study recommends analysis of more edge related parameters that provide data on annual rate of tree mortality, annual rate of tree recruitment, liana abundance and overall abundance of pioneer and invasive tree species. Other parameters that may be necessary include mean rate of tree-species turnover and the overall rate of change in tree community composition. The study further recommends the discouragement of forest fragmentation so as to increase tree species abundance and diversity.

Areas for further research

The study also recommends further research on factors that can aid in increasing total edge length and maintaining a high edge density on the fragments. The study recommends further research on the differences and interrelatedness in species richness, diversity and tree abundance in edge, intermediate and forest interior in the three studied fragments. It would also be interesting to conduct a qualitative research on perceived societal relevance of seedling and sapling species composition as well as the presence of exotic species and how they influence tree species abundance at the forest edges.

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APPENDICES

APPENDIX 1: Results and analyses

Objective 1: Edge length vs. Tree species richness
NB: The sample size in all the fragments were the same hence the standard edge length figure of 896.25 in all the three fragments

A. IKUYWA

Plot #	Number of Quadrants (2m*2m)	Total Edge Length (m)	Total area of the plot (m^2)	Approx. no. of tree species
A	1	8.00	4	1
B	2	11.30	8	2
C	3	13.90	12	3
D	4	16.00	16	6
E	5	17.00	20	4
F	6	19.60	24	7
G	7	21.17	28	9
H	8	22.63	32	8
I	9	24.00	36	10
J	10	25.30	40	12
K	11	26.53	44	14
L	12	27.71	48	14
M	13	28.84	52	17
N	14	29.93	56	17
O	15	30.98	60	19
P	16	32.00	64	22
Q	17	32.98	68	21
R	18	33.94	72	23
S	19	35.33	78	25
T	20	35.78	80	26
U	21	36.66	84	28
V	22	37.52	88	27
W	23	38.37	92	26
X	24	39.19	96	27
Y	25	40.00	100	28
Z	26	40.79	104	29
AA	27	41.57	108	29
AB	28	42.33	112	31
AC	29	43.08	116	36
AD	30	43.82	120	39
TOTAL	465	896.25	1862	560

B. KISERE

i. Current measured Fragment edge length (8.2 Km)

ii. Original area (Km^2) as gazetted in 1933- *4.58*

Plot #	Number of Quadrants (2m*2m)	Total Edge Length (m)	Total area of the plot (m^2)	Approx. no. of tree species
A	1	8.00	4	1
B	2	11.30	8	2
C	3	13.90	12	2
D	4	16.00	16	3
E	5	17.00	20	3
F	6	19.60	24	2
G	7	21.17	28	3
H	8	22.63	32	8
I	9	24.00	36	8
J	10	25.30	40	10
K	11	26.53	44	11
L	12	27.71	48	10
M	13	28.84	52	11
N	14	29.93	56	12
O	15	30.98	60	13
P	16	32.00	64	16
Q	17	32.98	68	17
R	18	33.94	72	16
S	19	35.33	78	16
T	20	35.78	80	17
U	21	36.66	84	17
V	22	37.52	88	18
W	23	38.37	92	19
X	24	39.19	96	20
Y	25	40.00	100	21
Z	26	40.79	104	23
AA	27	41.57	108	23
AB	28	42.33	112	24
AC	29	43.08	116	25
AD	30	43.82	120	26
TOTAL	465	896.25	1862	397

C. MALAVA

i. Fragment edge length (4 Km)

ii. Original area (Km^2) as gazetted in 1933 - *7.03*

Plot #	Number of Quadrants (2m*2m)	Total Edge Length (m)	Total area of the plot (m^2)	Approx. no. of tree species
A	1	8.00	4	0
B	2	11.30	8	1
C	3	13.90	12	1
D	4	16.00	16	1
E	5	17.00	20	2
F	6	19.60	24	2
G	7	21.17	28	3
H	8	22.63	32	3
I	9	24.00	36	4
J	10	25.30	40	5
K	11	26.53	44	6
L	12	27.71	48	7
M	13	28.84	52	7
N	14	29.93	56	8
O	15	30.98	60	7
P	16	32.00	64	9
Q	17	32.98	68	8
R	18	33.94	72	9
S	19	35.33	78	10
T	20	35.78	80	10
U	21	36.66	84	9
V	22	37.52	88	10
W	23	38.37	92	11
X	24	39.19	96	12
Y	25	40.00	100	13
Z	26	40.79	104	14
AA	27	41.57	108	13
AB	28	42.33	112	14
AC	29	43.08	116	14
AD	30	43.82	120	15
TOTAL	465	896.25	1862	228

Objective 2: Edge density Vs. Tree Species Richness

NB: The total edge length and consequently the Edge density for the three fragments were similar as the sample size was maintained in all the fragments.

