Linköping University | Department of Physics, Chemistry and Biology
Type of thesis, 60 hp | Educational Program: Physics, Chemistry and Biology
Autumn and Spring term 2019/2020 | LITH-IFM-A-EX—20/3801--SE

Differences in forest structure in relation to energy-efficient cookstoves in the Kakamega forest, Kenya

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Linköping University

Date: 2020-07-10

Språk

Language

☐ Svenska/Swedish

☒ Engelska/English

☐ _______________

Rapporttyp

Report category

☐ Licentiatavhandling

☒ Examensarbete

☐ C-uppsats

☒ D-uppsats

☐ Övrig rappor

☐ ____________

ISBN

ISRN: LITH-IFM-A-EX--20/3801--SE

Serietitel och serienummer **ISSN**

Title of series, numbering ___________________________

URL för elektronisk version

Titel

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Författare

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Sammanfattning

Abstract

Tropical forests are amongst the most important ecosystems in the world. It is also the biome estimated to experience the most rapid losses of habitats in the next 50 years, mainly due to anthropogenic exploitation. The Kakamega forest, western Kenya, is important both for conservation and human livelihood and is essential for peoples' survival. The main threat to the forest's subsistence is collection of firewood used for cooking. Energy-efficient cookstoves, with almost 50 % lower demand for firewood compared to traditional 3-stone-stoves, have been installed to ease the pressure on the forest. The present study evaluates the effect of utilizing energy-efficient cookstoves, installed during the project Stoves for Life (years 2010-2019), on the forest structure of the Kakamega forest, Kenya. This was done by quantifying forest structural and compositional differences, as well as occurrence of human made damage, within the Kakamega forest. Sampling was made in 59 plot locations, with varying numbers of energy-efficient cookstoves in the surrounding area. Results indicate that the stoves 1) promote recruitment of both pioneer and climax trees and 2) increase survival of fast-growing pioneer trees, 3) ease the pressure on preferred species used as firewood and 4) preserve important structural components such as woody debris found on the forest floor. Additionally, the growth of pioneer trees is potentially creating a climate suitable for later successional species to thrive and establish, potentially leading to forest maturation. However, future comparative studies should be conducted before any statement about the stoves' effect on forest structure is made.

Nyckelord

Rainforest, energy-efficient cookstoves, forest structure, Kakamega forest, Kenya

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1. Abstract

Tropical forests are amongst the most important ecosystems in the world. It is also the biome estimated to experience the most rapid losses of habitats in the next 50 years, mainly due to anthropogenic exploitation. The Kakamega forest, western Kenya, is important both for conservation and human livelihood and is essential for peoples' survival. The main threat to the forest's subsistence is collection of firewood used for cooking. Energy-efficient cookstoves, with almost 50 % lower demand for firewood compared to traditional 3-stone-stoves, have been installed to ease the pressure on the forest. The present study evaluates the effect of utilizing energy-efficient cookstoves, installed during the project Stoves for Life (years 2010-2019), on the forest structure of the Kakamega forest, Kenya. This was done by quantifying forest structural and compositional differences, as well as occurrence of human made damage, within the Kakamega forest. Sampling was made in 59 plot locations, with varying numbers of energy-efficient cookstoves in the surrounding area. Results indicate that the stoves 1) promote recruitment of both pioneer and climax trees and 2) increase survival of fast-growing pioneer trees, 3) ease the pressure on preferred species used as firewood and 4) preserve important structural components such as woody debris found on the forest floor. Additionally, the growth of pioneer trees is potentially creating a climate suitable for later successional species to thrive and establish, potentially leading to forest maturation. However, future comparative studies should be conducted before any statement about the stoves' effect on forest structure is made.

2. Introduction

Tropical rainforests are estimated to provide habitat for about 50 % of the world's species (Kahn Academy, 2019) and is the most diverse terrestrial ecosystem in the world (Brooks *et al.*, 1999; Primack, 2010; Fuller, 2012). Forests in the tropics provide a diverse range of ecosystem services at local, regional, and global scale and is one of the Earth's most important ecosystems (Hansen *et al.*, 2013). The diversity and spatial distribution of forest structural components, such as trees, logs of different age, condition and size, and species, have shown to be important to maintain forest functions (Bormann and Likens, 1979) and ecosystem services. These forest functions and ecosystem services are for instance clean air, fresh water, food, wood, medicine and storage of carbon, and many people therefore depend on the forest for subsistence (WWF, 2019). Anthropogenic exploitation can have devastating effects that leads to deforestation and halt new regeneration of forests (Kasenene, 1987; Struhsaker *et al.*, 1996). Due to logging, building of roads, agricultural expansion, mining, urbanization and over-exploitation of resources, the coverage of rainforest has gone from 12 % to 5 % of the Earths land area (Brandon, 2014; Brooks *et al.*, 1999; Primack, 2010; Fuller, 2012; Kormos, 2018). Projections show that the tropical forest is one of the biomes that will experience the most rapid losses of habitats and species in the next 50 years (Millennium Ecosystem Assessment, 2005).

Up until 200 to 300 years ago, large areas of tropical rainforest were intact on the African continent (KIFCON, 1994; White, 1983 through Espira, 2001). The forested area composed the Guineo-Congolian tropical rainforest that stretched continuously from the coast of Western Africa to Western Kenya in East Africa (Kokowaro, 1988 in Kefa *et al.*, 2018). However, after two centuries of forest clearing, over 80 % of the forest area was lost (Stattersfield *et al.*, 1998; Allport, 1999; Myers *et al.*, 2000). The Kakamega-Nandi Hills forest complex in the Kakamega county, western Kenya, is Kenya's only remnant of the Guineo-Congolian rainforest. It is also the most eastern relic that was once part of the belt that stretched over the continent. The Kakamega-Nandi Hills forest complex is now surrounded by a landscape of bush, savannah woodland (Blackett, 1994), agricultural land and human settlements (Tsingalia, 1988). After being exploited commercially by both selective and clear-cut logging until the mid-1980s (Mitchell and Schaab, 2008) and gold mining in the 1930s, big gaps has created the fragmented forest complex (Kamugisha *et al.*, 1997 in Mitchell *et al.*, 2012).

The Kakamega forest is part of the Kakamega-Nandi Hills forest complex. As many other tropical forests, the Kakamega forest is located in an area with large number of people living in poverty (Wunder, 2001). Kenya is home to almost 48 million people (KNBS, 2019), with 27 million people living in poverty. For these people, health care, education, clean water, and sanitation is considered a luxury (UNICEF, 2019). Further, the forest is located in the Kakamega county, this county is one of the most densely populated rural areas in the country with 618 people per km^2 (KNBS, 2019). The population in Kakamega county continues to increase (Lung and Schaab, 2004) and many people in the area are poor and rely on the resources that the forest provides (Wambua, 2008). Thus, the demand for resources to fulfil the locals' daily needs, such as charcoal, hunting, logging, and collection of firewood, is increasing (Bleher, 2006). The commercial logging stopped in the mid-1980s (Mitchell and Schaab, 2008), and the forest is amongst the prioritized forest areas for biodiversity conservation (KIFCON, 1994). Despite that, both legal and illegal harvest for resources continues to be a threat to conservation of the forests' plant and animal species (Di Marco *et al.*, 2014; KNBS, 2015). The large populations and high poverty rate are the main challenges when it comes to conservation actions and still filling the needs for the local people (Myers, 1992 through Kefa *et al.*, 2018).

