East African Scholars Journal of Education, Humanities and Literature

OPEN ACCESS

Abbreviated Key Title: East African Scholars J Edu Humanit Lit
ISSN: 2617-443X (Print) & ISSN: 2617-7250 (Online)
Published By East African Scholars Publisher, Kenya

Volume-3 | Issue-4 |Apr-2020 | DOI: 10.36349/EASJEHL.2020.v03i04.007

Research Article

Influence of forest fragmentation on tree species diversity in the detached portions of Kakamega forest, Kakamega County, Kenya

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Article History
Received: 04.04.2019
Accepted: 25.04.2019
Published: 27.04.2020

Journal homepage:
https://www.easpublisher.com/easjehl

Quick Response Code

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. In various tropical developing countries, the twin pressures of poverty and increase in population are resulting in considerable fragmentation of forests, increasing the probability of extermination of many indigenous species. This results to the need of studying the effects of forest fragmentation on tree species richness and to highlight possible remedial actions. The process of habitat loss and fragmentation is widely considered to be one of the primary threats to global biodiversity. Few studies have analysed the effects of special physical dynamics of a fragment such as egde lenthg, area to edge lenth ratio and new fragment area to original size of forest fragments in determining the efects of fragmentation on tree species. The aim of this study was therefore to assess the diverse impacts of fragmentation on forest habitats by intergrationg the relationship between special land dynamics of a fragement to changes in species ricnhess and diversity along the edge in three fragments of Kakamega forest, Kakamega County in Western part of Kenya. We selected three frgments of the forest namely Malava, Kisere and Ikuywa for field sampling and analysis. A total of 20 plots of 0.04 ha each were randomly placed in each of the habitats whereby all trees with DBH ≥10 cm were inventoried in every plot and the average for the fragment calculated. Shannon-Weaner diversity index was used to analyse species diversity. A total of 39 species of trees were recorded from the three fragmnets with *Funtumia africana* being recorded as the most abundant species. Of the recorded species, 77.78% were common in the three fragments while 5.56%, 11.11%, and 5.56% occurred exclusively to specific fragments Kisere, Ikuywa, and Malava fragments, respectively. The Ikuywa fragment was significantly rich in terms of species abundance while in terms of diversity, Malava fragment was revealed to be the most diverse of the three at a mean average 3.79 Shannon Wiener diversity index. There was a significant linear correlation between edge density and edge length and species abundance. In summary, the results suggest that the three detached portions do not contrast significantly in terms of tree species richness, diversity, and relative tree abundnce. Moreover, the edge habitats of the three fragments were observed to be characterized by high anthropogenic activities with the edge density and edge length siginificantly affecting tree species diversity and richness respectively. This consequently leads to continued fragmentation as the distance from one forest fragment to another is likely to keep on increasing. The results of this research was important in understanding the ecological effects of the fragmentation in respect to tree species richness and therefore come up with viable recommendations on conservation. Data regarding the fragmentation will also be useful in assessing the potential risk of changes in the weather patterns on the surrounding region.

Keywords: Forest fragmentation, relative abundance, edge density, edge length, species diversity, species richness.

1.0 INTRODUCTION

Forest fragmentation occur in many forests across the world and has been reported to be a threat to various species of plants and animals (CBD, 2005, Foley *et al.*, 2005). Forest fragmentation involves continuous reduction of a forest habitat into smaller isolated forest patches (Andrens 1996). 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 (MacArthur and Wilson 1967). Tropical forests world over have been subjected to massive anthropogenic activities consequently resulting into extensive fragmentation with newly created edges (Lung *et al.*, 2008). The newly created edges expose trees to other biotic and abiotic factors, thus increasing tree mortality (Laurance *et al.*, 2000; Harper *et al.*, 2005). Effect of habitat fragmentation on various species world over have been extensively studied (Miller-Rushing, *et al.*, 2019).

In Sub Saharan Africa for expamle, high population densities resulting form rapid increase of population has led to numerous arthropogenic activities with negative impacts on forest fragments consequently affecting the species richness (Peres 2001). The rise in population coupled with extreme poverty situations has led to indiscriminate activities in the forest that inturn lead to loss of forests and the forest land (FAO 2001). In Kenya, tropical forests such as Kakamega forest which is actually the Kenya's only tropical forest has bore the brunt of fragmentation (Brooks *et al.*, 1999). Kakamega forest has undergone massive fragmentation resulting into quite a number of small fragments since it was first gazetted in 1933 leading to different ecological pressure (Brooks *et al.*, 1999; Peters *et al.*, 2009). Various studies on Kakamega forest have generally revealed effects of fragmentation and habitat loss emanating from anthropogenic activities (Maina and Jackson 2003). Few studies however have been done in this forest with respect to fragmentation and edge attributes on tree diversity, species richness and the species relative abundnace. Key aspects that are important when analyzing fragmentation effects on species richness of both palnts and animals include: the fragment area (Lovejoy *et al.*, 1984, 1986; Newmark, 1991), the fragment shape (Schonewald-Cox and Bayless, 1986), and the fragment's isolation from the main forest block (Buechner, 1989). With respect to shape, length of edges and the edge density is an important consideration. 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 (Bennett, 2003).

Fragmentation has affected tree species richness and diversity in a number of ways including by limiting biotic pollinators which some plants may be dependant on (Tabarelli *et al.*, 1999; Kolb & Diekmann, 2005). (Bustamante & Castor, 1998). In addition, fragmentation expose the fragment to vagaries of anthropogenic activities such as selective logging and farming thereby interfering with tree count and diversity (Pollman, 2002; Hitimana *et al.*, 2004) (Cannon *et al.*, 1998). The main objective of this study was to assess the impact of forest fragmentation on the rain forest of Kakamega in Western region of Kenya on various species dynamics such as richness and diversity. Three major fragments of the forest: Ikuywa, Kisere and Malava all of which were created after 1933 were selected for the purpose of analyzing the correlation between fragmentation attributes suchas edge leghth and edge density and species richness, species diversity and the tree species relative abundance in the fragments.

2.0. MATERIALS AND METHODS

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 (Figure 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. Data from the Kenya meteorological station (mean of 2002-2005) 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 shorter rains which begin in July and end in October with a peak in August. Annual rainfall averages between 1500 – 2000 mm. 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 (Wass 1995). 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 (Kokwaro, 1988). Kakamega forest is the headwaters for the County's two rivers and is an important watershed for the Lake Victoria basin (Kumagisha *et al.*, 1997). Soils throughout the area are composed largely of volcanic clays and clay loams classified as ferralo-chromic or humic cabrisoils (Kendall 1969, Loven and Wasser 1993). The main forest block is located about 7.5 km from Kakamega town. It has several frgments that vary in shape, in distance to the main forest as well as in distance to each other and in age (Glenday 2006) (Figure 2).

