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The impacts of human activities on tree species richness and diversity in Kakamega Forest, Western Kenya

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Tropical rain forests are species rich ecosystems that are being depleted at very high rates through human encroachment. Kakamega forest is one of the heavily fragmented and disturbed tropical rain forests due to the high human population densities that surround the forest. The purpose of this study was to investigate the impact of human activities on tree species richness, diversity, canopy surface area and seedling density in Kakamega forest. The study was conducted in four sites within Kakamega forest: Handidi, Lukusi, Isecheno and KWS as a control site. The data was collected between June and December, 2011. Vegetation sampling was done in randomly selected sites within each study site using belt transects and quadrants. Within each transect, the number of tree species and seedlings were counted and the intensity of human disturbances assessed. Vegetation data were analyzed by two-way analysis of variance. Correlation and regression analysis were done between dependent and independent variables. Simpson's diversity index was used to calculate tree species diversity in each study site. There were significant differences between species diversity, richness, canopy surface area and seedling density with distance from the forest edge. The study showed that there was negative impact of human activities (logging, grazing, debarking and charcoal burning) on tree species in the three study sites as compared to the control site. The results revealed a negative influence on the forest by human activities. The study recommended strict enforcement of the existing conservation laws concerning forest use by the local communities as well as formulating more integrated approach to the needs of local communities for natural resource use.

Key words: Canopy area, seedlings, debarking, logging, disturbances.

INTRODUCTION

Tropical forests are species rich ecosystems that are being depleted at very high rates (Myers, 2000). As a result, many initiatives of conserving tropical forests and enhancing the economic wellbeing for communities living around these forests have been put in place to reduce the dependence on them. In Kenya, the most documen-ted initiatives are around protected forest areas (PFAs). These initiatives aim at reducing pressure on the protected areas by providing alternative livelihoods to the surrounding local communities (Miller, 1982). Tropical rainforests are mainly exploited by man for economic, political and social reasons (Soper, 1995). Poor farmers trying to make a living on marginal lands cause a significant portion of deforestation (Myers, 1988). In addition to subsistence agriculture, activities like logging, clearing for cattle pasture and commercial agriculture contribute significantly to deforestation on a global scale (Anderson, 1990). Agricultural fires used in land clearing are increasingly spreading outside cultivated areas and into the degraded forest regions.

Studies have shown that countries with significant rainforest cover generally have the poorest local people living in and around forests, who depend almost entirely on the forest resources (Myers, 1992). Their poverty costs their country and the world through loss of biodiversity and ecosystem services like erosion prevention, flood control, water and fisheries protection (Myers, 1992). This scenario applies to Kakamega Forest in western Kenya. Majority of families living around the Kakamega Forest are poor and rely heavily on forest resources to earn their living (Nambiro, 2000). Most families own very small farm plots for growing household staple foods like maize, beans, cassava and bananas.

The primary contemporary drivers of tropical forest biodiversity loss include direct effects of human activities such as habitat destruction and fragmentation (land use change), invasive species and over-exploitation as well as indirect effects of human activities such as climate change (Millennium Ecosystems Assessment, 2005). Over- exploitation of a particular species can result in species or group of species driven to local extinction or even global extinction. The most well known example of overexploitation of tropical forest species involves large mammals for bush meat (Miller Gulland et al., 2003) and tropical hardwoods for timber (Asner et al., 2005). The over exploitation of large mammals has consequences for the structure and species composition of tropical plant communities by affecting their interactions with seed predators, seed dispersers, herbivores and browsers (Wright, 2005).