To ease the anthropogenic pressure on tropical forests and to solve problems associated with collection of firewood from tropical forests such as the Kakamega forest, installation of energy-efficient cookstoves in local peoples' homes is one potential solution (Lung and Espira, 2019). These kinds of projects have been executed in several developing countries by, for instance, the United Nations and their Sustainable Energy for All (SE4ALL) initiative (UN, 2013), the Global Alliance for Clean Cookstoves (GACC, 2011 through Malla and Timilsina, 2014) and the World Bank with several initiatives working for regional clean cooking. Along with the global initiatives, several local initiatives promote clean cooking. Among those, ECO_2LIBRIUM started the project Stoves for Life (SFL) in Kenya in 2010 (ECO_2LIBRIUM, 2019) in partnership with Swiss foundation Myclimate.

Up until 2017, the project SFL had installed over 46 000 energy-efficient cookstoves in the surrounding area of the Kakamega forest (ECO_2LIBRIUM, 2017). These ceramic stoves (called Upesi) have almost 50 % lower demand for wood fuel compared to traditional 3-stone-stoves that most people in the area use today (Figure 1).

Figure 1. Left: traditional 3-stone-stove. Right: energy efficient Upesi stove.

The investment in buying an energy-efficient cookstove means less time spent collecting firewood (either by cutting trees or collecting woody debris), less money spent buying firewood from collectors, better indoor air quality and decreased emission of carbon dioxide thanks to burning less forest vegetation (ECO$_2$LIBRIUM, 2019). The initiative to install stoves hope to benefit conservation and regrowth of forest. During regrowth, forests undergo a similar succession process as when natural gaps have been created. Moreover, restoration of forest surrounded by mature forest have great potential to gain tree species richness and diversity over time (Kappelle *et al.*, 1995; Finegan, 1996; Cook *et al.*, 2005). A diverse forest structure is fundamental for high biodiversity within rainforests. For example, species richness, variation in tree size and age creates habitats suitable for many different species to thrive within (Cannon *et al.*, 1998). Many original ecosystem functions, components and biodiversity can be restored by letting the forest re-establish (Chazdon, 2008). Regrowth and conservation of forests also contribute to storage of carbon which is an important ecosystem service (Pan *et al.*, 2011).

The main objective of the present study was to quantify forest structural and compositional differences within the Kakamega forest, Kenya, in relation to density of energy-efficient cookstoves installed by the project SFL (between years 2010-2019). This was done by comparing forest structure in areas with different numbers of installed stoves, stove age, and number of houses. To evaluate the potential impact of energy-efficient cookstoves on forest structure and human pressure, forest stand variables (diameter at breast height and structural layers), tree species diversity, signs of human damage, amount of woody debris and occurrence of epiphytes was sampled.

3. Methods

3.1 Study area

The Kakamega forest in western Kenya lies between 0°10’-0°20’ N and 34°48’-34°58’ E in the Lake Victoria basin approximately 50 km north of Lake Victoria, at an altitude between 1500-1700 m above sea level (Figure 2; Glenday, 2006). The Kakamega forest is part of the Kakamega-Nandi Hills forest complex and is Kenya’s most eastern remnant of the lowland Congo Basin rainforest of Central Africa (Kokowaro, 1988 through Bleher *et al.*, 2006). The 240 km^2 of forest is described as a multi-storey, dry peripheral semi-evergreen Guineo-Congolian transitional rainforest (Fischer *et al.*, 2010) and is characterized by hot days and cool nights (Zimmerman, 1972). The mean monthly temperature ranges between 13 °C and 26 °C with an average of 19 °C. The annual rainfall in Kakamega forest is just above 2000 mm (Gliniars *et al.*, 2013) and falls mainly during two rainy seasons: April to June and August to October, with a dry season lasting from December to February (Espira, 2001).

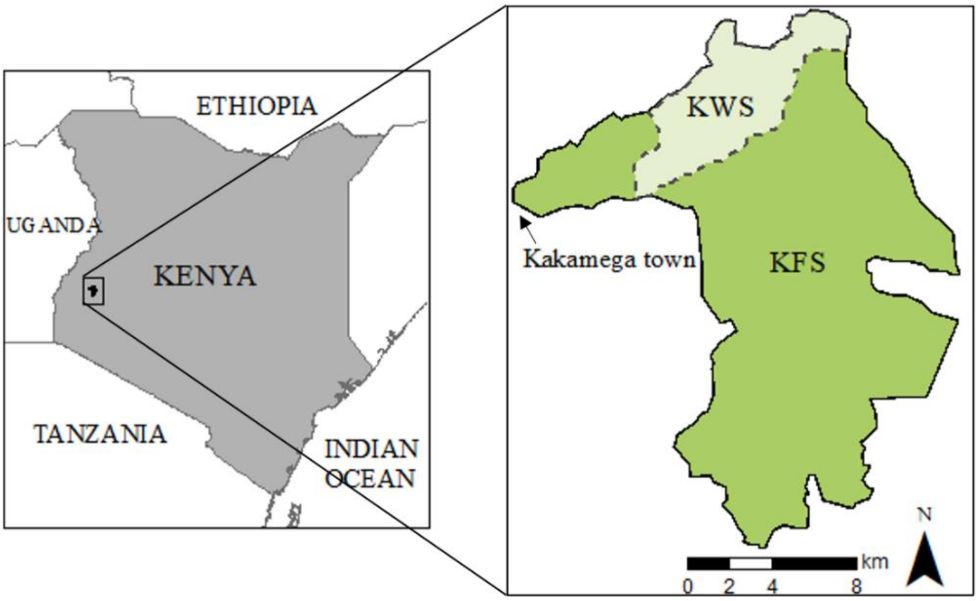


Figure 2. Map showing the geographical location of the study area, Kakamega forest in western Kenya. The map includes the borders for the two governmental agencies managing the forest: Kenya Forest Service (KFS, green) and Kenya Wildlife Service (KWS, white). The KWS area was not sampled in the present study.
Cartographer: Fanny Edenborg

Because of the long history of fragmentation and disturbance, the Kakamega forest comprise different stages of succession. The forest includes disturbed primary and secondary forest, grasslands, and clearings as well as timber and tea plantations (Bennun and Njoroge, 1999 through Bleher *et al.*, 2006), with middle-aged and young secondary forest being the most dominant stages (Fischer *et al.*, 2010). Despite fragmentation, the forest is still defined as a hotspot for biodiversity with several endemic plant and animal species. The rich flora consists of over 380 species of plants, of which trees, shrubs and vines compose 134 of them (KIFCON, 1994).

The forest is, since 1985, divided in two semi-autonomous government agencies: the Kenya Forest Service (KFS) and Kenya Wildlife Service (KWS). The KFS manages 82 % (196 km^2) of the forest area, where the present study is conducted, while the KWS manages 18 % (44 km^2) (Kefa *et al.*, 2018). By purchasing a permit, the locals are allowed to legally harvest forest resources within the KFS area in contrary to the KWS that bans all kinds of harvest in the forest (Kefa *et al.*, 2018). Despite the different approaches to conserve forest areas, illegal harvest occurs in both areas (Bleher *et al.*, 2006) and unsustainable harvest of fuelwood is one of the main threats to the Kakamega forest (KIFCON, 1992).

