International Journal of Humanity and Social Sciences

(IJHSS)

The Relationship between the Edge Density of the Forest Fragments and the Tree Species Richness in the Detached Fragments of Kakamega Forest.

CARI Journals

International Journal of Humanity and Social Sciences
ISSN: 3005-5407 (Online)
Vol.2, Issue No.2, pp. 28 – 47 2024
www.carijournals.org

The Relationship between the Edge Density of the Forest Fragments and the Tree Species Richness in the Detached Fragments of Kakamega Forest.

[1*] Emma Anyango, [2] Prof. Boniface O. Oindo (Phd), [3] Joan Namasaka,
[4] Catherine Nyongesa, [5] Grace Onoka.
School of Arts and Social Sciences
Department of Geography and Natural Resources Management
Maseno University.

Accepted: 15th Feb 2024 Received in Revised Form: 7th Mar 2024 Published: 22nd Mar 2024

Abstract

Purpose: The theoretical approach guiding this study was based on the Island Biogeography Theory. The purpose of this study was to assess the influence of the edge density of the forest fragments on tree species richness.

Methodology: 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.

Findings: The findings show 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 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.

Unique Contributor to Theory, Policy and Practice: 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.

Keywords: *Fragmentation, Edge Density, Fragments, Tree Species Richness, Tree Species Relative Abundance*

1.1 INTRODUCTION

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.

2.0 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 (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 shorter rains 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).

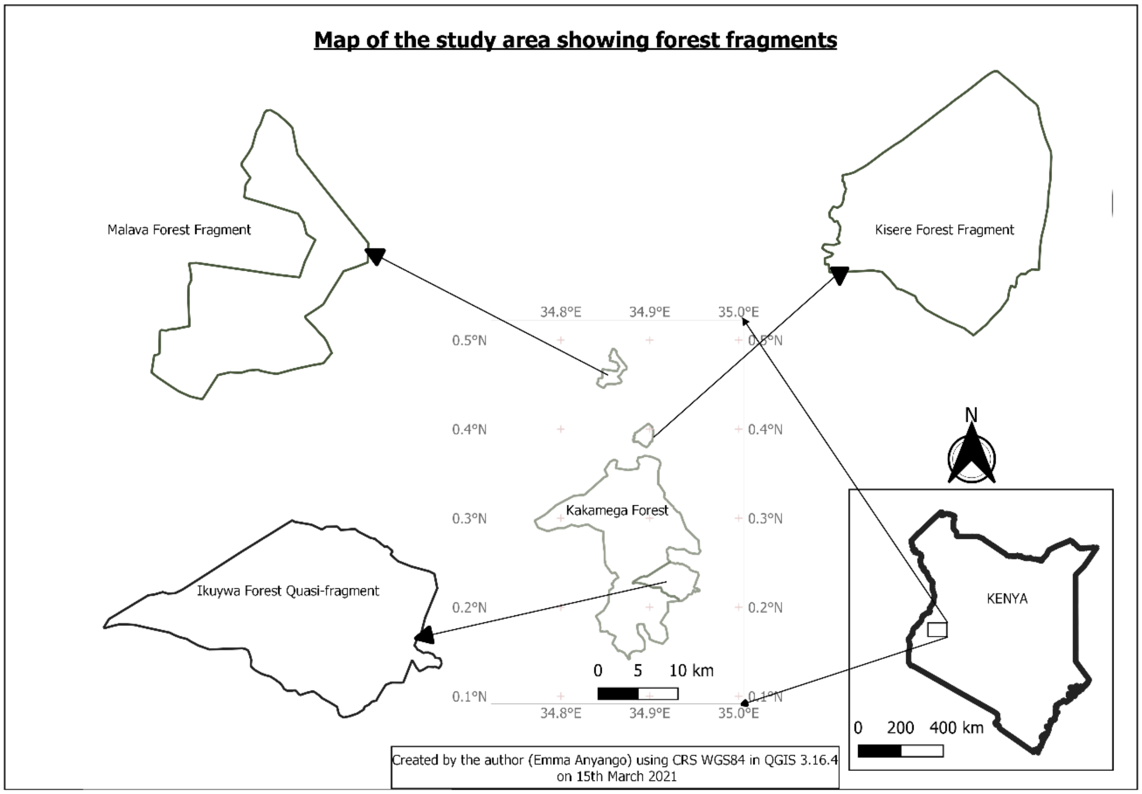


Figure 3.1 Map of Kakamega Forest showing the three fragments (Ikuywa- quasi-fragment, Malava and Kisere)

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.