Kakamega forest is one of the heavily fragmented and disturbed forests (Kokwaro, 1988) due to the high human population densities that surrounds the forest most of which is involved in small-scale agriculture. Anthropogenic disturbances like selective logging, grazing, debarking and charcoal burning can reduce the diversity of plant and animal species, thereby reducing seedling species richness and hence the forest ecosystem in the long-term. This is because the germination and establishment of seedlings of many species in rain forests depends on the events on the forest floor below the canopy (Chazdon, 2008). The purpose of this study was to quantitatively assess and determine how human activities are affecting plant species diversity, richness, canopy area and seedling density with reference to Kakamega forest; specifically to (i) determine the effect of logging, debarking, grazing and charcoal burning on the tree species diversity and richness between study sites with distance from forest edge, (ii) determine the effect of logging, debarking, grazing and charcoal burning on the tree canopy surface area and seedlings density between study sites with distance from forest edge and (iii) assess the relationship between tree species diversity and canopy area.

MATERIALS AND METHODS

Study area

Kakamega forest is located in Kakamega East District in Kakamega County, Western Kenya. It lies between longitudes 34° 40’ and 34° 57’ 30” East and 0° 15” South. The entire population of Kakamega East District was projected at 159475 by 2009, according to 2009 population census and a population density of 358 persons per km square (Mars Group Kenya, 2009). The forest has a varied topography with altitudes ranging from 1250 to 2000 m above sea level (Tsingalia, 1988). 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 begin in July and end in October with a peak in August. Annual rainfall averages between 1500-2000 mm (Tsingalia, 1988). The vegetation of the forest includes closed indigenous forest, grasslands and open forest. The area surrounding the forest is densely populated and intensively used for farming (Sharp, 1993; Emerton, 1994; Nambiro, 2000). There is widespread dependence on the forest by the local people who obtain their livelihood by mainly harvesting firewood, thatch grass and medicinal plants (Emerton, 1994; Sharp, 1993; Nambiro, 2000). They also use the forest grasslands as traditional grazing grounds. There are incidences of illegal logging, charcoal burning and hunting of small mammals in the forest (Kokwaro, 1988). The study sites selected within this forest include Handidi, Lukusi, Isecheno and KWS. Three of these sites, Handidi, Lukusi and Isecheno were chosen based on the fact that some human activities are allowed in these sites while KWS site was used as a control because it is well protected from any human disturbance.

Identification of human activities

To identify the main human activities that take place in Kakamega forest, questionnaires were administered to 300 households within 5 km stretch from the forest. Households were randomly selected from the community around the forest. A population of 2000 persons was obtained from the households from which the respondents were picked.