3.2 Selection of plot locations

Plot locations (Figure 3) for sampling forest structure were chosen based on three criteria: 1) the locations had to be covered by closed canopy, such as secondary or primary forest, or a plantation with mixed indigenous tree species, and 2) the forested locations had to be at least 600 m deep and wide. The latter gave each plot a buffer with at least 300 m distance to the forest edge. The buffer excludes closeness to the adjacent habitat as a factor that changes the forest structure, and potentially masking the effect from the stoves. The buffer also excludes the distance walked from the forest edge to collect firewood from being a varying factor during analysis. Finally, 3) the plot locations had to have a minimum distance of 250 m from each other. Sampling plots fulfilling the given criteria but bordered by tea plantations deeper than 500 m were excluded to make all plots similarly accessible to locals collecting firewood. In total, 59 plot locations were chosen and sampled, and their coordinates noted in the field using GPS (eTrex® 10 Garmin).

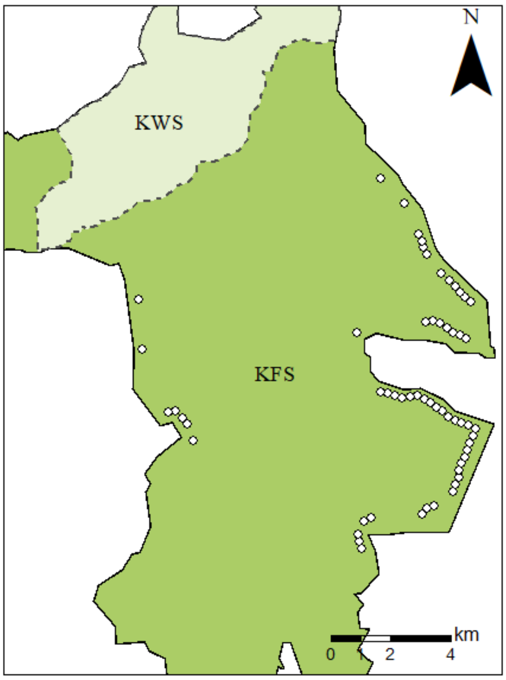


Figure 3. Plot locations sampled in the Kakamega forest. All plot locations were located in the area of the forest managed by the Kenya Forest Service (KFS). The area managed by Kenya Wildlife Service (KWS) was excluded from the present study.*

**The polygon showing the forest border does not completely match the actual forest edge. The 300 m buffer between each plot location and the forest edge was measured in the field, making all plots located at the correct distance to the actual forest edge.*

Cartographer: Fanny Edenborg

3.3 Sampling design

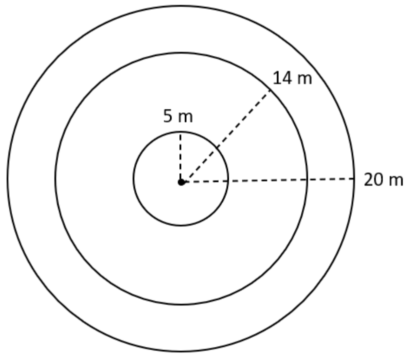


Figure 4. Plot design showing the three subplots originating from the geographical point for each plot location. The subplots were 5, 14 and 20 m in radius, respectively.

The sampling and plot design were based on Pearson *et al.* (2007), where each plot location consisted of three subplots with a radius of 5, 14 and 20 m originating from the center of the plot (Figure 4). The same sampling method and plot design have previously been used in the Kakamega forest (Lung and Espira, 2015). With the assistance of two local botanists (Solomon Atswenje and Copeland Musumba) throughout the sampling, all trees and shrubs within each plot were identified to species level and stem diameter at breast height was measured (DBH, 130 cm). Small shrubs with multiple small stems were excluded. The measurements of living and dead standing trees were included and distributed in the three subplots as followed: large trees with a stem diameter of >50 cm at breast height in the large subplot (20 m radius), medium sized trees with a DBH of 20-49 cm in the medium subplot (14 m radius) and small trees taller than 130 cm with a DBH of 1-19 cm in the small subplot (5 m radius). Trees taller than 130 cm with a stem diameter <5 cm was noted as <5 cm in diameter. In those cases when the tree had buttresses, the DBH was measured at a height of 3 m or directly above the buttress, whichever came first. The identification and confirmation of tree species, as well as information about the species ecological characteristics such as succession type (pioneer or climax), was decided with reference to sources stated in Appendix 1. Pioneer species are usually abundant at early stages of forest succession and tends to disappear with forest maturation when the stand is taken over by mid- and late-successional, climax species (Oliver and Larson, 1996; Franklin *et al.*, 2002; Wirth *et al.*, 2009). Knowledge about the species succession type could assist to assess the forest successional stage and if it shows signs of maturing.

Within the large subplot (20 m radius) any signs of human damage such as human-made stumps (later referred to as stumps), cut branches or charcoal burning sites were noted. Stumps were noted in size classes: small (0-19 cm in diameter), medium (20-49 cm in diameter) and large (> 50 cm in diameter). With the help from the two local botanists, the time (years) past since damaged was estimated by observing freshness of the cut, degree of decomposition (with differences in decomposition rates between species taken into account), and occurrence of new shoots. For all damage apart from charcoal burning sites, the species was noted. In those cases when the species could not be identified, such as when a stump was in a late stage of decay, the species was noted as unknown.

In the medium sized subplot (14 m radius) the foliage coverage of five designated structural layers were estimated (%). The layers were defined as followed: herb (0-2 m in height), shrub (0-9 m in height), under canopy (10-20 m in height), canopy (20-30 m in height) and emergent (>30 m in height). Further, the numbers of herbaceous vines (later also referred to as vines), epiphytic ferns and woody lianas (later also referred to as lianas) were estimated in the medium subplot. The estimations and counting were made by the same observer throughout the study to decrease variation.

Within the small subplot, the diameter of woody debris (later also referred to as logs) longer than 1 m in length and thicker than 3 cm in diameter was measured. In addition, Visual Obstruction Readings (VOR) were performed in four, non-random directions 4 m from the plot center with an angle of approximately 90 degrees in between (Figure 5). The VOR gives information about the density of the understory layer of the forest and was performed by two people, one standing at the center holding a checkerboard and one observer standing at a four meters distance facing the center. The checkerboard had seven red and seven white squares distributed in two columns. The observer counted all squares on the checkerboard that were completely visible through the vegetation. The fewer squares that are seen, the higher the density of the vegetation. The bottom of the checkerboard had to touch the forest floor and was always observed from a height of approximately 150 cm above the ground to make all readings made equally.

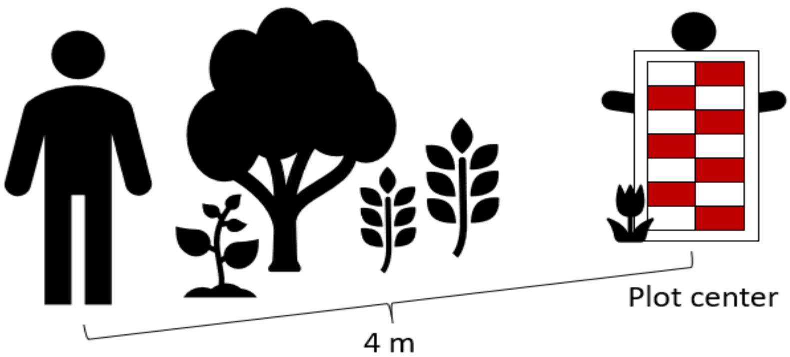


Figure 5. Visualization of how VOR (Visual Obstruction Readings) was performed. Note that the checkerboard was observed from a standard height (150 cm) in all readings and the bottom of the checkerboard had to touch the forest floor.

An overview of all sampled parameters is shown in table 1.

Table 1. An overview of all parameters sampled in each plot location and their distribution in the three subplots. The sizes of the three subplots were 5, 14 and 20 m in radius, respectively. The diameter at breast height was measured on trees taller than 130 cm.