IKUYWA

Plot #	Number of Quadrants (2m*2m)	Total area of the plot (m^2)	Total Edge Length (m)	Edge density (m/m^2)	Approx. no. of tree species (Ikuywa)
A	1	4	8.00	2.00	1
B	2	8	11.30	1.41	2
C	3	12	13.90	1.16	3
D	4	16	16.00	1.00	6
E	5	20	17.00	0.85	4
F	6	24	19.60	0.98	7
G	7	28	21.17	0.75	9
H	8	32	22.63	0.71	8
I	9	36	24.00	0.67	10
J	10	40	25.30	0.63	12
K	11	44	26.53	0.60	14
L	12	48	27.71	0.58	14
M	13	52	28.84	0.55	17
N	14	56	29.93	0.53	17
O	15	60	30.98	0.52	19
P	16	64	32.00	0.50	22
Q	17	68	32.98	0.49	21
R	18	72	33.94	0.47	23
S	19	78	35.33	0.45	25
T	20	80	35.78	0.45	26
U	21	84	36.66	0.44	28
V	22	88	37.52	0.43	27
W	23	92	38.37	0.42	26
X	24	96	39.19	0.41	27
Y	25	100	40.00	0.40	28
Z	26	104	40.79	0.39	29
AA	27	108	41.57	0.38	29
AB	28	112	42.33	0.38	31
AC	29	116	43.08	0.37	36
AD	30	120	43.82	0.37	39
TOTAL	465	1862	896.25	19.92	560

KISERE

Plot #	Number of Quadrants (2m*2m)	Total area of the plot (m^2)	Total Edge Length (m)	Edge density (m/m^2)	Approx. no. of tree species (Kisere)
A	1	4	8.00	2.00	1
B	2	8	11.30	1.41	2
C	3	12	13.90	1.16	2
D	4	16	16.00	1.00	3
E	5	20	17.00	0.85	3
F	6	24	19.60	0.98	2
G	7	28	21.17	0.75	3
H	8	32	22.63	0.71	8
I	9	36	24.00	0.67	8
J	10	40	25.30	0.63	10
K	11	44	26.53	0.60	11
L	12	48	27.71	0.58	10
M	13	52	28.84	0.55	11
N	14	56	29.93	0.53	12
O	15	60	30.98	0.52	13
P	16	64	32.00	0.50	16
Q	17	68	32.98	0.49	17
R	18	72	33.94	0.47	16
S	19	78	35.33	0.45	16
T	20	80	35.78	0.45	17
U	21	84	36.66	0.44	17
V	22	88	37.52	0.43	18
W	23	92	38.37	0.42	19
X	24	96	39.19	0.41	20
Y	25	100	40.00	0.40	21
Z	26	104	40.79	0.39	23
AA	27	108	41.57	0.38	23
AB	28	112	42.33	0.38	24
AC	29	116	43.08	0.37	25
AD	30	120	43.82	0.37	26
TOTAL	465	1862	896.25	19.92	397

MALAVA

Plot #	Number of Quadrants (2m*2m)	Total area of the plot (m^2)	Total Edge Length (m)	Edge density (m/m^2)	Approx. no. of tree species (Malava)
A	1	4	8.00	2.00	0
B	2	8	11.30	1.41	1
C	3	12	13.90	1.16	1
D	4	16	16.00	1.00	1
E	5	20	17.00	0.85	2
F	6	24	19.60	0.98	2
G	7	28	21.17	0.75	3
H	8	32	22.63	0.71	3
I	9	36	24.00	0.67	4
J	10	40	25.30	0.63	5
K	11	44	26.53	0.60	6
L	12	48	27.71	0.58	7
M	13	52	28.84	0.55	7
N	14	56	29.93	0.53	8
O	15	60	30.98	0.52	7
P	16	64	32.00	0.50	9
Q	17	68	32.98	0.49	8
R	18	72	33.94	0.47	9
S	19	78	35.33	0.45	10
T	20	80	35.78	0.45	10
U	21	84	36.66	0.44	9
V	22	88	37.52	0.43	10
W	23	92	38.37	0.42	11
X	24	96	39.19	0.41	12
Y	25	100	40.00	0.40	13
Z	26	104	40.79	0.39	14
AA	27	108	41.57	0.38	13
AB	28	112	42.33	0.38	14
AC	29	116	43.08	0.37	14
AD	30	120	43.82	0.37	15
TOTAL 30	465	1862	896.25	19.92	228

SUPPLEMENTARY DATA

D. Summary of the parameters under study in each fragment

Fragment	IKUYWA	KISERE	MALAVA	MAIN FOREST BLOCK	TOTAL (3 Fragments)
Area (Km^2)	13.50	4.20	1.00	85.37	17.7
Total edge length (Km)	14.70	8.20	4.00		26.9
Av. Edge density	0.92	0.52	0.25		1.69
Percentage proportion of size of the forest cover	5.7	1.8	0.4		7.9
Tree species richness	560	397	228		1185
Gazetted area in 1933 (Km^2)	Within main forest block (Approx 13.70 plus 0.5 (current distance to main block)	4.58	7.03	236.34	247.95
Total edge length as at 1933	15.07	8.56	10.61		34.24
Edge density as at 1933	0.94	0.54	0.66		2.14
Distance from the main block (Km)	1.34	1.6	0.5		

IKUYWA

i. The least abundant type of tree species

Bischofia javonica
Chaetacme aristata
Cordia africana
Harungana madacascariensis

ii. The most abundant type of tree species in the fragment

Funtumia africana
Antiaris toxicaria
Craibia brownii

iii. Original area (Km^2) as gazetted in 1933- *Part of the main forest block (Total 23.632)*