Measurement of trees species richness and diversity

Belt transects were used in vegetation sampling in randomly

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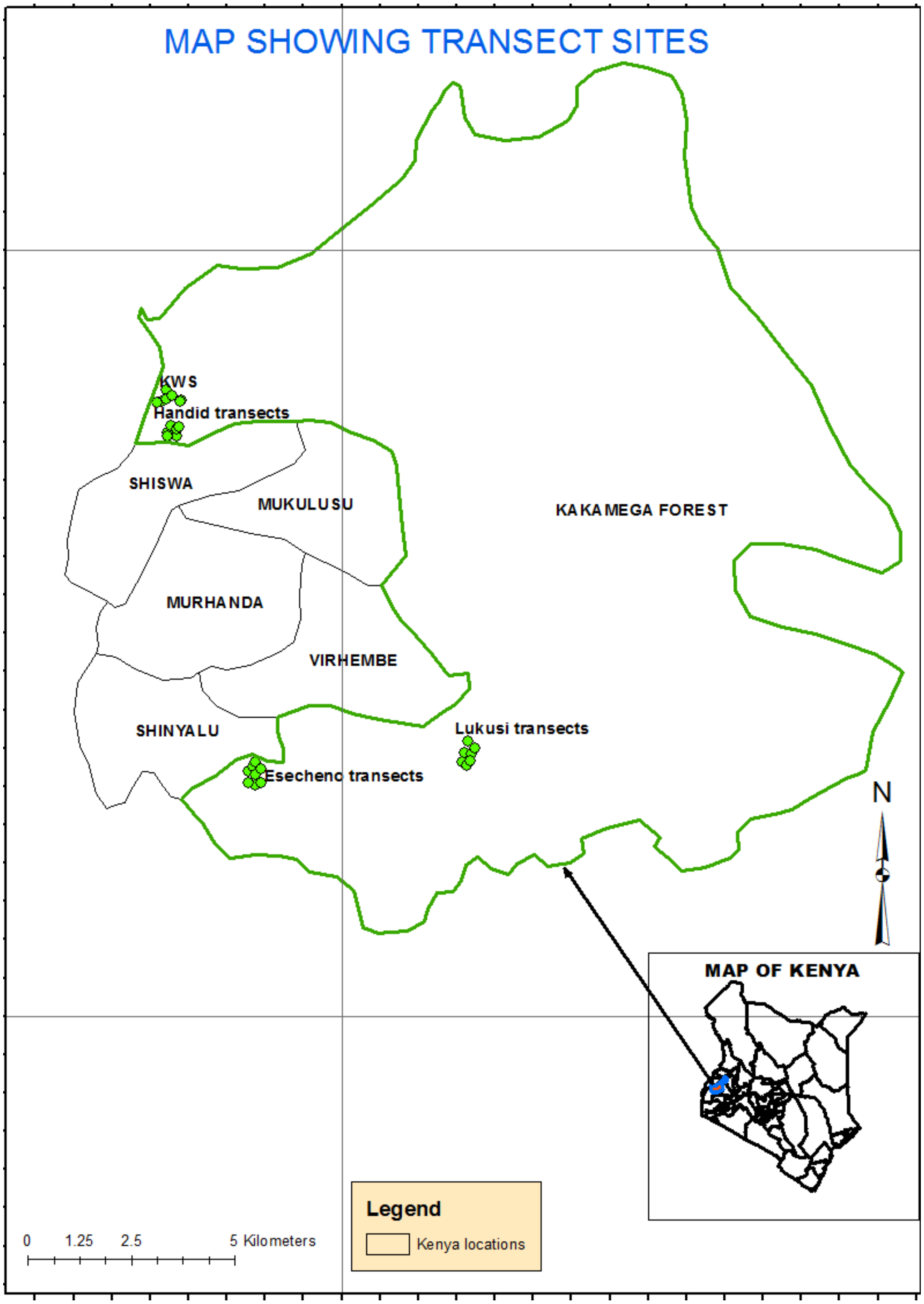

Figure 1. Map of Kakamega forest showing study sites (Source: BIOTA Africa).

selected regions within the forest, in the four study sites shown in Figure 1. The regions were chosen based on their location in the forest, that is, they were adjacent to the NTZ making it easy to assess the impact of human activities on the forest species diversity and species richness. The transects were laid from the edge of the forest adjacent to the tea zone to the interior of the forest (Figure 1). Two belts transects measuring 2 km long and 10 m wide were established in each of the four study sites using a global positioning system (GPS) and a compass. Another transect was laid at Kakamega National Reserve at Buyangu (KWS site) that acted as a control, since the area is effectively managed by Kenya Wildlife Service (KWS) as a protected area. Five quadrates of 10 by 10 m were set up along each transect at 500 m interval. Within each quadrant/plot, tree species richness was assessed where the

Table 1. Pearson's correlation coefficient between dependent variables and human activities (marked correlations * are significant at p<0.05. N=35).

Variable	Logging	Grazing	Debarking	Charcoal burning
Species richness	R= -0.2872	R= -0.0372	R= -0.283	R= -0.378
	P= 0.028*	P= 0.099	P= 0.025*	P= 0.094
Species diversity	R= -0.280	R= -0.244	R=-0.250	R=-237
	P= 0.0102	P= 0.157	P=0.147	P= 0.169
No. of seedling	R=-0.504	R= -0.412	R=-0.618	R= -0.422
	P= 0.002*	P= 0.014*	P=0.000*	P= 0.012*
Canopy volume	R= -0.49	R= -0.471	R=-0.545	R= -0.404
	p= 0.002*	p= 0.004*	p=0.001*	p= 0.016*

different tree species were identified, counted and noted. This was used to assess the species diversity of trees within each quadrant. The Shannon diversity index was used to calculate the species diversity of the vegetation samples in the different plots (Shannon and Weiner, 1948).