Study sites

The present study was conducted at 3 different sites in Kakamega Forest namely Kisere, Malava and Ikuywa fragments. The approximate sizes of the fragemnets in ha are 1370, 400 and 100 for Ikuywa, Kisere and Malava respectively, while the main block measure is about 8500 ha. Kisere fragment is located to the north of the main forest block. This location is within the small-scaled agricultural land. The surrounding portions of the fragment have therefore been converted to agricultural land (Lung and Schaab 2007). It lies about 1.6 Km from the main forest block. Its original gazette size as of 1933 was 458 ha

(Eberhard Fischer and Barthlott 2005). Malava fragment is located to the north east side of Kisere fragment along Kakamega - Webuye highway. Its surrounding is dotted with settlements suggesting 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 pf the main forest block as of 1933. It is about 1370 ha in size currently and lies about 1.5 Km from the main forest block (Eberhard Fischer and Barthlott 2005).

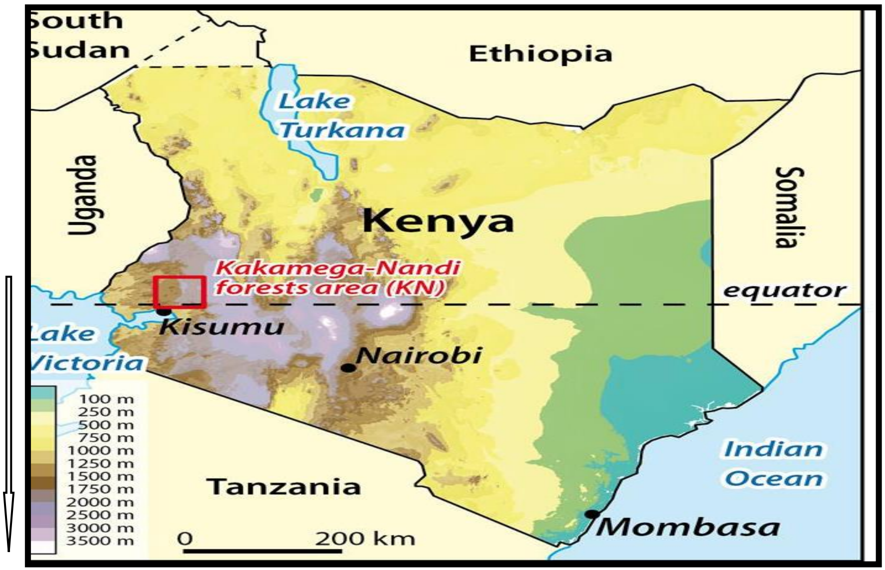

Figure 1: Map of Kenya showing the study area at longitudes 34^0 40’ and 34^0 57’ 30” East and 0^0 15” (Lübker*et al* 2014).

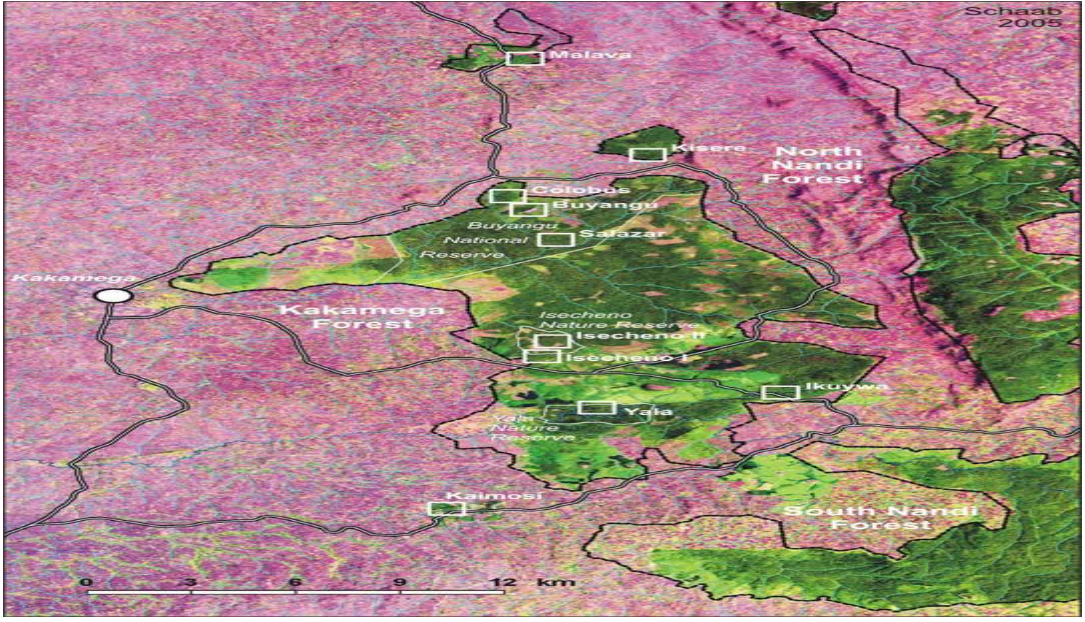

Figure 2: Satellite image of the Kakamega forest and its surroundings. (Source: Eberhard Fischer and Barthlott 2005).

Field sampling

Data was collected within randomly selected 45 study sites located within each of the three forest fragments. The interraction between the variables were determined through field observations and determination of the forest edge length and forest edge density.The plots were established from the forest edge adjacent to the interior of the forest. Quadrants were used in tree species sampling where different tree species was identified, counted and recorded in each quadratnt. Also their Relative abundance in every fragment was calculated and recorded. The sampling plots each measuring 20m by 20m was established randomly in the fragments 15 each. Two quadrants each measuring 10m by 10m was established randomly within each plot.

Tree species and diversity along the edges (0–200 m) of the three established forest fragments were characterized. The 0-200m edge measurement was prefered due to the fact that the edge effects can penetrate to 200 m to the forest interior from the margin (Ewers and Didham 2006b). 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 and recorded from each plot in the fragments. Trees with multiple stems at 1.3 m height were treated as a single tree by averaging the diameters of all stems. Trees with buttresses or abnormalities at 1.3 m height, were considered from the points after the abnomality whwre the stems appeared more cylindrical. Each plot within the studied fragments was considered as an independent sample.

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 edge length in relation to the forest area. 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 fragmentation and tree species richness, diversity and relative abumdance.