KISERE

i. The list abundant type of tree species
Macaranga kilimandschirica

ii. The most abundant type of tree species in the fragment
Funtumia africana
Antiaris toxicaria
Trichilia emetica

iii. Original area (Km^2) as gazetted in 1933- *4.58*

MALAVA

i. The least abundant type of tree species
Hagenia abyssinica
Strombusia scheffleri
Zanthoxylum gilletti

ii. The most abundant type of tree species in the fragment
Funtumia africana
Antiaris toxicaria
Trichilia emetica

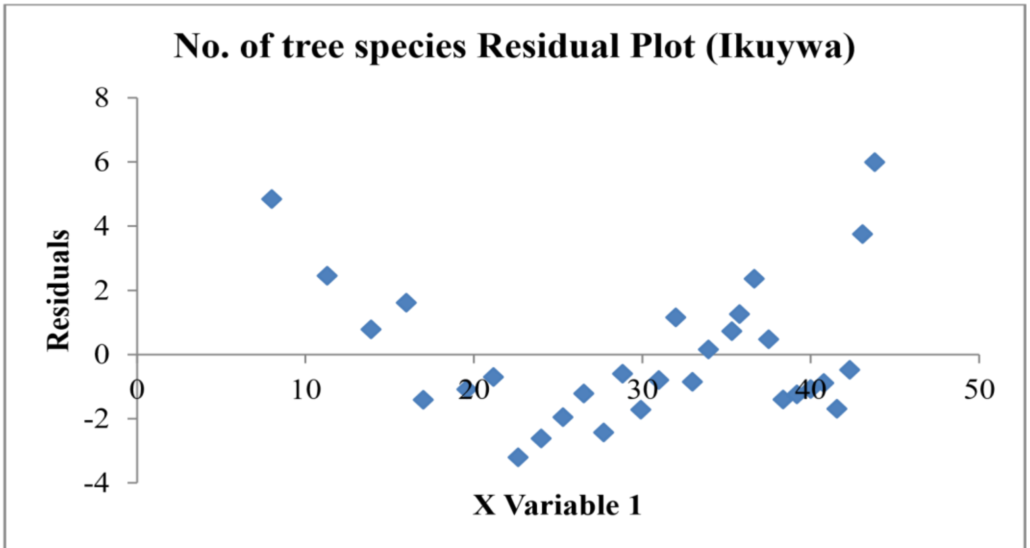
iii. Original area (Km^2) as gazetted in 1933 - *7.03*

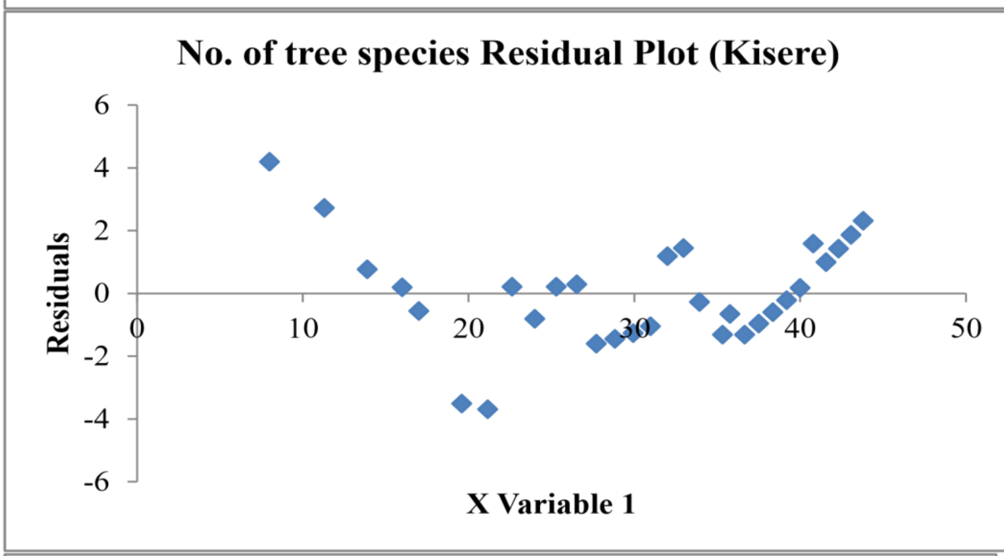
E. Types of tree species identified per site and the relative abundance