STUDY SITE

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).

FIELD 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).

DATA COLLECTION

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.

International Journal of Humanity and Social Sciences
ISSN: 3005-5407 (Online)
Vol.2, Issue No.2, pp. 28 – 47 2024
www.carijournals.org

Measures of 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.

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

International Journal of Humanity and Social Sciences
ISSN: 3005-5407 (Online)
Vol.2, Issue No.2, pp. 28 – 47 2024
www.carijournals.org

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

International Journal of Humanity and Social Sciences
ISSN: 3005-5407 (Online)
Vol.2, Issue No.2, pp. 28 – 47 2024
www.carijournals.org

SUMMARY OF RESIDUAL PLOTS

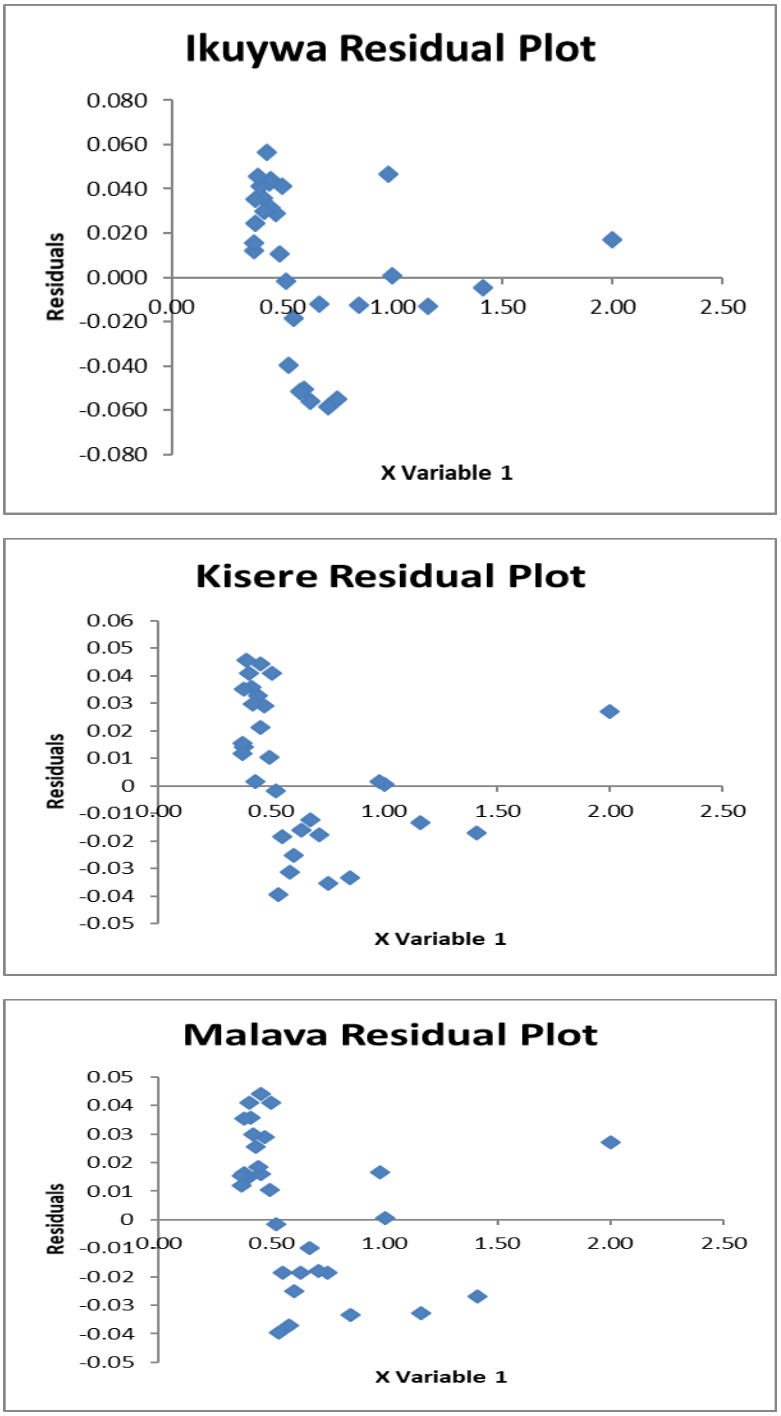


Figure 4.1 residual plots showing results for the three fragments- Ikuywa, Malava and Kisere.