	Small	**Medium**	**Large**
Tree Diameter at Breast Height	< 20 cm	20-50 cm	> 50 cm
Identification of tree species	x	x	x
Occurrence of human made damage	x	x	x
Foliage cover of structural layers (%)	x	x	
No. of vines, ferns, and lianas	x	x	
No. and diameter of woody debris	x		
Visual Obstruction Readings	x		

3.4 Estimation of population density

The number of houses around the forest was used as a proxy for pressure from locals on forest structure. According to Kefa et. al (2018), the mean distance walked to collect firewood is 3045 m. Therefore, the number of houses within a 3045 m radius from each plot was counted using a satellite base map (2009) in ArcMap 10.7.1.

3.5 Analyses

To test the effect from the utilization of the stoves and anthropogenic pressure on forest structure, a series of Multiple Linear Regressions (MLR) were performed. A number of values were calculated from the data for the dependent variables for each plot location: the total number of damage as well as the number of each type of damage, mean stem diameter, the average cross-sectional area (m^2), the number of species and individuals of trees and the number of individuals of climax and pioneer type species. For VOR, the mean value from the four separate readings from each plot location was used. Age of damage from 12 % of the plots was missing. For 1.5 % of the living tree species and 3.6 % of the species found damaged, information about the succession type (pioneer or climax) was unspecified and were therefore not included in the analyses including succession types. Each dependent variable was tested against the three independent variables: Number of stoves, Stove age (years) and number of houses. The variables were tested on a significance level of $\alpha= 0.05$ and p-values <0.1 were reckoned to indicate a correlation. Since the onset of the SFL project, over 46 000 stoves have been installed (ECO$_2$LIBRIUM). In the present study, only the number of stoves within a 3045 m distance (mean distance walked to collect firewood, Kefa *et al.*, 2018) from each plot location was included, giving each plot location their individual number of stoves. Mean age of the stoves included for each plot was calculated and represented the average time that the stoves had been utilized in each area. To increase readability, the results from the MLRs are presented in two separate tables including (1) variables quantifying forest structure and (2) variables related to human damage. A chi^2-test was used to find potential preference in species and size amongst trees found as stumps.

4. Results

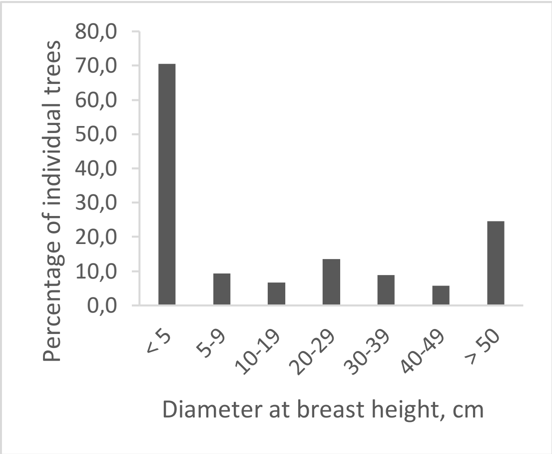
4.1 Forest structural components

During the field study, 2107 individuals of living trees from 84 species and 34 families were measured and identified (Appendix 1). Out of these, 67 species were classified as climax succession species, 14 as pioneer and the number of species of unclassified succession type or that were categorized to neither pioneer nor climax was 3. The top five most common species regarding the highest number of individuals of living trees, were *Trilepisium madagascariense*, *Funtumia africana*, *Heinsenia diervilleoides*, *Blighia unijugata* and *Antiaris toxicaria*, of which all are categorized as climax succession type species.

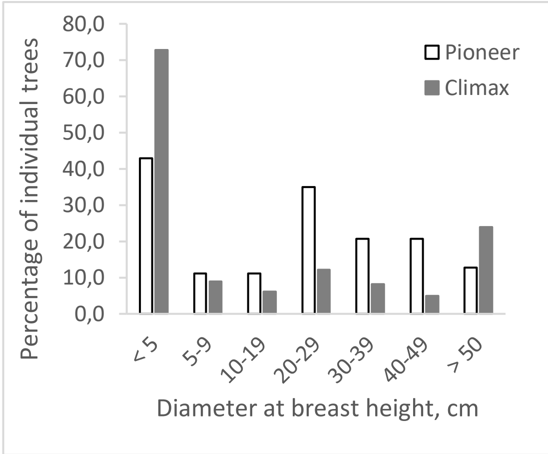
On average, there were 16 species/plot (SD ±5.2), 284.3 individual trees/ha (SD ±141.3) and the basal area was 48.6 m^2 ha^{-1} (SD ±22.8). In 38 % of the plots, 10–20 species were found, and only 7 % of the plots housed more than 25 species (Figure 6C). Most of the plots (27 %) had 30–40 individual trees (Figure 6D), only 2 % of the plots had 1–10 and 60–70 individual trees, respectively. The basal area ranged between 13.6 and 96.1 m^2 ha^{-1} amongst the plots, with 20 % of them comprising basal areas between 30–40 m^2 ha^{-1} (Figure 6E).

The size distribution amongst living trees show a dominance (70.5 %) of small trees with a DBH of <5 cm (Figure 6A). The size classes including trees with a DBH of 5-19 cm comprised 16 %. Further, trees with a DBH of 20-49 cm and >50 cm comprised a similar proportion with 28.1 (including three size classes) and 25.6 % respectively. Comparing size distribution of trees divided in their succession types, figure 6B show that the majority of climax (72.8 %) and pioneer (42.9 %) trees had a DBH of <5 cm. Both succession types had a small proportion of trees of DBH 5-19 cm, trees of that size class comprised 15.1 and 22.2 % for climax and pioneer trees, respectively. The number of pioneers peaked again in size class 20-29 cm in diameter (34.9 % of pioneer individuals) and climax type trees at DBH >50 cm (24 %).

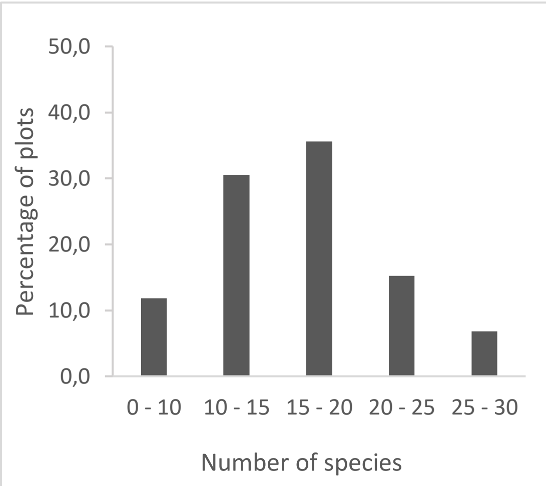
A.



B.



C.