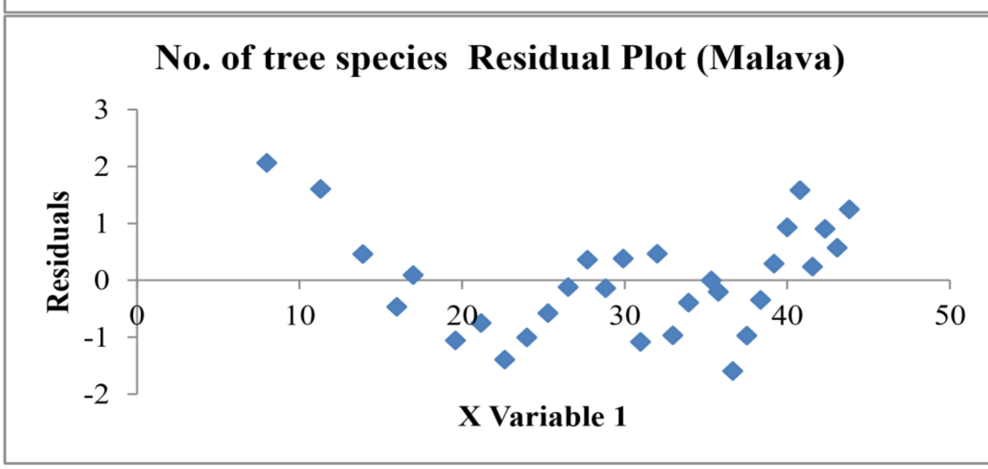
	Fragment	Ikuywa		Kisere		Malava			
	Fragment total edge length (m)	**896.25**		**896.26**		**896.25**			
	Fragment total Edge density (m/m2)	**19.92**		**19.92**		**19.92**			
	Scientific names	**Total count**	**Relative abundance (%)**	**Total count**	**Relative abundance (%)**	**Total count**	**Relative abundance (%)**	**Total count for the 3 fragments**	**Total Relative abundance (%) of top 5 Species**
1	*Albizia gummifera*	0	0.00	0	0.00	2	0.88	2	0.17
2	*Aningeria altissima*	18	3.21	20	5.04	10	4.39	48	4.05
3	*Antiaris toxicaria*	50	8.93	40	10.08	18	7.89	108	9.11
4	*AcanthusPubescens*	4	0.71	4	1.01	2	0.88	10	0.84
5	*Bersama abysinica*	6	1.07	4	1.01	0	0	10	0.84
6	*Bischofia javonica*	2	0.36	0	0.00	0	0	2	0.17
7	*Blighia unijugata*	23	4.11	20	5.04	17	7.46	60	5.06
8	*Bosquica Phaberos*	13	2.32	17	4.28	5	2.19	35	3.38
9	*Cassipourea ruwensorensis*	21	3.75	17	4.28	2	0.88	40	3.38
10	*Celtis Mildbraedii*	10	1.77	13	3.27	2	0.88	25	2.11
11	*Chaetacme aristata*	2	0.36	4	1.01	0	0	6	0.51
12	*Cordia Africana*	2	0.36	2	0.504	0	0	4	0.34
13	*Craibia brownie*	37	6.61	22	5.54	15	6.57	74	6.24
14	*Croton megalocarpus*	3	0.53	5	1.26	2	0.88	10	0.84
15	*Croton Slyvaticus*	6	1.07	5	1.26	2	0.88	13	1.01
16	*Celtis durantii*	28	5.00	18	4.53	12	5.26	58	4.90
17	*Clausena anisate*	0	0.00	3	0.76	0	0	3	0.25
18	*Diospyros abyssinica*	0	0.00	4	1.01	0	0	4	0.35
19	*Devalysis macrocalyx*	23	4.11	27	6.80	0	0	50	4.22
20	*Ficus lutea*	3	0.53	2	0.54	0	0	5	0.42
21	*Ficus sar*	13	2.32	7	1.76	2	0.88	22	1.86
22	*Funtumia africana*	117	20.89	100	25.19	55	24.12	272	22.95
23	*Harungana madagascariensis*	2	0.36	0	0	2	0.88	4	0.34
24	*Hagenia abyssinica*	4	0.71	2	0.54	1	0.44	7	0.59
25	*Markhamia lutea*	26	6.42	12	3.02	10	4.39	48	4.05
26	*Morus lacteal*	14	2.50	1	0.25	0	0	14	1.18
27	*Macaranga kilimandschirica*	1	0.18	1	0.25	0	0	1	0.08
28	*Olea capensis*	0	0.00	3	0.76	5	2.19	8	0.68
29	*Polyscias fulva*	16	2.86	12	3.02	6	2.63	34	2.87
30	*Prunus Africana*	6	1.07	4	1.01	3	1.32	13	1.10
31	*Rawsonea lucia*	5	0.89	11	2.77	4	1.75	20	1.69
32	*Sapium ellipticum*	15	2.68	6	1.51	0	0	20	1.69
33	*Solanum mauritianum*	5	0.89	2	0.50	0	0	07	0.59
34	*Strombusia scheffleri*	3	0.54	5	1.26	1	0.44	9	0.76
35	*Teclea nobilis*	29	5.18	10	2.52	17	7.46	57	4.81
36	*Trema orientalis*	3	0.54	5	1.26	2	0.88	10	0.84
37	*Trichilia emetic*	20	3.57	29	7.30	18	7.89	47	3.97
38	*Trilepisim madagascariensis*	22	3.93	14	3.53	12	5.26	48	0.04
39	*Zanthoxylum gilletti*	4	0.71	2	0.50	1	0.44	7	0.59
	TOTALS	560	100	397	100	228	100	1185	100