Measures of richness, diversity and relative abundance

Tree species richness at the edge was estimated by a simple count and recording of the number of tree species in each of the sampling plot. The diversity of tree species between the fragments was estimated in terms of beta (β)-diversity. Beta diversity was preffered to enable us have put into consideration the differences in composition of the species among the three studied fragemnts. The relative abundance of the species per fragment was calculated from the richness.

Data analysis and results presentation

Descriptive statistics was used to desribe the Edge trees species richness. The mean number of species per plot were calculated to arrive at the value per fragment. To assess the influence of the fragment size on the species richness, linear regression models were fitted using abundance of trees as response variables and fragment size as the explanatory variables. The slope coefficients resulting from the models were used to analyse the relationship of tree species to the forest fragmentation. Species diversity was estimated using Shannon-Wiener diversity index (H). While the tree relative abundance between the three fragments were analysed using simple linear regression models.

3.0 RESULTS

We analysed species richnes, diversity and and relative abundance within the edges of the three studied fragments in relation to such variables as the edge length and edge density.

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

The total estimated length of edges of the three fragments was 26.9 km, a decrease from 1933 by 7.4 km. The estimated total edge length as at 1933 was 101.9 km while the area to edge length ratio was 2.41 (Table 4.1). Total Edge length to area ratio was 1.69 which is 21 % lower than 1933. From the total sampled edge length of 2.69 km for the three fragments combined, the total number of tree species identified is 1185 belonging to 39 different tree species' stems (Table 4.1). According to regression, the slopes have registered an increasing trend from the larger fragments edge length to the smaller forest fragment (Table 4.1). The level of species increase per edge length (i.e., regression slope) was significantly higher in the smaller fragments compared to larger and medium sized fragment, which did not differ substantially (Table 4.2).

Table 4.1. Showing the fragments, edge length, tree species richness and the relationship

Fragment	Edge Length (Km)	Edge length (1933) (km)	Sampled Edge Length (km)	Tree species richness	R^2-Value	Regression equation
Ikuywa	14.70	15.07	0.896	560	0.957	Spp. Richness =1.029 In Edge length -12.07
Kisere	8.20	8.56	0.896	397	0.951	Spp. Richness =0.751 In Edge length -9.191
Malava	4.00	10.61	0.896	228	0.958	Spp. Richness =0.442 In Edge length -5.95

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 stems accounting for 47% of the total tree species identified from a sampled edge length of 0.9 km (Appendix D). 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 D). Species richness along the edge was found to be significantly related to fragment edge length (R^2= 0.957, p<0.0001) (Figure 3). The mean species richness increased with increase in slope, the slope coefficient for edge length being 1.029 (Figure 3).

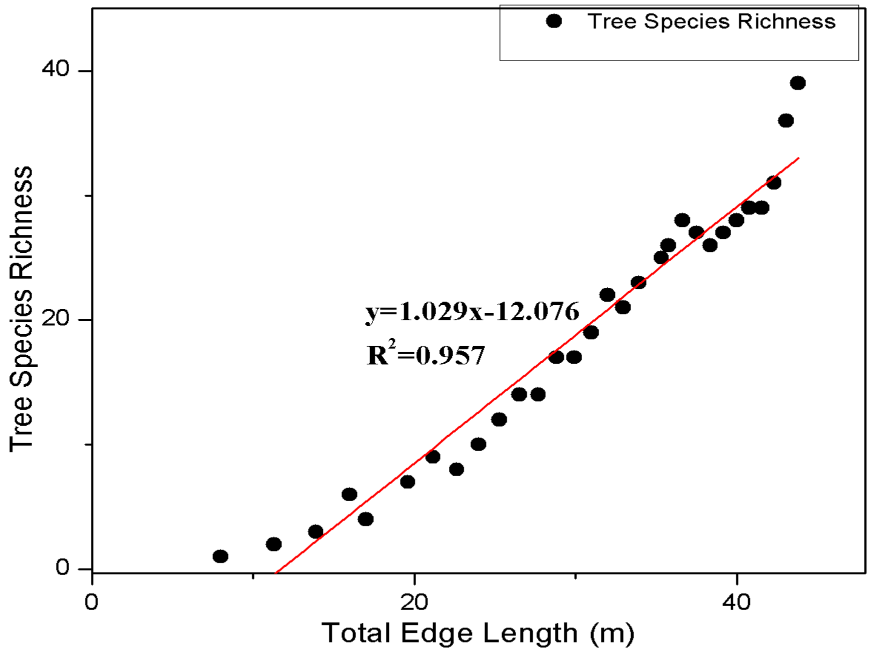

Figure 3: Tree species richness versus total edge length over Ikuywa

Kisere which was the second largest fragment of the three studied fragments with a total estimated area of 4.2 Km^2 and total edge length of 8.2 Km had a total of 397 stems representing 33.5% of the total tree species identified from a sample edge length of 0.9 km. The most abundant species from this fragment again were *Funtumia africana* with a total of 100 stems contributing 25% of the total number of species in this fragment (Appendix D). Species richness along the edge was found to be significantly related to fragment edge length (R^2= 0.951, p<0.0001) (Figure 4). The mean species richness increased with increase in slope, the slope coefficient for edge length being 0.751 (Figure 4)