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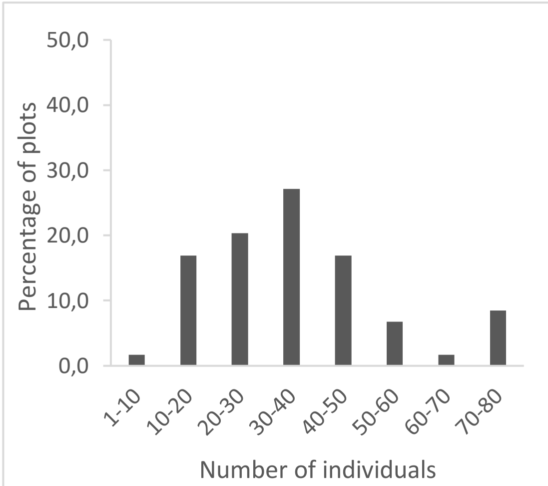

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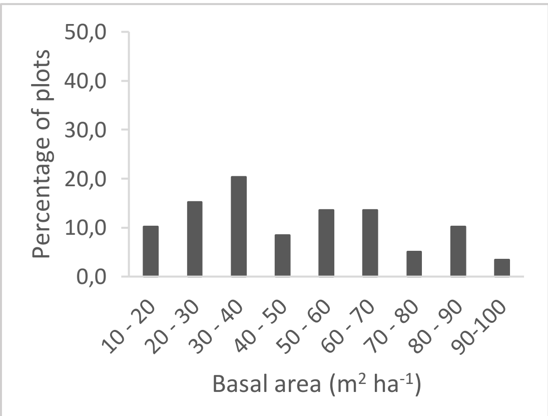

Figure 6. Figures showing A) size distribution of living trees amongst size classes, B) size distribution divided in the two succession types pioneer and climax trees. C) number of species, D) number of individual trees and E) basal area (m^2 ha^{-1}, C). The y-axis for graph C, D and E shows the percentage of plots divided into the different parameters.

The most dominant forest structural layer was the shrub layer, covering a total of 38 % of the studied area, followed by under canopy, herb, canopy and emergent covering 26, 17, 13 and 6 %, respectively. Looking at foliage coverage of trees, the most dominant tree layer was under canopy. Almost half the plots (49 %) had 100 % or more cover from the under canopy, canopy, and emergent layer together (trees of height 10 to >30 m). However, looking at foliage coverage of taller trees separately, canopy and emergent (trees with a height >20 m), only 39 % of the plots were covered 50 % or more of the plot area. Moreover, as much as 24 % of the plots had only 10 % of its area covered by trees taller than 20 m. The mean value for VOR ranged from 0 to 9.5 between the plots, with 93 % of the plots having a value below 4, and almost half the plots having a value below 1. The number of epiphytes ranged between 0–21, 0–370 and 0–50 within the plots for lianas, vines, and ferns, respectively. Within 78 % of the plots, vines were the most dominant epiphyte followed by ferns and lianas being dominant in 17 % and 5 % of the plots, respectively.

4.2 Occurrence of human made damage

The total number of damaged species identified was 66, of which climax species comprised 54 species, pioneer 11 and one (1) species was classified as generalist (Appendix 1). Out of the 59 plots locations, 54 of them had recently used trails and or paths within the 20 m radius. The top five most common species found damaged were *Trilepisium madagascariense*, *Funtumia africana*, *Antiaris toxicaria*, *Celtis gomphopylla* and *Aningeria altissimas* of which all are categorized as climax succession type species. The total number of human damages was 1233, with stumps (small 1-19 cm, medium 20-49 cm and large >50 cm in diameter) comprising 1186 (96 %) of them (Figure 7). Amongst all types of damage, small stumps were completely dominant at a number of 952 (77 %) and thereafter followed by medium and large stumps at 163 (13 %) and 71 (6 %), respectively. Further, the number of cut branches and charcoal burning sites were 23 (1.86 %) and 24 (1.94 %), respectively.

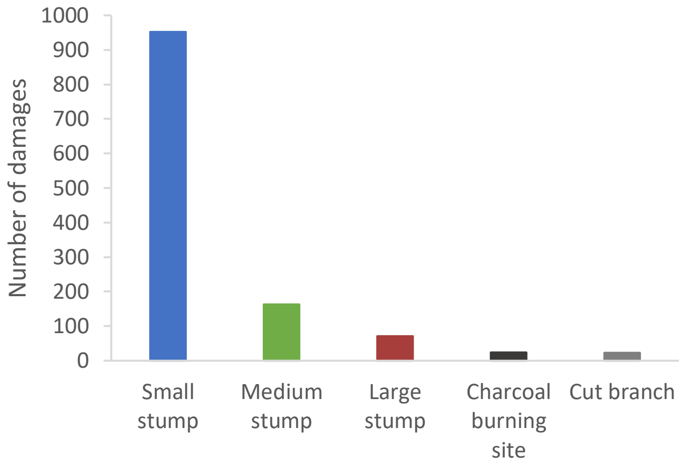

Figure 7. The total number of each type of human made damage.

When looking at age distribution of the most common damages (stumps), the majority of the stumps (small 60.5 % and medium 6 %) was estimated to have been cut in the last 5 years (Figure 8). However, over 12 % of the small stumps and most of the large stumps (3.8 %) were cut over 10 years ago.

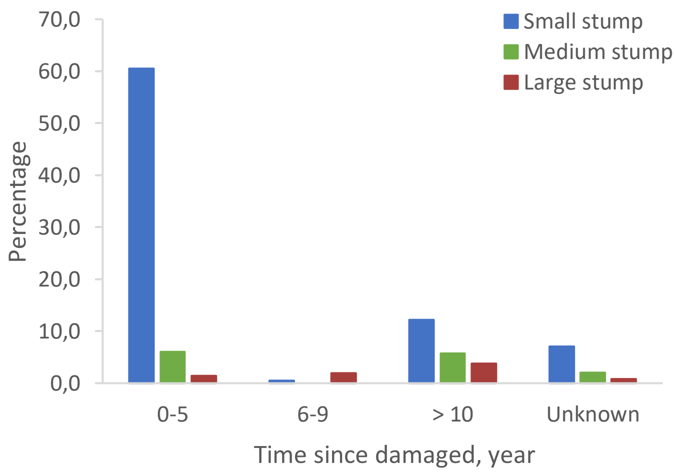

Figure 8. Age distribution amongst the most common damage, the stumps (small 0-20 cm, medium 20-50 cm, and large >50 cm in diameter).

Looking at the spatial distribution of number of damages, the number of damages vary a lot between plots (Figure 9).

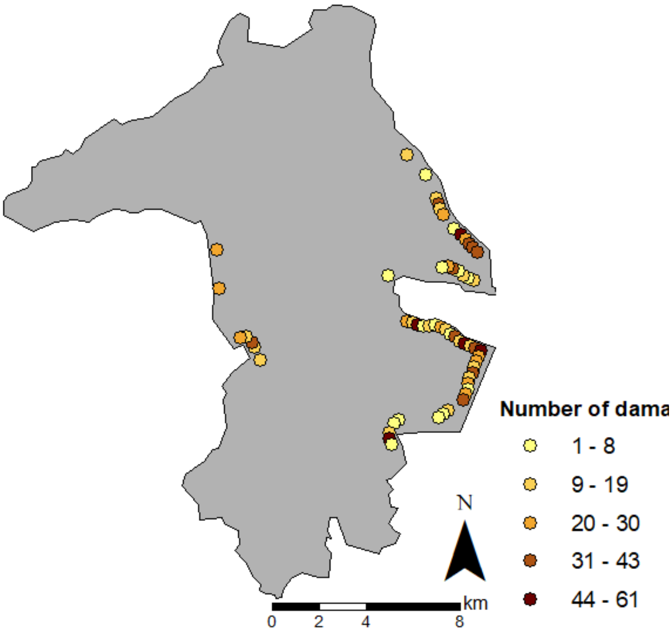

Figure 9. Distribution of number of damages within each plot.
Cartographer: Fanny Edenborg

Living trees and trees with damages (found as stumps), have three species in common among their top five most common species: *Trilepisium madagascariense*, *Funtumia africana* and *Antiaris toxicaria*. Out of all living trees, *T. madagascariense*, *F. africana* and *A. toxicaria* comprise 11.3, 7.1 and 5.3 %, respectively. These three species all show a higher proportion of human damages on small trees (16.9, 12.0 and 6.1 %) compared to the composition of living trees of the same size (10.4, 8.2 and 3.4 %, Figure 10). Damaged trees, stumps and cut branches (damage with species unidentified excluded), comprise 18.5, 12.8 and 7 % for *T. madagascariense*, *F. africana* and *A. toxicaria*, respectively. Results confirms that certain species are preferred and that small sized trees are aimed for when collecting woody recourses in the forest ($X^2_{(9,\ N=\ 1733)}$= 110.69, p= $1.06*10^{-19}$ and $X^2_{(2,\ N=\ 3059)}$= 146.99, p= $1.21*10^{-32}$, respectively).