Measurement of seedling density and disturbance

Within each transect, canopy area and numbers of seedlings were identified. Canopy diameter was obtained using a tape measure on the ground by taking the longest diameter of tree canopy on the ground. The seedlings in each quadrant were also identified on the basis of their stem diameters and counted. All plant tree species with a diameter of 10 cm and below are regarded as seedlings hence counted and recorded. Incidences of forest disturbance were also assessed within each transect. Logging was assessed by noting the number of tree stumps within each plot along the transect and expressing it as a percentage of the total number of mature trees in each transect. Debarking was assessed by noting the number of trees debarked within each plot along the transect and expressed as a percentage. Grazing was assessed by number of grazed sites within each plot along the transect and expressed as a percentage while charcoal burning was assessed by noting the number of charcoal burnt sites within each plot along the transect and expressing it as a percentage.

Data analysis

Quantitative data from vegetation sampling was analyzed by two-way analysis of variance (ANOVA) to test any significant difference in the dependent variables (species diversity, richness, number of seedlings and canopy area) with distances from the forest edge and between sites ($p \leq 0.05$). Correlation analysis was also done between dependent (species diversity, richness and seedling density) and independent variable (canopy surface area) to determine the factors responsible for the patterns in species diversity, richness, seedling density and canopy surface area in the study sites.

RESULTS

Correlation between human activities and the dependent variables

The human activities that were identified in the four study sites included logging, debarking, grazing and charcoal burning. All the dependent variables (logging, grazing, debarking and charcoal burning) were negatively correlated with human activities. They also show that species richness was significantly affected by logging and debarking but not by grazing and charcoal burning, number of seedlings and canopy surface area were significantly influenced by all the human activities while there was only significant different in species diversity with logging with P-value less than 0.05 but not with the other human disturbances (Table 1).

Variation of dependent variables with distance from edge of forest and between study sites

The distance from forest edge affected the dependent variables significantly and the variables were also significantly different between the study sites. There was a significant difference in canopy surface area at the forest edge at 100, 500 and 1000 m, but no significant difference at 1500 and 2000 m in the interior of the forest. The number of seedlings significantly increased with distance from forest edge; and was also significantly different at each distance as shown in Table 2.

Regression analysis between seedling density, species richness and diversity and canopy area

There were significant relationships between the different dependent variables and distance from the forest edge (Table 3). Of greater significance was the effect of distance on species diversity, canopy surface area and seedling density, all of which were highly significant. This suggests that forest disturbance, most likely from the local people decrease significantly with distance from the forest edge. Seedling density, canopy surface area and species diversity can be predicted fairly well by distance from the forest edge. Regression analysis between canopy area and seedling density, species richness and diversity reveals a linear regression between the predictor

Table 2. Variation of dependent variables with distance from forest edge and between study sites.

Variable	Interaction	DF	ANOVA SS	Mean sq.	F-value	P-value
	Site	3	17301.17	5767.06	70.76	< 0.0001
Species richness	Distance	4	7912.88	1978.22	24.27	< 0.0001
	Site*Distance	12	4679.84	389.99	4.79	0.0028
	Site	3	0.39	0.13	18.83	< 0.0001
Species Diversity	Distance	4	0.15	0.04	5.24	0.0076
	Site*Distance	12	0.086	0.07	1.13	0.4700
	Site	3	9282.51	3094.2	46.07	< 0.0001
Seedling density	Distance	4	3970.32	992.58	14.78	0.0001
	Site*Distance	12	860.24	7199	1.07	0.4454
	Site	3	12848.51	4282.84	39.56	< 0.0001
Canopy area	Distance	4	5053.84	1263 46	11.67	0.0002
	Site*Distance	12	81.23	6.77	0.06	1.0000

Table 3. Regression of dependent variables with distance from forest edge ($p \leq 0.05$).