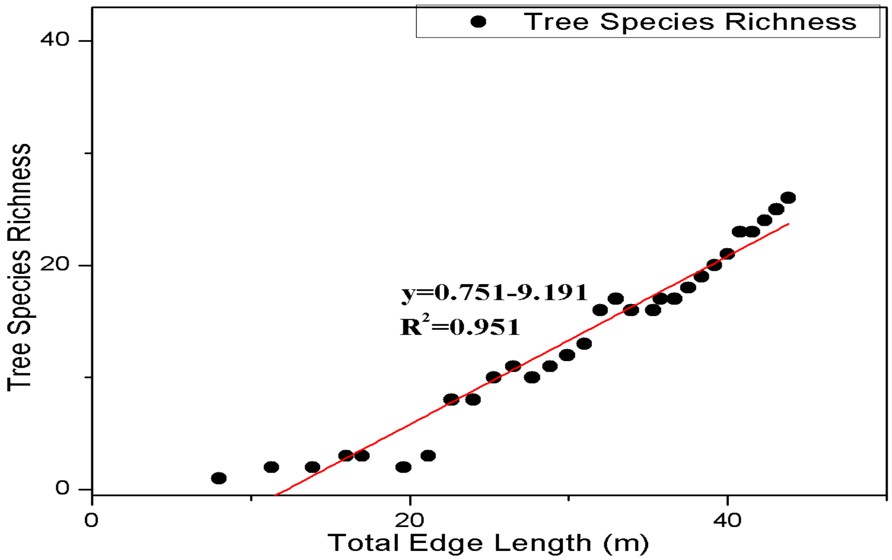

Figure 4: Tree species richness versus total edge length over Kisere

Malava fragment which had the lowest estimated edge length of 4 Km and was the smallest of the three fragments in terms of area ($1 km^2$). From the sampled size of about 0.9 km, it had a total of 278 stems 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 stems which represent 25% of the total number of species identified in the fragment. Of the total observed species, 58.97% were common in all the three studied forest fragments while 7.14% (2 species), 5.56% (5 species), and 12.82% (5 species) occurred exclusively to Malava, Kisere, and Ikuywa fragments, respectively (Table 3). Overally *Funtumia africana* was the most abundant tree species with a total 272 stems recorded giving a relative abundance of 22.29%. This was followed by *Antiaris toxicaria*, *Craibia brownie, Blighia unijugata,* and *Celtis durantii* with a relative abundance of 9.11 %, 6.24% and 5.06% respectively. In average 13 species could be found in every studied site. The lowest species numbers were recorded at Malava fragment followed by Kisere. From the regression slopes the species richness along the edge was found to be significantly related to fragment edge length (R^2= 0.442, p<0.0001) (Figure 5). The mean species richness increased with increase in slope, the slope coefficient for edge length being 5.59 (Figure 5).

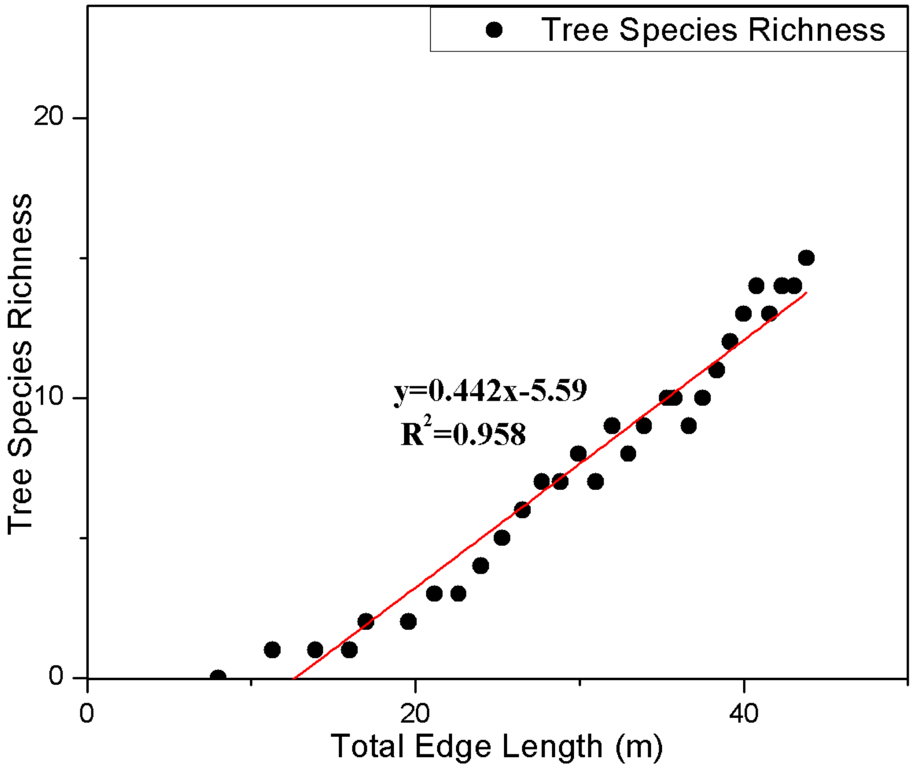

Figure 5: Tree species richness versus total edge length over Malava

Edge density of the forest fragments and tree species diversity

Species diversity within the fragments was determined using the Shannon-Wiener diversity index analysis. The relationship between the species diversity and the edge density was then analysed using simple linear regression. From the Shannon Wiener diversity index calculations, Malava fragment had higher species diversity than the other two fragments. Malava fragment appears to be a more disturbed fragment at the edge with lower current estimated edge density of 0.25 compared the original estimates of 0.54. On the other hand we recorded low species diversity in a seemingly less disturbed fragmented area such as Kisere. Malava fragment was revealed to be the most diverse fragment with significantly higher species richness (35 species) and Shannon-Wiener index (3.79) compared to Malava and Kisere fragments, which did not differ appreciably. We also calculated the edge density as at 1933 when the forest was first gazetted as well as the current edge density based on the current area estimates. The area to edge length ratio for the three fragments are currently estimated at 0.92, 0.25 and 0.52 for Ikuywa, Malava and Kisere respectively. As of 1933 when the fragment was first gazetted, the diversity was 0.94, 0.25 and 0.66 for the three fragments respectively. We had sampled an average edge density of 0.1992 km/km^2 per fragment. Shannon Wiener Diversity Index analysis revealed that the diversity of the species between the studied fragments varied significantly (*P* = 0.001) ranging from mean density 3.41 (at Kisere) to 3.79 (at Malava) with an overall average of 3.6 when all fragments are pooled together (Figure 6).