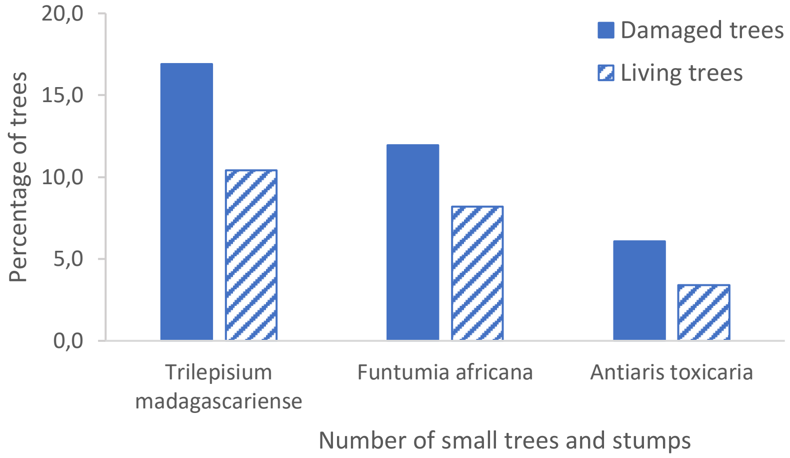

Figure 10. The percentage of damaged and living trees (size <20 cm in diameter) of the three the most common species.

4.3 Population trend and stove installations

Since 2009, just before the onset of the SFL project, up until year 2019, the population in Kakamega county has risen 12.5 % (Table 2).

Table 2. Population trend in Kakamega county in 2009, 2015 and 2019.

	2009	2015	2019
Number of people	1 660 651	1 876 000	1 867 579
Population density (people per km^2)	479	542*	618

Source: KNBS 2009; KNBS 2015/2016; KNBS 2019.
**The low value on population density in 2015 generates from calculations made using 3461 km^2 as the area for Kakamega county in contrary to 2009 and 2019 using 3021 km^2.*

The number of installed stoves included in the study were 3668, the number of houses were 12 879 and their spatial distribution is shown in figure 11A and 11B respectively.

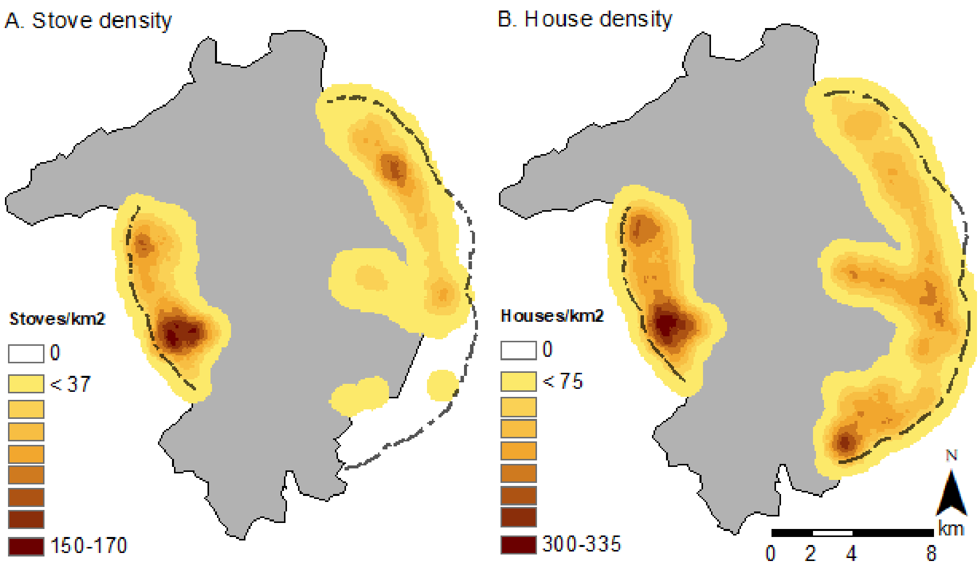

Figure 11. Spatial distribution of the density of installed stoves (A) and number of houses (B) within a 3045 m radius from the plots. The density is given in number of units per km^2. The area in which stoves and houses were included is bordered with the dashed line. Stoves located outside the area bordered by the dashed line was excluded from the present study.
Cartographer: Fanny Edenborg

The majority of stoves (77 %) within a 3045 m distance from the plots were installed during the project's 2nd to 5th year (year 2011-2014), with a decreasing trend between 2015 and 2019 (Figure 12).

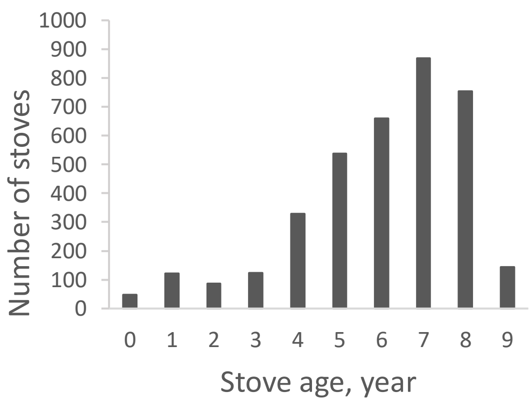

Figure 12. The number of stoves installed within a 3045 m distance from the plot locations during the Stoves for Life project between the years 2010 and 2019.

4.4 Stove effect

4.4.1 Stove effect on forest structural components

The number of stoves had a significant, positive effect on the proportion of pioneer individuals and a negative effect on the proportion of climax individuals (Table 3). The number of houses had a significant, negative effect on the proportion of pioneer individuals. The number of herbaceous vines increased significantly and the foliage coverage of under canopy decreased with increased stove age. The total number of logs (woody debris), size 10-15 cm in diameter in particular, increased with an increasing number of stoves. Meanwhile, the number of logs of size 3–15 cm in diameter decreased with an increasing number of houses.

Table 3. Results from multiple linear regressions (estimate and test of partial regression coefficients, and p-value from the Goodness of fit-test for the model) that tested the relationship between independent variables (number of stoves, stove age and number of houses) and variables quantifying forest structure.