Interaction	N	P- Value	R^2	F- Value
Sp. Richness vs. distance	35	0.0003	0.56	$F_{(4,30)} = 10.033$
Sp. diversity vs. distance	35	0.0001	0.68	$F_{(4,30)} = 30.135$
Canopy area vs. distance	35	0.0001	0.81	$F_{(4,30)} = 40.744$
Seedling density vs. distance	35	0.0001	0.83	$F_{(4,30)} = 38.622$

variable (canopy surface area) and the dependent variables (seedling density, species richness and diversity). The regression equation between seedling and canopy area was $y = 44\ln(x) - 107.5$, with R^2 value of 0.72. The regression equation between species diversity and canopy surface area was $y = 0.122\ln(x) + 0.234$ with R^2 of 0.32 while regression equation between species richness and canopy surface area was $y = 38.85\ln(x) - 92.84$ with R^2 of 0.75. This clearly shows that canopy surface area had a great influence on species richness and seedling density in Kakamega forest.

Variations of canopy area, seedling density, species richness and diversity in different study sites

The dependent variables were compared in the different study sites. Table 4 shows ANOVA results that compare the means of dependent variables among the four study sites. Species richness was significantly different between sites being highest at KWS site and lowest at Lukusi. There was no significant difference in species richness between Isecheno and Handidi. Species diversity was significantly different between sites being highest in KWS followed by Handidi. There was no significant difference in species diversity between Lukusi and Isecheno. Seedling density and canopy area were higher in KWS site and lowest in Lukusi. There was no significant difference in seedling density between Handidi and Lukusi while canopy surface area did not differ significantly between Handidi, Lukusi and Isecheno.

From the results, KWS had a higher mean in the dependent variables, that is, species richness, diversity, canopy area and seedling seedling density in all the four study sites. This could be attributed to the fact that some human activities take place in the other three regions as opposed to the KWS site, which is under strict management that does not allow any human activity in the reserve. A significant difference in species diversity was observed in the different study sites, with KWS having the highest species diversity. This is attributed to the fact that it is highly protected from any human disturbance. Canopy area was significantly higher in KWS but did not differ significantly in Lukusi, Handidi and Isecheno. Species richness differed significantly between Lukusi and KWS but did not differ significantly between Handidi and Isecheno. The number of seedlings did not differ significantly between Lukusi, Handidi and Isecheno, but was significantly higher in KWS (control) site.

DISCUSSION

Logging had a negative correlation with species richness, seedling density and canopy surface area as these were found to be low in areas where logging had occurred.

Table 4. Mean values of dependent variables in the four study sites (means of same letters are not significantly different at 95% confidence limit).

Site	Specie richness	Specie diversity	Seedling density	Canopy area
Handidi	52.1b	0.73b	28.8c	46.4b
Lukusi	22.1c	0.61c	28.3c	43.7b
Isecheno	47.5b	0.56c	39.8b	47.1b
KWS site	86.7a	0.85a	70.9a	93.4a
Mean	52.2	0.68	39.8	57.65
LCD (<0.05)	9.3	0.09	8.4	0.42
CV	18.2	12.2	20.7	18.8

LCD = Least common denominator; CV = coefficient of variation.

This is attributed to large open gaps within the forest that create a dry climate which interferes with seedling density and seedling establishment. This reduces species richness and canopy area in the long run. Logging leads to total removal of some mature tree species from the forests, which are important in providing cool climate under the canopy for seedling germination. The tree species exploited for logging in Kakamega forest included the hardwoods like *Olea carpensis*, *Prunus africanus* and *Celtis africana.* Logging also causes habitat destruction and a general decline in forest species abundance and diversity (Lawton et al., 1998). Moreover, Asner (2005) noted that selective logging reduces plant species diversity thereby reducing seedling species richness and hence forest seedling density in the long-term. Deforestation and logging have the greatest impact on biodiversity in tropical forests (Sala et al., 2000). Further, the new habitat that results from logging determines the biodiversity. For instance, secondary forest regenerating after the natural forest has been cleared may never reach the same species and composition as the primary forest (Chazdon, 2008)