APPENDIX 2. RESIDUAL PLOTS

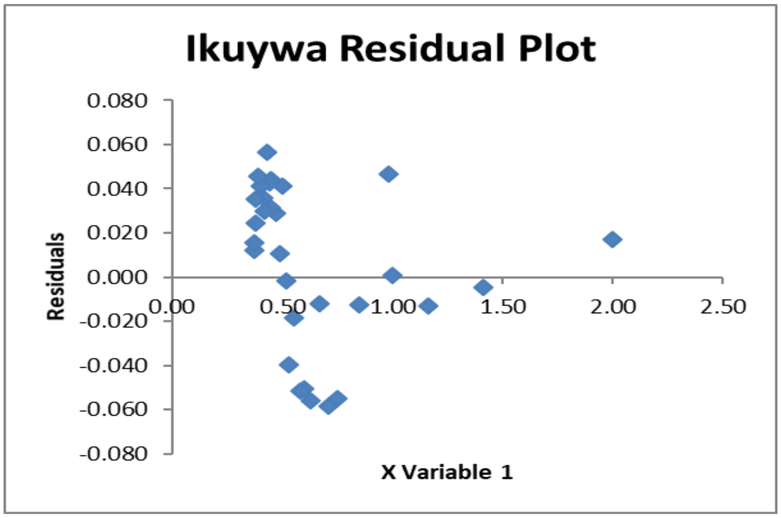
i) Objective one

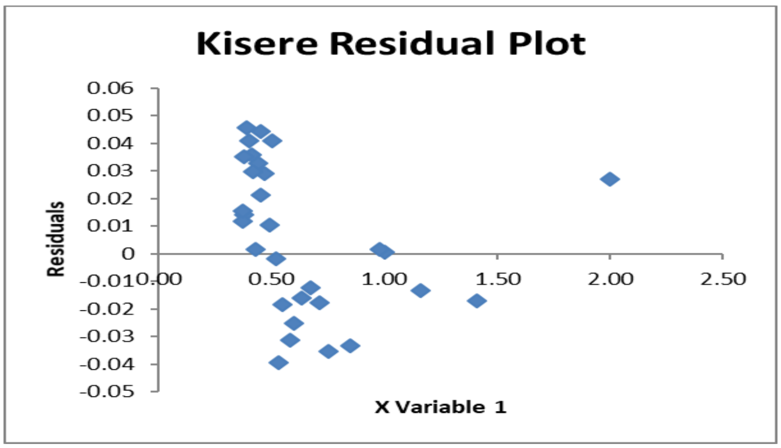


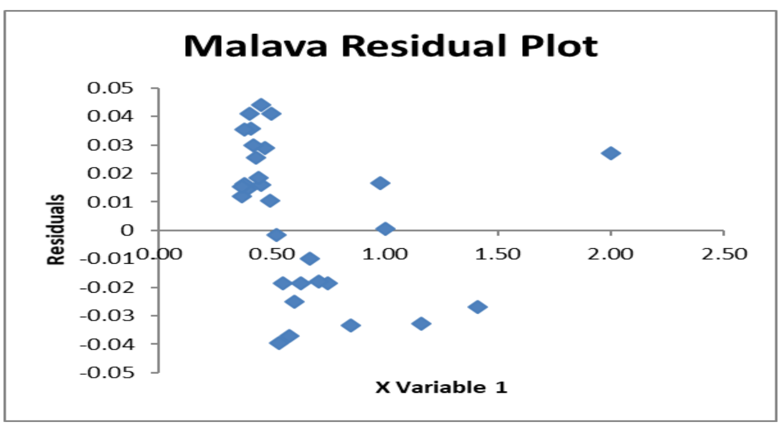