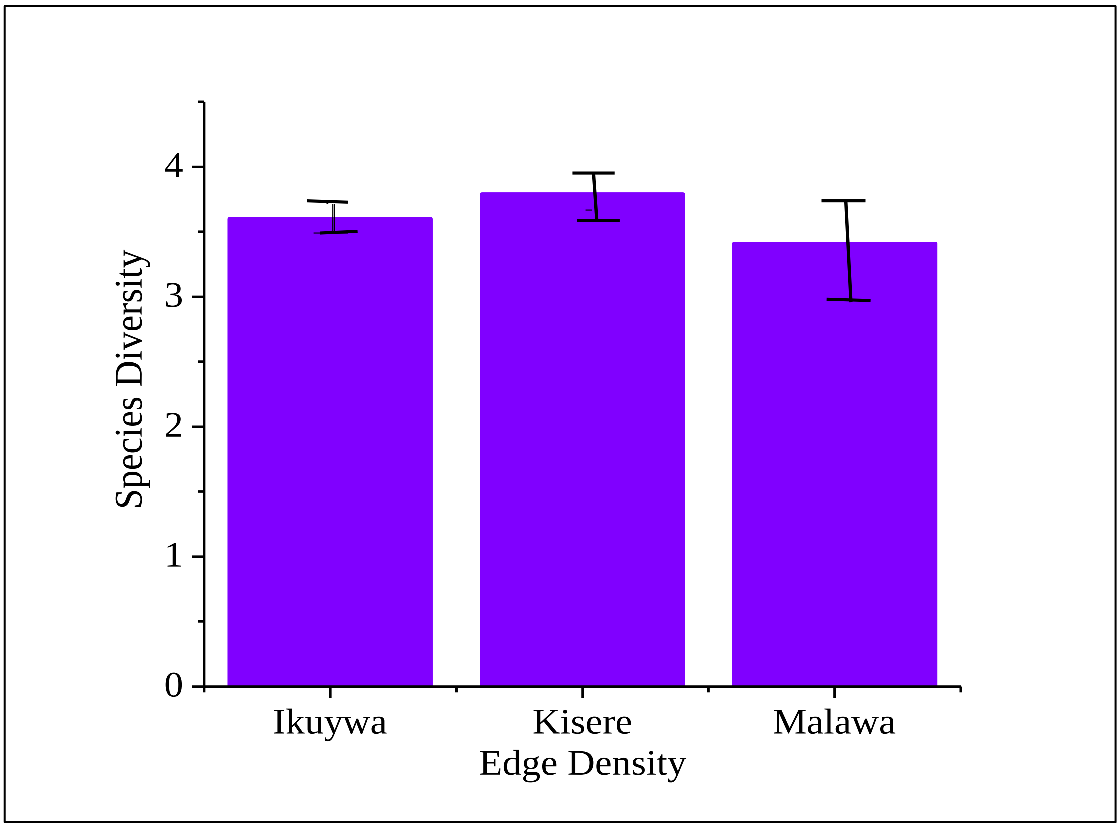

Figure 6: Mean species diversity (±standard error) in the three studied forest fragments.

Influence on edge density and total edge length on tree species abundance

We compared tree species relative abundance in the three forest fragments of 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 7, 8 and 9). 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 increase with increase in total edge length. The coefficient is 2.192 and the r^2 values being 92.2% indicating a very strong relationship between the variables (Figure 7).

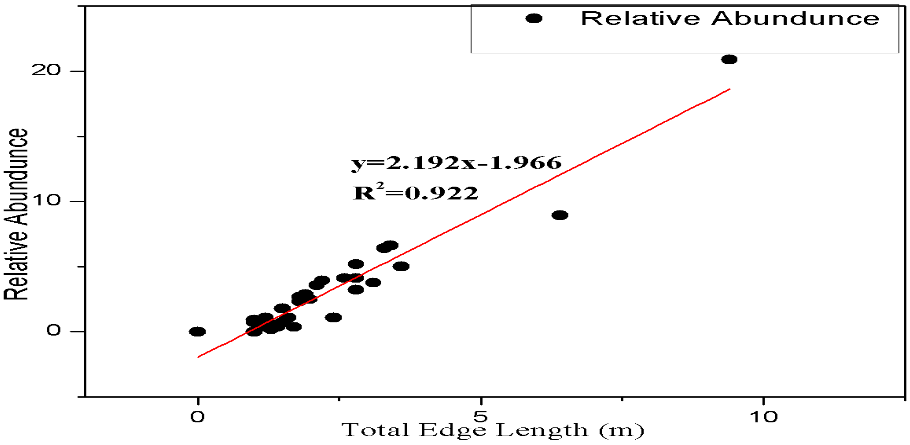

Figure 7: Total Edge Length vs Relative abundance over Malava

Similarly the relationship coefficient for the relationship between relative abundance and edge length in the same Malava fragment was revealed to increase with increase with the edge density. The coefficient was 0.841 and the R^2 values being 0.865 indicating a very strong relationship between the variables (Figure 8).

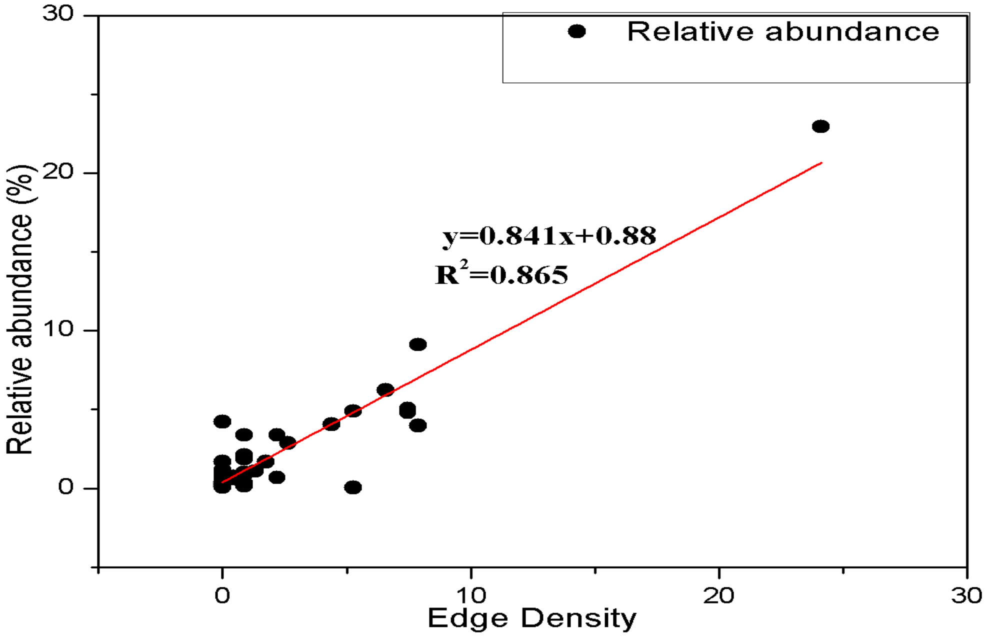

Figure 8: Edge density vs Relative abundance over Malava

Similar relationships were recorded for Kisere fragment, with the regression slopes indicate that the species abundance along the edge sampled was found to be significantly related to fragment edge length (R^2= 0.832, p<0.0001) and the slope coefficient was 2.443 (Figure 9).