Debarking correlated negatively with canopy surface area and seedling density. It occurred in three of the four study sites: Lukusi, Handidi and Isecheno but not KWS site. The three sites are not effectively protected from human activities and hence paving way for detrimental activities like debarking, logging, charcoal burning and grazing. KWS site is under strict surveillance and does not allow any human activity from taking place within the forest. Debarking was mainly practiced by herbalists from the community around the forest .The tree species exploited for medicinal purposes in Kakamega forest include *P. africana* and *Gravillea* ssp. and *Mondia whytei.* This leads to death of mature trees with big canopies that provide a cool climate on the floor necessary for seedling density. It also leads to slow growth rate in trees since removal of the bark interferes with translocation of manufactured food. To counter this, the Kenya Forest Service has developed a conservation strategy that provides herbalists with seeds of the medicinal trees to grow on their farms. This is an ongoing project that is yet to take root and is beset by the rising demand of herbal medicines and the slow growth rate of indigenous trees (KIFCON, 1994).

Grazing had a negative impact on seedling density. Grazing was noted in three study sites, Handidi, Lukusi and Isecheno where some extractive use was allowed in the forest hence interfered with seedling density. This was done illegally within the forest and penalties were given to the offenders. However, the ineffective surveillance of the forest and inadequate resources for management pave way for destructive activities. KWS site does not allow human activities from taking place and offenders face hash penalties. The grazing animals also stumble on young seedlings making them unable to establish themselves (Tsingalia, 2009). Even limited grazing can cause significant shifts in vegetation and damage to the soil crusts. Kleiner and Harper (1997) found that seven plant species that were common in the un-grazed area were absent or insignificant in comparable grazed sections of Canyon lands National Park. This was attributed in part to changes to cryptobiotic soil crust which decreased from 38% cover in the un-grazed area to 5% in the lightly grazed area.

Charcoal burning had a negative correlation with tree species richness, diversity, canopy surface area and seedling density and significantly affected seedling density and canopy area. Charcoal burning is detrimental to both species diversity and richness due to overexploitation of certain species for charcoal production. It also interferes with seedling density as mature trees are eliminated resulting to poor dispersal of seeds. This also interfered with canopy provided by mature trees. Tree species exploited for charcoal burning in Kakamega forest included hard woods such as *C. africana* and *P. africana*. These are known to produce finest charcoal. This was noted to be taking place in the interior remote areas inside the forest in three study sites, that is, Handidi, Lukusi and Isecheno, where the local community does not adhere to the rules and regulations. This kind of disturbance was noted to be most detrimental especially in the sites where extractive use was allowed.

There was a positive correlation between all the dependent variables with distance from the forest edge. This shows that there is low species diversity, richness, canopy surface area and number of seedlings at the forest edge and increases towards the interior. This is because forest edges have greater impacts of human activities such as logging and grazing due to easy accessibility as compared to the interior areas. At the forest edge there are microclimate changes (Harper, 2005). Edge areas in forest are typically warmer, more exposed to light and wind and are drier than the interior areas. Gradients of these microclimate conditions extend into the interior approximately 15 to 75 m (Kapos, 1989; Lawrence and Bierregaad, 1997). Microclimate changes along forest edges often have secondary effects such as altering vegetation structure and eventually plant and animal communities (Matlack, 1993). Increased wind along the edge physically damages trees causing stunted growth and tree falls (Essen, 1994). Furthermore, wind tends to dry out the soil, decrease air humidity and increase water loss from leaf surfaces creating a drier microclimate. Increased light along the edges affects both the rate and type of plant growth, favoring fast growing light loving species at the expense of slower growing shade loving ones (Harper, 2005). Edges are also more susceptible to invasion by generalized or 'weedy' species that are better adapted to handle disturbance and new microclimate, for example lianas, vines, creepers and exotic weeds.