DATA ANAYSIS AND RESULTS

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 scatter plots were used to present the results at significance level, $p \leq 0.05$.

3.0 RESULTS

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).

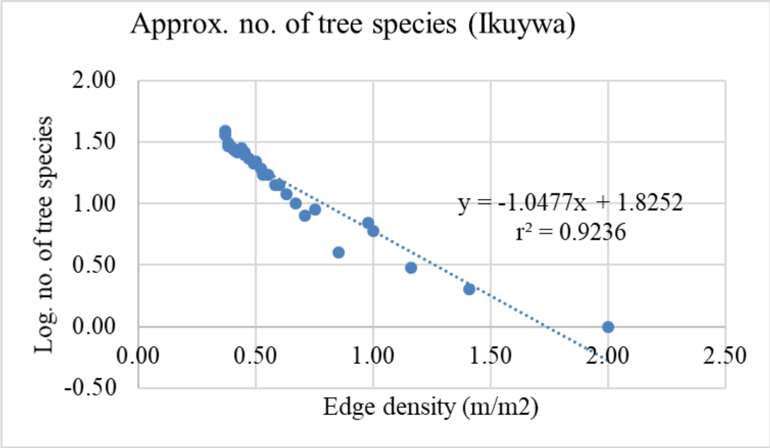


Figure 1: The scatter plot showing log-linear regression result on the influence of edge density on Tree species richness in Ikuywa forest fragment.

Figure 1 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($y=-1.0246x+1.6519$).

International Journal of Humanity and Social Sciences
ISSN: 3005-5407 (Online)
Vol.2, Issue No.2, pp. 28 – 47 2024
www.carijournals.org

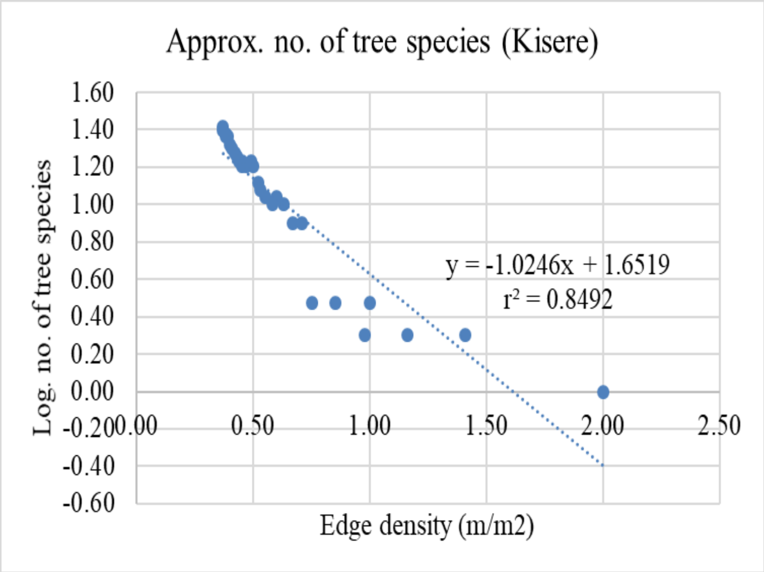
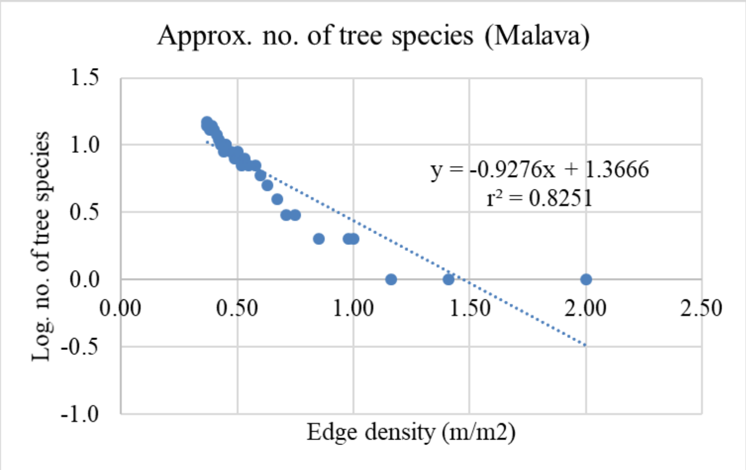