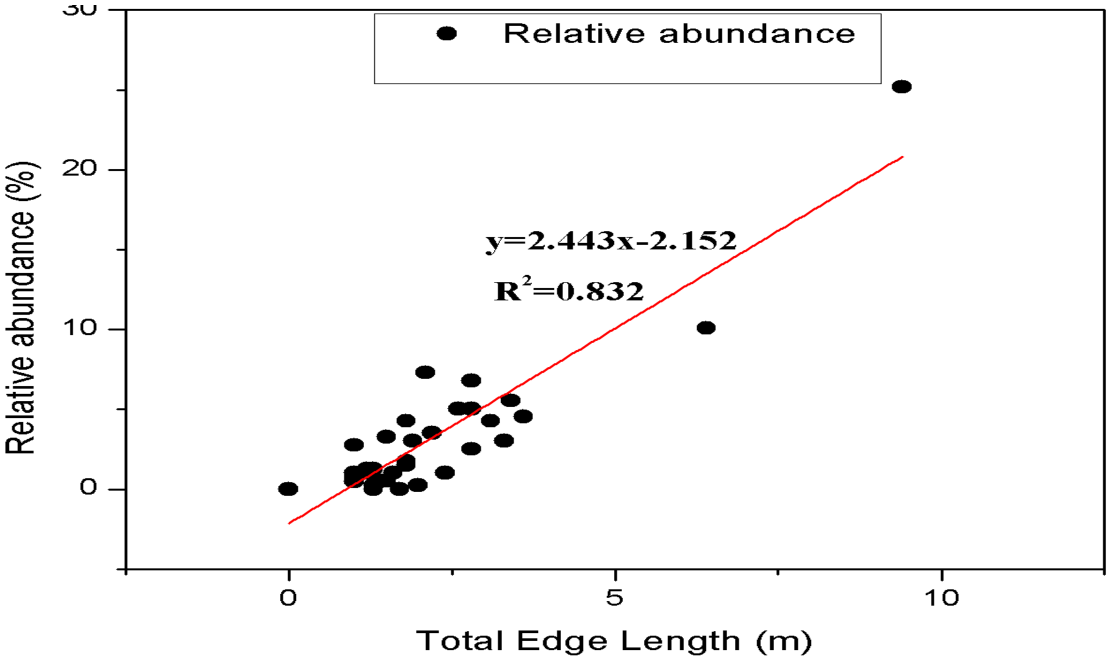

Figure 9: Total Edge length vs Relative abundance over Kisere

Concerning relative abundance against edge in the same fragment, R2 is 0.939 while the slope coefficient is 0.882 also suggesting a significant relationship (Figure 10).

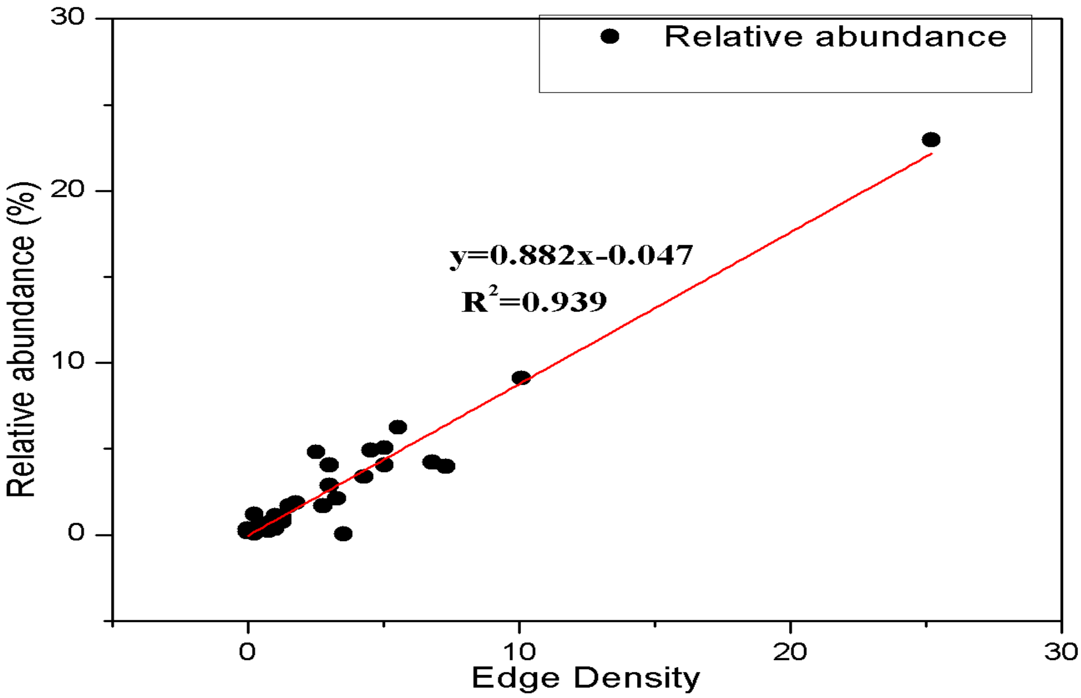

Figure 10: Relationship between Edge density and Relative abundance over Kisere

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 11).

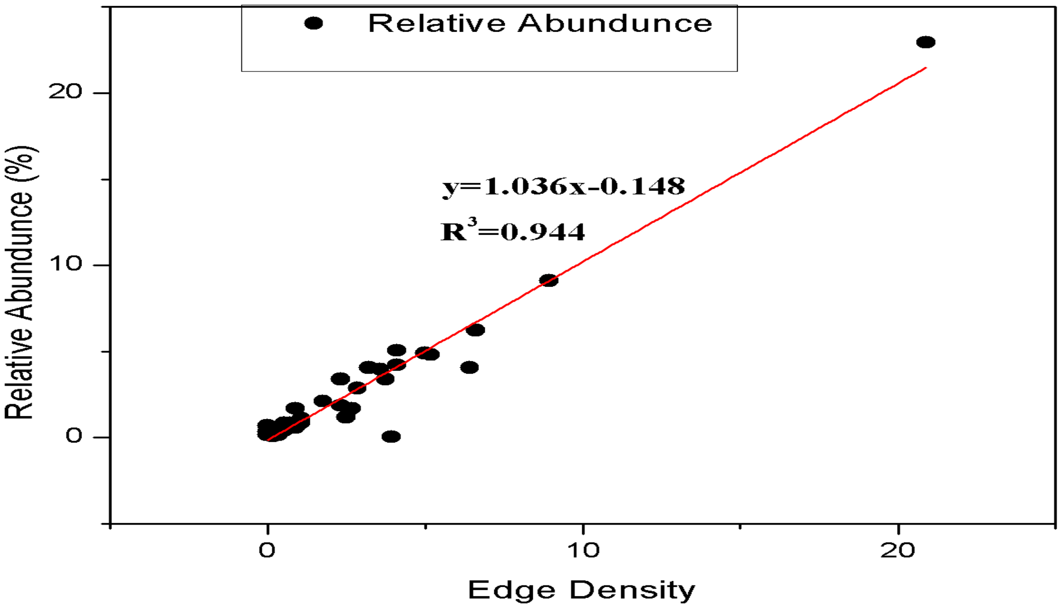

Figure 11: Edge Density in relation to Relative Abundance over Ikuywa fragment

From the linear regression equation, the coefficient indicates that the relative abundance increase with increase in total edge length for Ikuywa fragment. The coefficient is 2.192 and the R^2 values being 0.922 indicating a very strong relationship between the variables (Figure 12).