Species diversity, richness, number of seedlings and canopy surface area were found to be relatively high in the protected site (KWS) than in the areas where extractive use occurs (Handidi, Lukusi and Isecheno). As noted earlier, human activities have a negative impact on the species diversity, richness, canopy surface area and seedling density. KWS site does not allow any extractive use and is under strict management that does not allow any destructive human activities. There are also harsh penalties to law offenders and this keeps off people from the reserve and hence no human interference with the forest. This explains the high species diversity, richness, canopy surface area and seedling density in this site as compared to the other three sites. The indigenous forest area including grasslands/glades and open forest, is under multiple management strategies enforced by different institutions. The Forest Department manages 20,000 ha of which 11,000 ha is indigenous forest in which three of the four study sites (Handidi, Lukusi and Isecheno) occur. Some extractive forest uses such as collection of dead fuel wood, medicinal plants and thatching grass are permitted in much of the forest, but logging, debarking and charcoal burning are illegal. Cattle grazing are only allowed in the open glades. The Isecheno forest block has been established as a nature reserve by the forest department and all extractive use is forbidden in this region. However, the study established that some destructive human activities like grazing, charcoal burning and debarking take place within the forest leading to relatively low species diversity, richness, canopy surface area and seedling density as compared to KWS site. This is attributed to ineffective surveillance on the forest by the guards. Kakamega Wildlife Service (KWS) has a small area of 4,000 ha as compared to the area managed by the forest department (Isecheno, Handidi and Lukusi), that is, 20,000 ha, hence maximum surveillance on the reserve by the guards. This means all sections of the reserve is effectively guarded from any destructive human activities and hence the surrounding community cannot access the forest. This leads to a more intact forest with relatively high species diversity, richness, canopy surface area and seedling seedlings density, as compared to areas where extractive use and human disturbance occurred.

The canopy surface area greatly influenced the tree species richness and seedling density. An increase in canopy surface area would lead to an increase in the number of seedlings. Large canopies limit light penetration and may lead to a decrease in seedling density and species richness as well. Seeds in tropical forests require a cool climate at the canopy floor for germination and this can be provided by closed canopies (Whitmore, 1998). Open canopies allow too much heat to the forest floor interfering with seedling establishment, and hence dry up (Whitmore, 1998).

The human activities noted within three study sites namely, Handidi, Lukusi and Isecheno included logging, charcoal burning, debarking and grazing. There was no human disturbance noted in Kenya Wildlife Service (KWS) site at Buyangu since extractive use is forbidden in this site and harsh penalties given to offenders. In Handidi, Lukusi and Isecheno regions, some human disturbance was noted since extractive use is allowed though in a controlled manner. For instance, an interview with one of the forest guides revealed that the Forest Department office gives licenses for allowed extractive use like grazing, thatching grass collection, firewood collection and seed collection. However some illegal activities were noted within the forest areas managed by the forest department like charcoal burning, debarking and logging. This impacted negatively on the forest tree species diversity, richness, canopy surface area and seedling density. As noted earlier, these human activities reduce plant species diversity, interfere with seedling germination and establishment due to open canopies and also interfere with soil properties. The forest is generally highly degraded and fragmented and the composition of the plant communities has been greatly influenced by past commercial logging activities and other anthropogenic disturbances (Mitchel, 2004). A high abundance of middle aged individuals of *Funtumia africana* observed indicates past and recent human disturbances in the forest.

Conclusions and recommendations

The study found that the human activities (logging, debarking, grazing and charcoal burning) identified within the forest impacted negatively to the forest tree species as depicted by the relatively low tree species richness and diversity in the sites where human disturbances occurred as compared to the control site (KWS).The human activeties had a negative impact on seedling density and canopy surface area. This is evidenced by the relatively low seedling density and canopy surface area in the three study sites where human disturbances were recorded as compared to the control site (KWS). The Nyayo Tea Buffer zone around the forest did not effectively prevent the local communities from carrying out destructive activities within the forest. The national natural resource management bodies therefore should enforce strict penalties to law offenders concerning forest use by the local community. The government and other conservation stakeholders should device alternative source of livelyhood for the local community rather than rely fully on the forest resource. The government should device a more integrated approach to forest conservation. There is need for further research to look at the effect of other factors like climate change on the forest species diversity and richness.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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