Dependent variable	F-value	df	Adjusted R2	Goodness of fit p-value	Estimate		
					No. of stoves	*Stove age*	*No. of houses*
No. of species	2.043	55	0.051	0.119	0.003	**-1.757***	-0.002
No. of individuals	0.797	55	-0.011	0.501	0.007	-3.664	-0.003
Pioneer individuals (%)	3.385	55	0.110	**0.024***	**0.005**	1.190	**-0.004***
Climax individuals (%)	3.505	55	0.115	**0.021***	**-0.005**	-1.055	**0.004***
Basal area (m^2 ha^{-1})	1.621	55	0.031	0.195	0.002	**-8.040***	-0.007
Mean stem diameter	0.128	55	-0.047	0.943	-0.002	-0.553	-0.001
Herb layer (%)	0.550	55	-0.024	0.651	0.002	1.366	-0.007
Shrub layer (%)	1.01	55	0.001	0.395	$6.42*10^{-4}$	**3.560**	$5.16*10^{-4}$
Under canopy (%)	2.204	55	0.059	**0.098**	0.002	**-9.644***	-0.007
Canopy (%)	0.646	55	-0.019	0.589	0.010	-1.508	-0.008
Emergent (%)	2.252	55	0.061	**0.093**	**-0.017***	-5.576	0.003
VOR	1.264	55	0.013	0.296	0.000	**-0.582**	-0.000
No. of lianas	1.813	55	0.040	0.156	**-0.004**	-0.882	-0.002
No. of vines	7.515	55	0.252	**0.000*****	-0.023	**30.84*****	-0.008
No. of ferns	1.65	55	0.033	0.188	0.004	**-36.622**	$-5.12*10^{-5}$
Tot. no. of logs	2.533	55	0.073	**0.066**	**0.0019**	-0.547	**-0.0015***
Logs 3–5 cm	1.222	55	0.011	0.310	0.000	-0.236	**-0.001**
Logs 5–10 cm	2.095	55	0.054	0.111	0.001	-0.075	**-0.001***
Logs 10–15 cm	2.766	55	0.0837	0.050	**0.001***	-0.099	**-0.000**
Logs 15–20 cm	0.510	55	-0.026	0.677	0.000	-0.027	0.000
Logs 20–25 cm	0.960	55	-0.002	0.418	$5.75*10^{-5}$	-0.093	$-1.16*10^{-4}$
Logs 25–30 cm	0.747	55	-0.013	0.529	$-2.53*10^{-5}$	-0.002	$5.31*^{-5}$
Logs 30–35 cm	0.685	55	-0.017	0.565	$1.53*10^{-4}$	-0.025	$-5.63*10^{-5}$
Logs 35–40 cm	0.201	55	-0.043	0.895	$3.54*10^{-5}$	0.002	$1.21*10^{-5}$
Logs 40–45 cm	0.173	55	-0.045	0.915	$-1.15*10^{-5}$	-0.010	$2.76*10^{-5}$
Logs 45–50 cm	1.119	55	0.006	0.349	$1.02*10^{-4}$	0.015	$7.91*10^{-5}$
Logs 50–55 cm	1.138	55	0.007	0.342	$8.70*10^{-5}$	0.017	$1.13*10^{-5}$
Logs 75–80 cm	0.075	55	-0.050	0.973	$1.26*10^{-5}$	-0.009	$-1.39*10^{-6}$

Significant and trend correlations (α= 0.05 and α= 0.1) are presented in bold with significant values marked with asterisk.
** p<0.05; ** p<0.01; *** p<0.001*

4.4.2 Stove effect on occurrence of human made damage

The proportion of damaged pioneer individuals shows an indication to increase with an increasing number of stoves (Table 4). The proportion of damaged trees of climax type decreased with an increasing number of stoves. Finally, one can see that the proportion of damaged climax type individuals have a tend to increase with an increased number of houses.

Table 4. Results from multiple linear regressions (estimate and test of partial regression coefficients, and p-value from the Goodness of fit-test for the model) that tested the relationship between independent variables (number of stoves, stove age and number of houses) and variables related to human damage.

Dependent variable	**F-value**	**df**	**Adjusted R2**	**Goodness of fit p-value**	**Estimate**		
					No. of stoves	*Stove age*	*No. of houses*
No. of damaged species	1.538	55	0.027	0.215	0.001	-1.344	0.001
No. of damaged ind.	1.73	55	0.036	0.172	0.001	-2.311	0.006
Pioneer individuals (%)	2.735	54	0.084	**0.052**	**0.008***	0.113	-0.003
Climax individuals (%)	1.853	54	0.043	0.149	-0.007	-1.79	**0.009**
Tot. no. of damage	1.539	55	0.027	0.215	0.002	-2.651	0.006
No. of small stumps	1.538	55	0.027	0.215	0.001	-2.503	0.005
No. of medium stumps	1.357	55	0.018	0.266	-0.001	0.083	**0.001**
No. of large stumps	0.938	55	-0.003	0.429	0.001	-0.158	-0.001
No. of cut branches	1.132	55	0.007	0.344	$\mathbf{5.06*10^{-4}}$	-0.063	$6.15*^{-6}$
No. of charcoal	0.383	55	-0.033	0.765	$-2.55*10^{-4}$	-0.010	$-1.63*10^{-5}$
Mean age, total	0.240	48	-0.047	0.868	-0.001	-0.312	-0.000
Age of small stump	1.586	47	0.034	0.205	-0.001	0.046	**-0.001**
Age of medium stump	0.660	34	-0.029	0.582	-0.001	0.688	0.004
Age of large stump	0.530	31	-0.043	0.665	$-1.23*10^{-5}$	-0.016	0.003
Cut branch	0.891	11	-0.024	0.476	-0.003	0.164	-0.002
Charcoal burning site	1.218	15	0.035	0.338	0.002	-2.852	0.004

Significant and trend correlations (α= 0.05 and α= 0.1) are presented in bold with significant values marked with asterisk.
** p<0.05; ** p<0.01; *** p<0.001*

5. Discussion

5.1 Stove effect on occurrence of human made damage

Globally, poor people rely on resources from tropical forests to fulfill their daily needs (Myers, 1992). Wood is an important resource for many societies (Schnider, 1986). It is a renewable resource, and thanks to its wide variety of characteristics, wood is useful for many purposes (Lafleur and Fraanje, 1997). The most common tree species found damaged in the present study are collected for many different purposes, such as firewood, making of furniture, tools, fences, construction etc. (Maundu and Tengnäs, 2005; Kagombe, 2015; World Agroforestry Center, 2020; Tropical Plants Database, 2019). For most people living adjacent to the Kakamega forest, however, firewood is the main product that is harvested from the forest (Kiplagat *et al.*, 2008).

The results from the present study show that some species are preferred amongst people collecting woody materials from the forest. The reason is probably due to that some species have characteristics that make them more suitable as firewood than other. An earlier study performed the same region found that species burning consistently at a high heat and has a nice aroma are usually preferred as firewood (Kefa *et al.*, 2018). The same study lists nine species to be preferred to be used as firewood, of which six of them are categorized as climax type species. The present study indicates that the proportion of damaged individuals of climax type increases with increased number of houses (Table 4), giving an indication that these are the preferred group of species just like what is shown by Kefa *et al.* (2018). Thus, an increased mortality for climax type species due to harvest of firewood might give those species more disadvantage in regeneration, compared to pioneer type species (Panayotou and Ashton, 1992). However, the anthropogenic pressure on the preferred climax type trees seem to be eased with higher number of stoves. The stoves show a (although non-significant) negative correlation with the proportion of damaged climax type trees (Table 4). Further, the number of houses show a negative, significant correlation with the proportion of living pioneer trees which suggest that people do not only collect climax type trees for firewood. However, the proportion of living pioneer type individuals increase significantly with the number of stoves (Table 3). Pioneers are fast growing and might take advantage of the lowered pressure thanks to the stoves, and they sprout and grow in numbers. Thus, the stoves seem to lower the overall anthropogenic pressure, even though not strongly, on the Kakamega forest.