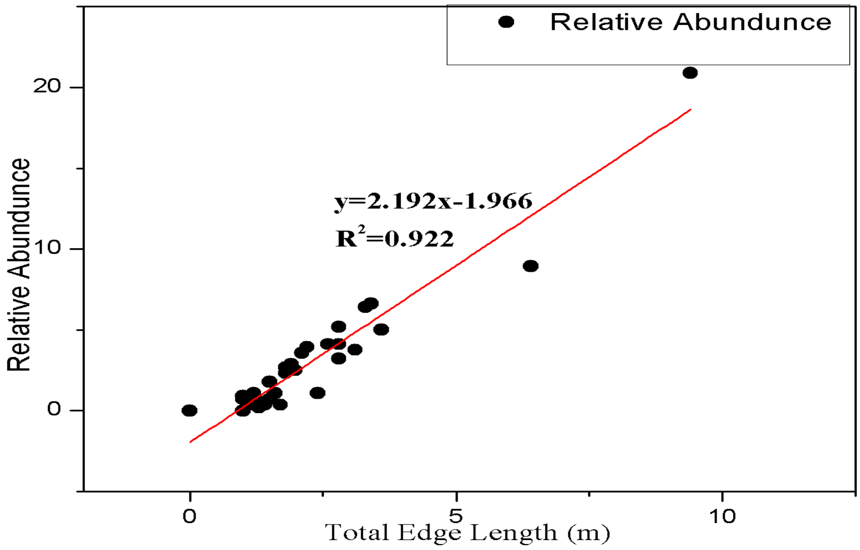

Figure 11: Edge Density in relation to Relative Abundance over Ikuywa fragment

4.0 DISCUSSION

Size of the fragment has been found to be significantly related to richness of tree species in other studies in different parts of the world (Metzger, 1997). In tropical forests for example, the abundance of shade tolerant species have been found be significantly related to changes in fragment size (Metzger, 2000). In this study the highest number of tree species was recorded from fragment with the largest size that is the Ikuywa fragment with 560 stems. Tropical forests like Kakamega forest are known to be home to more than half of the global species richness and they are often subjected to increasing anthropogenic pressure, which poses a great threat to existing biodiversity (Didham 2001). The forests of Kenya such as Kakamega are known to be rich in species diversity as they are located within the region of high rainfall and habitat heterogeneity (Echeverría *et al.*, 2007). This study has observed *Funtumia africana* to be the most dominant genus (with 272 trees) representing 23 % of the species recorded, which implies that the *Funtumia spp.* could be the most dominant tree genus in the region.

Higher species numbers were observed from the fragments which appear to be 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 (Lusk, 2002). High species numbers therefore cannot be said to be strictly correlated with high level of disturbance or with draconic conservation strategies (Mitchell 2004). Some of the most observable disturbance aspects in the forest in general include creation of footpaths, charcoal burning, harvesting of grass, tree, medicinal plants and grazing of livestock.

The tree species are not evenly distributed over Kakamega Forest. Each of the studied fragments had different level of abundance to certain specific species. Before the exploitation of the Kakamega forest started in 1933, the forest inventory was known as heterogeneous in the tree species composition (Mitchell 2004). 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, (Mitchell 2004). Ikuywa is today characterized mainly by *Funtumia africana* as per the results of this study. Although various species were selectively logged in high numbers the stand structure of the trees in the upper canopy has not changed much (Newmark 1998)). 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 (Mitchell 2004). 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*, *Prunus africana* and *O. capensis* were planted beside exotic species like *Khaya anthotheca* and *Bischoffia javanica*. 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 (Didham 2001).

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 proberly explain its low numbers. However we were still able to record a few of them especially in Malava fragment. The now most abundant tree species *Funtumia Africana* were cut in later decades than e.g. *Olea capensis* or *Prunus africana* in each area (Mitchell 2004). Perhaps, the valuable, favoured 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 (Mitchell 2004).

Records of foresters' enumeration, before the forest was logged, report that today's very abundant tree species *Funtumia africana* was always a major species in Kakamega Forest. There were high numbers of *F. africana* north of the Ikuywa. In the Annual Report of 1959 ecological reasons for the distribution patterns of certain species were denounced (Mitchell 2004). Beside *O. capensis* and *P. Africana Zanthoxylum gillettii* and *C. africana* became rare in the forest due to the logging activities. They were among the most logged tree species in the past. Now tall trees of *Z. gillettii* are rare in the forest, apart from the plantations. It was planted e.g. in Malava in high numbers to regenerate its stock. *Olea capensis* was considered to grow in Malava (Mitchell 2004). Due to the commercial activities all of these forest sites, as well as whole Kakamega Forest, are poor in this valuable timber tree nowadays, which is expected to be one of the primary tree species of the forest (Mutangah 1996).

In terms of relationship between the edge density and the diversity, there was a significant relationship for all the fragments ($P \leq 0.05$). Analysis of tree diversity in relation to fragment size has revealed significant relationship to similar studies in the past. For example secondary forests have been mostly associated with smaller fragments (Pardini *et al.,* 2005). The changes in species composition may lead to negative consequences on certain tree species that may be dependent on specific aspect of the forest and its composition. With increased fragmentation, there is likelihood of changes in forest composition in terms of composition of the various species and the microclimate (Laurance *et al.,* 2006). From the present study, the mean densities displayed an increasing trend with increase in fragment, 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 and therefore has a higher possibility of having many species. This observation 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. The higher the degree of disturbance, the more stems could be recorded (Mitchell 2004). The more disturbances took place in the past, the smaller and younger are the trees in a given area as a result of regeneration. 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. This may also lead to changes in pattern of growth, mortality and survival of the existing species (Laurance *et al.,* 2000).

Generally species abundance varied significantly between fragment types. The abundance was significantly higher in Ikuywa than in the other two fragments. As expected, species abundance were only slightly impacted by differences in the fragment's attributes. The effect 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 (Cordeiro and Howe 2001; Benı´tez-Malvido and Martı´nez-Ramos 2003a; Farwig *et al.,* 2008; Kirika *et al.,* 2010) and has been attributed to alterations of abiotic or biotic conditions in modified forests (Ramı´rez-Marcial 2003).

The top five species that were most abundant in the three studied fragments include: *Antiaris toxicaria, Blighia unijugata, Funtumia africana, Celtis durantii, Craibia brownie.* Others species with significantly higher contribution levels were *P. fulva, Trilepisium madagascarensis, Devalysis macrocalyx, Trichilia emetica and Teclea nobilis.* The tree densities for the five most abundant tree species were analyzed in each of the three fragments (Figure 4.8).