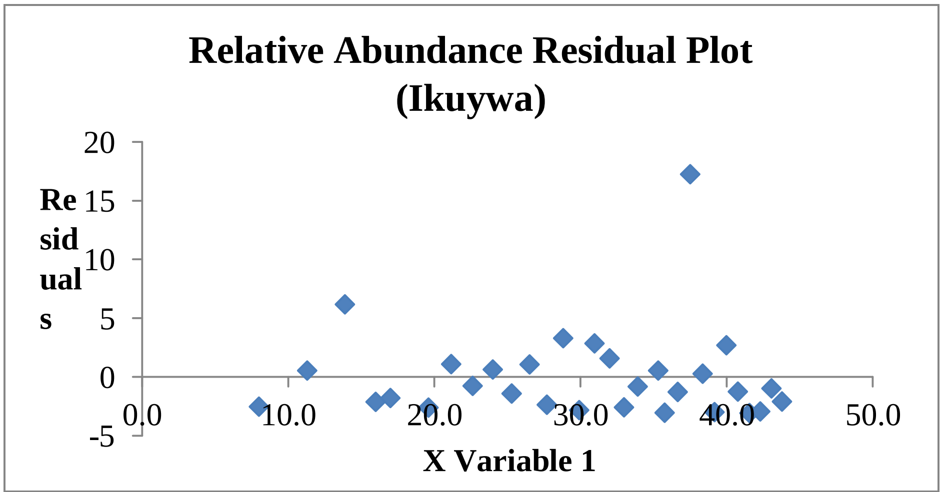
ii) Objective 2

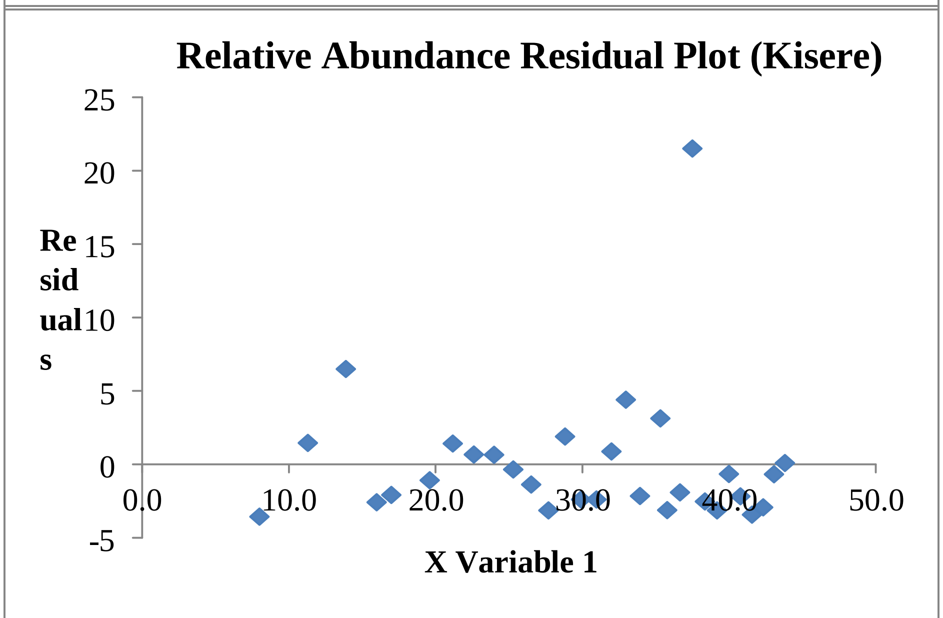


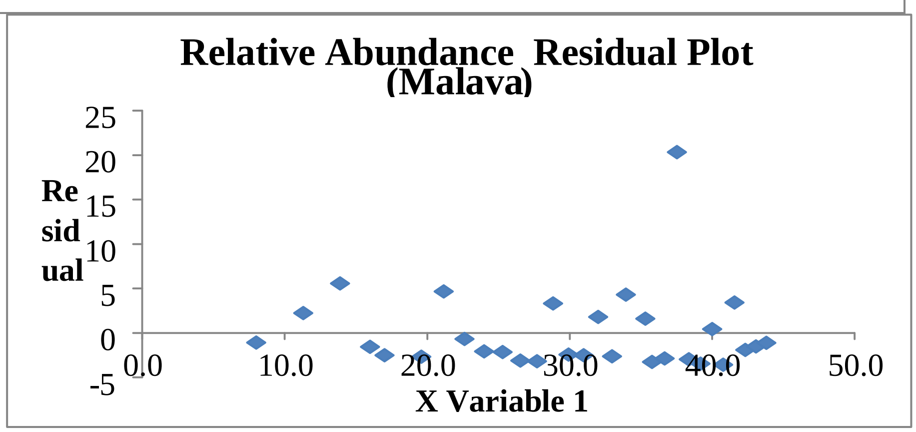




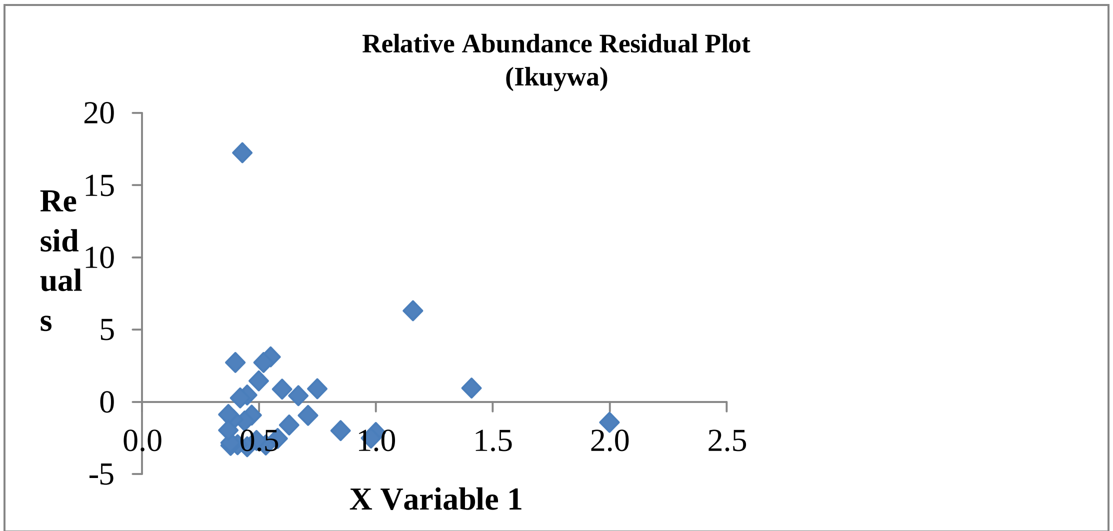
iii) Objective 3 a)