Figure 2: The scatter plot showing simple linear regression result on the influence of edge density on Tree species richness in Kisere forest fragment

Figure 2 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).



International Journal of Humanity and Social Sciences
ISSN: 3005-5407 (Online)
Vol.2, Issue No.2, pp. 28 – 47 2024

Figure 3: The scatter plot showing simple linear regression result on the influence of edge density on Tree species richness in Malava forest fragment.

Figure 3 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).

4.0 DISCUSSION

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.

5.0 CONCLUSION

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

For us to conserve more tree species richness and tree species abundance in the forest we need to maintain minimum 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.

6.0 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.

Competing interests

Authors have declared that no competing interests exist.

REFERENCES

1. De Laender, F., Rohr, J.R. Ashauer, R.et al (2016) Re- introducing environmental change drivers in biodiversity- ecosystem functioning research trends in Ecology and Evolution, **31**,905-915.
2. Driscoll, D. A., Banks, S. C., Barton, P. S., Lindenmayer, D. B., & Smith, A. L. (2013). Conceptual domain of the matrix in fragmented landscapes. Trends in Ecology and Evolution, **28**(10), 605–613. https://doi. org/10.1016/j.tree.2013.06.010.
3. Echeverría, C., Coomes, D., Salas, J., Rey-Benayas, J. M., Lara, A. & Newton, A. (2006). Rapid fragmentation and deforestation of Chilean Temperate Forests. *Biological Conservation*, **130**, 481-494.

4. Echeverría, C., Newton, A.C., Lara, A., Benayas, J.M.R., Coomes, D.A. (2007): Impacts of forest fragmentation on species composition and forest structure in the temperate landscape of southern Chile. Global Ecology and Biogeography **16**, 426-439.

5. Ewers, R.M. and Didham, R.K. (2006a): Confounding factors in the detection of species responses to habitat fragmentation. Biological Review **81**:117–142.

6. Ewers, R.M. and Didham, R.K (2006b): Continuous response functions for quantifying the strength of edge effects. Journal of Applied Ecology **43:**527–536.

7. Fahrig, L., (2003): Effects of habitat fragmentation on biodiversity. Annual review of ecology, evolution, and systematics, 487-515.

8. Fahrig L. (2017). Ecological responses to habitat fragmentation per se. Annual Review of Ecology, Evolution, and Systematics, **48**, 1–23.

9. Fahrig, L., V. Arroyo-Rodríguez, J. R. Bennett, V. Boucher-Lalonde, E. Cazetta, D. J. Currie, F. Eigenbrod, A. T. Ford, S. P. Harrison, J. A. G. Jaeger, N. Koper, A. E. Martin, J.-L. Martin, J. P. Metzger, P. Morrison, J. R. Rhodes, D. A. Saunders, D. Simberloff, A. C. Smith, L. Tischendorf, M. Vellend, and J. I. Watling. (2019). Is habitat fragmentation bad for biodiversity? *Biological Conservation***230**:179-186.

10. Fischer, E. (2004): Influence of anthropogenic and natural fragmentation on diversity of flora and vegetation in montane rainforests in East Africa, in: BIOTA East Africa, Final report phase **I**: 2001 – 2004

11. Fletcher, R. J., Didham, R. K., Banks-Leite, C., Barlow, J., Ewers, R. M., Rosindell, J. and Haddad, N. M. (2018). Is habitat fragmentation good for biodiversity? Biological Conservation, **226**, 9–15. https://doi. org/10.1016/j.biocon.2018.07.022.