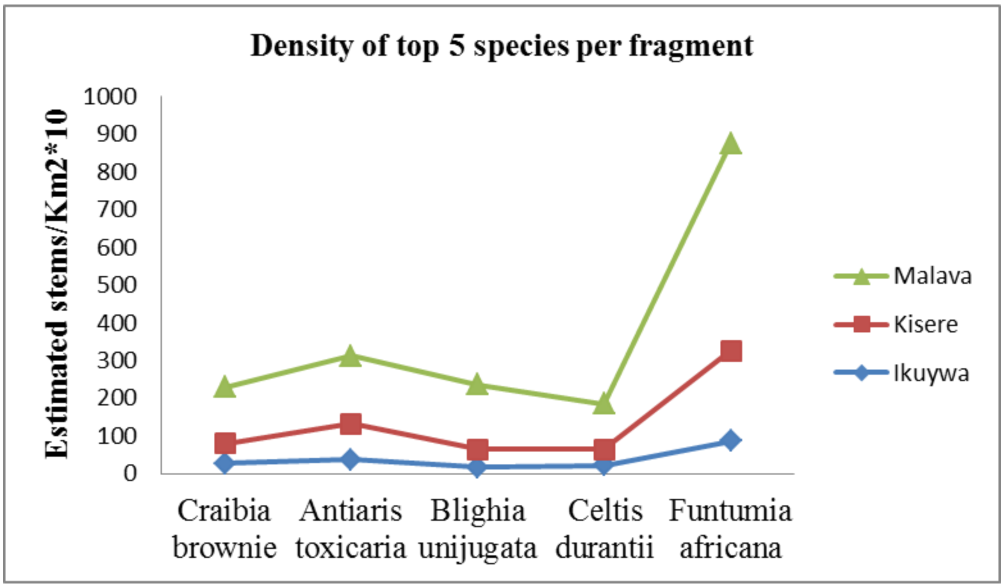

Figure 4.8: Estimated species abundance of five top tree species for the three fragments.

All the three forest sites do not differed much in relative abundance of the analyzed five tree species. The said species were slightly evenly distributed over the fragment. However, the number of individuals of the five tree species is not similar in all the fragments. *F. Africana* has the highest number of individuals in every studied fragment suggesting a possible disturbance. The high densities of the species in the two forests lead to the assumption that there was a past disturbance. The study has registered a clear pattern of changes in the tree community whereby the tree species diversity, richness and relative abundance are affected by forest fragment size which is directly proportional to the area edge length ratio. In most cases, Malava fragment had significantly higher values than the Kisere and Ikuywa fragments, which did not differ significantly. The results signify that fragmentation effects can affect the forest composition. Also, these findings suggest that the three fragments are not so contrasting habitats. A forest community is said to be diverse if it has a Shannon-Wiener diversity index value ≥3.5 (Gould, 2000). This confirms the observation of this study, which revealed significantly higher Shannon-Wiener diversity index value of 3.41 (Kisere) compared to Ikuywa (3.60) and Malava (3.79) habitats. The presence of less species diversity, 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.

The grazing and cattle trampling can also be the causal factor for the low values along the edges as livestock were observed to reach the forest edges in the studied fragments. Some farmers prefer to use fire to prepare their farms before starting a new agricultural season; this could also be a contributing factor to the low species abundance and diversity values as it kills the fire-sensitive species and affects their regeneration (Burgess *et al.,* 2007b). The periodic fires reduce canopy cover and drastically change vegetation structure and composition (Burgess *et al.,* 2007b). Another possible contributing factor to tree loss at the edges is the action of sporadic winds that, which will subsequently affect the composition and abundance of the species. 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 (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).

Other contributing factors to low tree richness along the edges according to past studies include unfavourable environmental conditions such as relatively higher temperature conditions, high light intensity, lower relative humidity (Burgess *et al.*, 2013), (Davidson *et al.*, 2004), (MacDougall *et al.*, 2013) and strong wings (Adams *et al.*, 2003). Other abiotic factors include inadequate soil carbon, nitrogen and phosphorus (Maeda *et al.*, 2010) as well as low levels of moisture and litter in the surrounding edge (Maeda *et al.*, 2010). This study has revealed that three fragments of Kisere, Malava nad Ikuywa have slightly different species composition from one other. 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. 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 (Olson *et. al.,* 2014). Therefore better tree species diversity would be achieved when the tree loss is reduced especially at the edges.

5.0 CONCLUSION

A comparison between tree species numbers of the three fragments shows that Ikuywa has higher numbers. Ikuywa is still a more compact block that is very close to the main block. Therefore, fragmentation of the forest seems to have an effect on the species number resulting in lower species numbers. Generally, the findings indicate that the Malava, Kisere and Ikuywa fragments of Kakamega forest are different from one another in terms of tree species richness, diversity, and edge density. Ikuywa possesses higher species richness than Malava and Kisere, while Kisere had higher species diversity than the other two fragments. If the Kakamega forest will continue being fragmented, there will be an increase of edge related habitats, which will cause structural and floristic composition changes due to increased edge effects and the forest will face a great threat of losing its original biota especially the rare species. Most parts of Kakamega Forest and its fragments contain disturbed forest sites and tall, old trees are rare, perhaps because they were selectively logged in the past hence low species abundance.

In summary, because of recent and past population pressure, the remaining forest fragments are now small, scattered, and are becoming more and more fragmented and degraded (Bytebier 2001). Indeed, large remnants of the Forest are becoming rare, and conservation of biodiversity will only be possible if these small- and medium-sized forest remnants can be protected and restored (Farah *et al.,* 2017).

6.0 RECOMMENDATIONS

This study recommends analysis of more edge related parameters and provides 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 their data may be necessary include mean rate of tree-species turnover and the overall rate of change in tree-community composition.

The observed trend in regression curves as species richness estimator, which provides increasing species richness estimates may be not so accurate considering other factors such as different disturbance levels. This observation may basically informs us that the sample size used was not enough to capture all the species in the forest habitats, therefore more plots is recommended for future inventories in the habitats.

The study recommends regular updates on data regarding continued forest fragmentation and reduction of edge length to enable more rapid and adaptive response to deforestation threats.

The further recommends research to study micro - environmental factors such as light availability, air and soil temperature, humidity, and nutrients along the edge-interior gradient in every fragment in order to determine their influence on tree species richness, composition, and structure. The study also 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.

Acknowledgement

We are thankful to the Maseno University School of Environment and Earth Sciences (SEES) for the provision of resources. We thank Kakamega Forest Department for provision of secondary information and the permission to access the forest and providing technical and transport logistics to and from the study sites together with Mr.Wandabwa and the group of enumerators who made it possible to collect data.

Competing interests

Authors have declared that no competing interests exist.

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