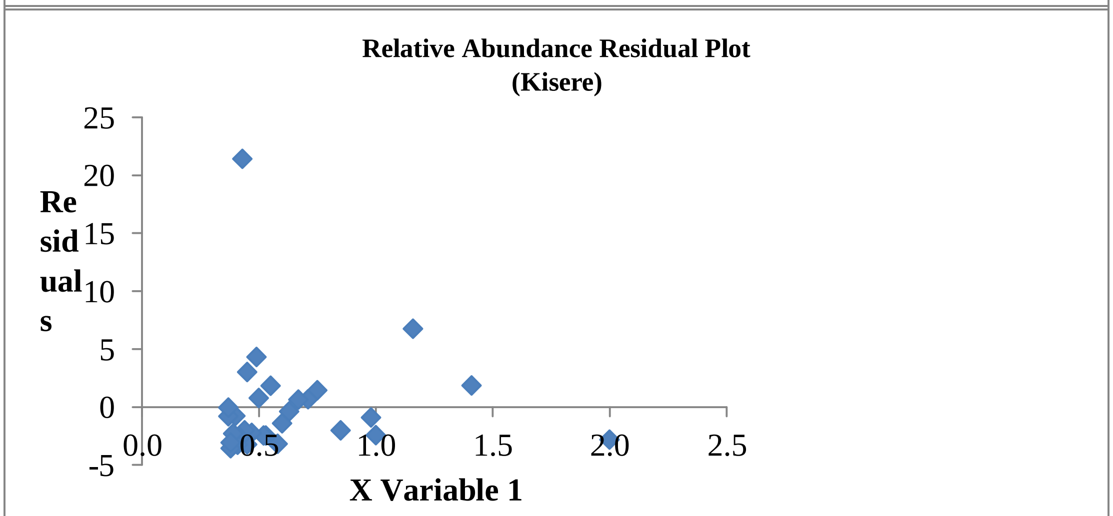


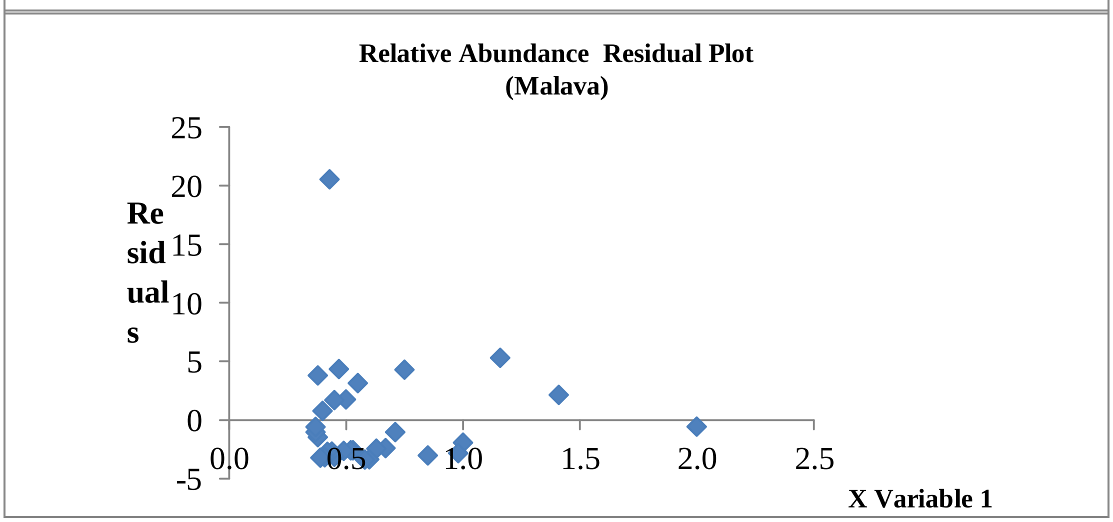




Objective 3 b)







APPENDIX 3: AUTHORITY LETTER

MASENO UNIVERSITY

SCHOOL OF GRADUATE STUDIES

Office of the Dean

Our Ref: PG/MA/00088/2013

Private Bag, MASENO, KENYA
Tel:(057)351 22/351008/351011
FAX: 254-057-351153/351221
Email: sgs@maseno.ac.ke

Date: 05th November, 2018

TO WHOM IT MAY CONCERN

RE: PROPOSAL APPROVAL FOR EMMA ANYANGO—PG/MA/00088/2013

The above named is registered in the Master of Arts Programme in the School of Environment & Earth Sciences, Maseno University. This is to confirm that her research proposal titled "Influence of Forest Fragmentation on Tree Species Richness in the Detached Portions of Kakamega Forest, Kakamega County, Kenya" has been approved for conduct of research subject to obtaining all other permissions/clearances that may be required beforehand.

DEAN SCHOOL OF GRADUATE STUDIES
MASENO UNIVERSITY
05 NOV 2018
P.O. BOX PRIVATE BAG, MASENO

Prof. J.O. Agure
DEAN, SCHOOL OF GRADUATE STUDIES

Maseno University *ISO 9001:2008 Certified*

APPENDIX 4. RESEARCH PERMIT

KENYA FOREST SERVICE

Telephone: 771115835
When replying please quote
Ref: No. KFS/KK/9/1/1/193
Email:zmkakamega@kenyaforestservice.org

KENYA Forest Service

THE ECOSYSTEM CONSERVATOR
P.O. BOX 1233
KAKAMEGA

Date: 21st November, 2018

The Chief Conservator of Forests
Kenya Forest Service
P.O. BOX 30513
NAIROBI

Thro' The Head of Conservancy – (W)
P.O. BOX 460
KAKAMEGA

HEAD OF CONSERVANCY
WESTERN.