12. Freund, W. (2005): Effects of fragmentation and degradation of an afrotropical rain forest on the diversity structure of leaf beetle communities (Coleoptera, Chrysomelidae), Ph.D. thesis, University of Bonn, Germany.

13. Geldenhuys CJ (1997) Native forest regeneration in pine and eucalypt plantations in Northern Province, South Africa; For Ecol Manage **99**:101–115

14.Gould, W., (2000): Remote sensing of vegetation, plant species richness, and regional biodiversity hotspots. Ecological Applications **10**, 1861-1870.

15. Haddad, N.M. *et al*., (2015). Habitat fragmentation and its lasting impact on earths' ecosystems. Sci. Adv.**1**, e1500052.

16. Harcourt, A. and D. Doherty., (2005). Species-area relationships of primates in tropical forest fragments: a global analysis. J Applied Ecology **42**:630-637.

17. Jan.M.Baert (2017) Non-linear partitioning of biodiversity effects on ecosystem functioning.Ecology,vol.8, no.**10**,pp. 204-210

18. Keenan, R.J., Reams, G.A., Achard, F., de Freitas, J.V., Grainger, A., Lindquist, E. (2015). Dynamics of global forest area: results from the FAO Global Forest Resources Assessment 2015. For. Ecol. Manage. **352**, 9–20.

19. KNBS (2019). 2019 Kenya Population and Housing Census: Volume 1A Population Distribution by Administrative Units; Nairobi. Kenya National Bureau of Statistics, Ministry of Planning & National Development, Kenya.

20. Kokwaro, J.O. (1988) Conservation status of the Kakamega Forest in Kenya: the easternmost relic of the equatorial rainforests of Africa. Monogr. Syst. Bot. Misouri Bot. Garden**25**:471-489.

21. Laurance, L. V. Ferreira, J. M. Rankin-deMerona, and S. G. Laurance, (1998). "Rain forest fragmentation and the dynamics ofAmazonian tree communities," *Ecology*, vol. 79, no. **6**, pp. 2032– 2040,

22. Laurance, W.F (2000): Do edge effects occur over large spatial scales? Trends Ecol Evol **15**:134–135.

23. Laurance WF, Nascimento HEM, Laurance SG, Andrade AC, Fearnside PM, Ribeiro JEL, Capretz RL (2006) Rain forest fragmentation and the proliferation of successional trees. Ecology **87**:469–482

24. Laurance, W., (2007): Ecosystem decay of Amazonian forest fragments: implications for conservation. In: Tscharntke, T., Leuschner, C., Zeller, M., Guhardja, E., Bidin, A. (Eds.), Stability of Tropical Rainforest Margins. Springer Berlin Heidelberg, pp**.** **9**-35.

25. Laurance W.F, Nascimento HEM, Laurance SG, Andrade A, Ewers RM, Harms KE, Luizao RCC, Ribeiro JE (2007): Habitat fragmentation, variable edge effects, and the landscape–divergence hypothesis. PLoS ONE **2**:e1017.

26. Laurance WF, Camargo JLC, Luizao RCC, Laurance SG, Pimm SL, Bruna EM, Stouffer PC, Williamson GB, Benı´tez- Malvido J, Vasconcelos HL, Van Houtan KS, Zartman CE, Boyle SA, Didham RK, Andrade AC, Lovejoy TE (2011). The fate of Amazonian forest fragments: a 32-year investigation. Biol Conserv **144**:56–67

27. Lung, T., Schaab, G. (2006). Assessing fragmentation and disturbance of west Kenyan rainforests by means of remotely sensed time series data and landscape metrics. African Journal of Ecology **44**, 491–506.

28. Mammides, C. Cords, M., Peters, M.K., (2009). Effects of habitat disturbance and food supply on population densities of three primate species in the Kakamega Forest, Kenya. African Journal of Ecology **47**, 87-96.

29. May F, Rosenbaum B, Schurr FM, Chase JM. (2019). The geometry of habitat fragmentation: Effects of species distribution patterns on extinction risk due to habitat conversion. Ecol Evol**.** **9**, 2775–2790.