RE: RESEARCH AUTHORIZATION
EMMA ONYANGO-PG/MA/00088/2013 – MASENO UNIVERSITY

Reference to the subject above and to the attached letter Ref: No. PG/MA/00088/2013 from the Dean school of Graduate Studies, Maseno University.

The student is proposing to undertake a research within Kakamega Forest on "Influence of Forest Fragmentation on Tree species richness in detached positions of Kakamega Forest, Kakamega County, Kenya."

Authority is hereby requested for the student to continue with her research. However, she should share her findings with Kenya Forest Service upon completion.

J.K. RONO
ECOSYSTEM CONSERVATOR
KAKAMEGA.

APPENDIX 5: RESEARCH PERMIT II

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **671024**

Date of Issue: **19/March/2018**

RESEARCH LICENSE

This is to Certify that Miss.. Emma Anyango of Maseno University, has been licensed to conduct research in Kakamega on the topic: INFLUENCE OF FOREST FRAGMENTATION ON TREE SPECIES RICHNESS IN THE DETACHED PORTIONS OF KAKAMEGA FOREST, KAKAMEGA COUNTY, KENYA for the period ending : 19/March/2019.

License No: **NACOSTI/P/21/9645**

671024

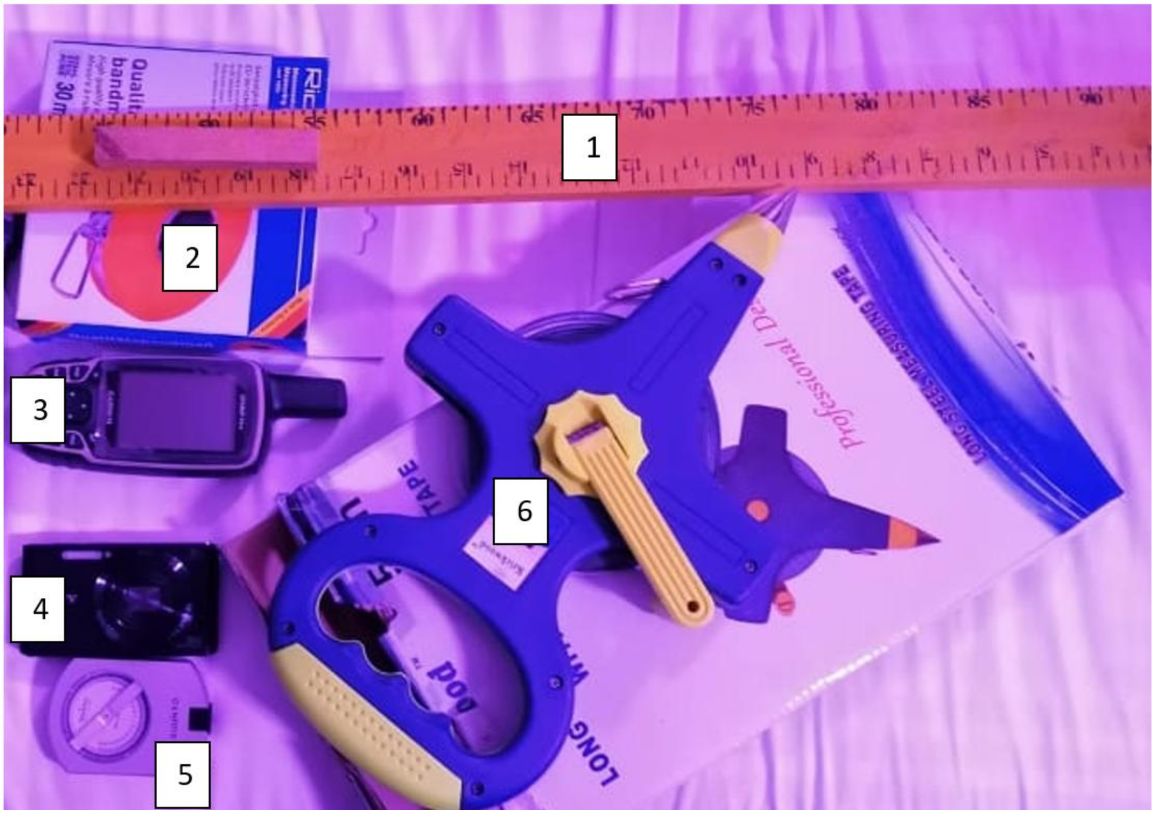
Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

APPENDIX 6: RESEARCH INSTRUMENTS



Label	Instrument	Use
1	1m ruler	For measuring the quadrats
2	30m diameter tape	Measuring the diameter of trees
3	GPS 64s Garmain	Geo-locating the sampled study sites
4	Sony Digital Camera	Taking photographs of the plots in the fragments
5	Suunto Inclinometer	For estimating tree heights
6	50m measuring tape	For demarcating plot sizes.