30 .Mitchell, N. (2004): The exploitation and disturbance history of Kakamega Forest, Western Kenya, BIOTA East Report No. **1**, Bielefelder Ökologische Beiträge, Band 20, Bleher, B. &Dalitz, H. (eds.).

31. Mumbi, C., Marchant, R., Hooghiemstra, H., Wooller, M., (2008): Late Quaternary vegetation reconstruction from the Eastern Arc Mountains, Tanzania. Quaternary Research **69**, 326-341.

32. Nackoney, J., Molinario, G. (2014). Impacts of civil conflict on primary forest habitat in Nothern Democratic Republic of the Congo, 1990-2010. Biol. Conserv. **170**,321-328.

33. Omoro, L.M.A., Pellikka, P.K.E., Rogers, P.C., 2010. Tree species diversity, richness, and similarity between exotic and indigenous forests in the cloud forests of Eastern Arc Mountains, Taita Hills, Kenya. J. For. Res. **21** (3), 255–264.

34. Pardini, R., Marquez de Souza, S., Braga-Neto, R. & Metzger, J. P. (2005) The role of Forest structure, fragments size and corridors in maintaining small mammal abundance and diversity in an Atlantic forest landscape. Biological Conservation, **124**, 253-266.

35. Rashid, I., Romshoo, S., Vijayalakshmi, T., (2013): Geospatial modelling approach for identifying disturbance regimes and biodiversity rich areas in North Western Himalayas, India. Biodivers Conserv, 1-30.

36. Ribeiro, J.C.T., Nunes-Freitas A.F., Fidalgo, E.C.C., Uzêda., M.C (2019).: Forest fragmentation and impacts of intensive agriculture: Responses from different tree functional groups. PLoe0212725.https://doi.org/10.1371/journal.pone.0212725

37. Regolin, A. L., Ribeiro, M. C., Martello, F., Melo, G. L., Sponchiado, J., de Campanha, L. S., Caceres, N. C. (2020). Data from: Spatial heterogeneity and habitat configuration overcome habitat composition influences on alpha and beta mammal diversity. Dryad Digital Repository, *https://doi.org/10.5061/dryad.9s4mw6mcd*.

38. Reinmann, A.B., Hutyra, L.R. (2017). Edge effects enhance carbon uptake and its vulnerability to climate change in temperate broadleaf forests. PNAS **114** (1), 107–112.

39. Republic of Kenya, (2013). The First Taita Taveta County Integrated Development Plan 2013-2017. Wundanyi, Kenya, **263**p.

40.Resende CL, Scarano FR, Assad ED, Joly CA, Metzger JP, Strassburg BBN, *et al*. (2018).From hotspot to hotspot: An opportunity for the Brazilian Atlantic Forest. Perspect Ecol Conserv. **16**, 208–214.

41. Saikia, A., Hazarika, R., Sahariah, D., (2013): Land-use/land-cover change and fragmentation in the Nameri Tiger Reserve, India. Geografisk Tidsskrift-Danish Journal of Geography **113**, 1-10.

42.Shirima, D.D., Munishi, P.K.T., Lewis, S.L., Burgess, N.D., Marshall, A.R., Balmford, A., Swetnam, R.D., Zahabu, E.M., (2011): Carbon storage, structure and composition of Miombo woodlands in Tanzania’s Eastern Arc Mountains. African Journal of Ecology **49**, 332-342.

43. Spasojevic, M.J, Harline K, Stein C, Mangan S.A, Myers J.A. (2019). Landscape context mediates the relationship between plant functional traits and decomposition. **438**, 377–391.

44. Wekesa, C., Leley, N., Maranga, E., Kirui, B., Muturi, G., Mbuvi, M., Chikamai, B. (2016). Effects of forest disturbance on vegetation structure and aboveground carbon in three isolated forest patches of Taita Hills. Open J. Forest**. 6**, 142–161.

45. Wekesa, C., Maranga, E.K., Kirui, B.K., Muturi, G.M., Gathara, M. (2018). Interactions between native tree species and environmental variables along forest edge-interior gradient in fragmented forest patches of Taita Hills, Kenya. For. Ecol. Manage. **409**, 789–798.