Apart from that the results show that certain species are preferred, the results also show that there is a preferred size among collectors of woody materials. The by far most common damage that was found during the present study were small stumps (1-20 cm in diameter). Bleher *et al.* (2006) assumed that trees and logs of size <10 cm in diameter are mostly used as firewood and collected by women and children, and that sizes >10 cm in diameter usually are collected by men for other purposes (e.g. polewood or timber). Additionally, stems of around 4.8 cm in diameter has been shown to be a preferred size to use as firewood (Kefa *et al.*, 2018). All accept one of the top five most common species found as stumps in the present study are, mainly or partially, used as firewood. Therefore, it is reasonable to believe that many of those chopped stems are to be used for firewood.

According to the present study, 60.5 % of the small stumps were estimated to have been cut in the last 5 years (Figure 8). During that time, the population in Kakamega county had actually decreased 0.5 % (between 2015 and 2019, KNBS 2015/2016; KNBS 2019), giving no strong reason to believe that the population trend would drastically increase the number of small tree stumps. Though, the moist and high temperature climate in rainforests enhance decomposition rates (Singh, 1969; Brinson, 1977), makes it reasonable to think that older small stumps have already been decomposed before the present study was conducted. However, 12 % of the small stumps were still visible even though they were estimated to have been cut more than 10 years ago. It is likely that these are stumps of hardwood species, that degrades at a lower rate. Thus, even if some of the older small stumps of softwood have decomposed, it seems like the number of damage (small stumps in particular) have increased in the last 5 years. It is difficult to tell the reasons for the increasing number of small stumps apart since the most common species found damaged also are used for other purposes than firewood. The increased number of damages of small stumps in the last five years could be due to an increased demand for woody resources for other purposes. For example, people may continue to collect firewood for selling or collecting building materials.

5.2 Stove effect on forest structural components

The stands in the Kakamega forest comprised of 284.3 individual trees per hectare, which is relatively standard compared to numbers of trees in western and central Africa and Tanzania (146-663 stems ha^{-1}, Obiang *et al.*, 2010; Rutten *et al.*, 2015; Mankou *et al.*, 2017). The basal area in the Kakamega forest is relatively high (48.6 m^2 ha^{-1}) compared to western and central Africa and Tanzania (20.7-73.1 m^2 ha^{-1}, LaFrankie *et al.*, 2006; Mbue *et al.*, 2009; Obiang *et al.*, 2010; Rutten *et al.*, 2015; Mankou *et al.*, 2017). Thus, in contrary to what could be expected with respect to the amount of pressure that is known, the Kakamega forest is still similar to other, mature forests, at least when looking at the number of trees and basal area. Though, the results show that the number of vines increase with stove age. The high number of vines suggest that the forest is still under pressure. Most vines in tropical forests benefit from disturbances creating open gaps, and they increase in abundance and diversity in these gaps (Richards, 1996). However, an increasing number of studies suggest that species richness and abundance of vines increase also in mature forests (Carrasco-Urra and Gianoli 2009; Gianoli *et al.*, 2010). Today, according to the present study, the most dominant forest layer is the shrub layer (0-9 m above the ground). Further, stove age shows a tendency to decrease the foliage coverage of the under-canopy layer. In general, temperate and tropical forests have similar successional processes (Oliver and Larson, 1990). Loss of lower tree canopy is a process, among many others, that is related to forest successional progress in temperate forests (Franklin *et al.*, 2002). The results therefore suggest that the longer the stoves are utilized, the forest show signs of forest maturation. If the forest is maturing, the complexity of vertical and horizontal structures will increase over time (Budowski, 1970).

As mentioned earlier, anthropogenic pressure can halt new successions and development of forest structure (Kasenene, 1987; Struhsaker *et al.*, 1996). Aiming for certain size and species of trees can give that specific group of trees disadvantage in regeneration since the number of those trees is decreased (Panayotou and Ashton, 1992). A diversity of structural components, such as diversity of tree sizes, making up the forest structure is fundamental to sustain a high biodiversity within rainforests (Cannon *et al.*, 1998). Given the fact that people living adjacent to the Kakamega forest are selectively collecting woody materials of size 1-20 cm in diameter, that could possibly hinder the forest to sustain a diverse structure. The present study shows a relatively low proportion of those specific size classes compared to other size classes amongst living trees in the Kakamega forest (Figure 6A and 6B). However, as mentioned earlier, the present study shows some signs that the number of stoves lowers the pressure on the forest.

Increased number of stoves seem to decrease the proportion of new stumps of the preferred group of species (climax type species, Table 4) and increase the proportion of living, fast-growing, pioneer type trees (Table 3).

Forest development and biomass growth rate of a tree depends on several factors such as climate, water supply, distribution of tree species, soil fertility, tree functional type and forest disturbance etc. (Fearnside, 1997; Luizão *et al.*, 2004; Sicard *et al.*, 2006; Slik *et al.*, 2008). Generally, pioneer species are initially fast-growing (Rueda and Williamson, 1992), which also applies to the most common pioneer species found in the present study that are considered being medium or fast-growing species (Legesse, 2010; Tropical Plants Database, 2019). When the pressure on the forest is lowered, pioneer species inhabit forest gaps and slow growing, shade-tolerant climax species establish underneath them with time (Whitmore, 1989). Given that the pioneer species are fast-growing and fast to sprout, compared to climax species, they rapidly increase in number causing a decreased proportion of climax trees (Table 3). The high abundance of recruiting trees (DBH <5 cm), of both pioneers and climax type, might indicate that the environment is suitable for both early and late successional individuals to sprout. The signs of the forest providing an environment suitable for late-successional species, such as climax type species, could possibly be due to that the fast-growing pioneer trees are growing in size. Today, the Kakamega forest show a lower abundance of trees of size 5-19 cm in diameter but a higher abundance of trees 20-29 cm in diameter amongst pioneer individuals (Figure 6A and 6B). The forest recovery can be fast in tropical regions (Ewel, 1980) and some pioneer species found in Africa can have an annual growth rate of 0.7-3.5 cm in diameter (Therrell *et al.*, 2007; de Ridder *et al.*, 2013). The pioneer species in the present study, that were spared thanks to the stoves, could therefore have grown from 6.3 up to almost 31 cm in stem diameter since the onset of the Stoves for Life project in 2010. That means that individuals of the preferred size might have grown into the larger size class (20-29 cm). The larger trees allow less light to reach the forest floor and could create a climate suitable for more shade-tolerant climax species to thrive (Finegan, 1984; Whitmore, 1989). This favors the shade-tolerant climax species and leads to mortality of the shade-intolerant pioneer trees (Capers *et al.*, 2005), suggesting that the decreased proportion of climax type trees is only temporary and that the forest will mature with time.

The number of woody debris (logs) seems to decrease with the pressure from an increased number of houses, especially logs of size 3-15 cm in diameter. It is likely that these logs are used as firewood since it is known that logs of sizes around 4.8 cm in diameter are logs preferred to use as firewood (Kefa *et al.*, 2018). Increasing number of stoves also show a tendency to increase the number of logs in total, especially logs of size 10-15 cm in diameter (Table 3). Presence of woody debris is an important component in a forest ecosystem. The dead wood creates microhabitats, promote establishment of seeds and biological diversity, and it increases the diversity of structures of the forest (Harmon *et al.*, 1986; Parks and Shaw, 1996). Additionally, woody debris also has a significant role when it comes to carbon storage in the forest (Delaney *et al.*, 1998; Clark *et al.*, 2002; Rice *et al.*, 2004; Iwashita *et al.*, 2013). The increase of woody debris thanks to the number of stoves might give many organisms the opportunity to survive in the forest even though it is experiencing pressure.

5.3 Social benefits from energy-efficient cookstove projects

The main focus in the present study was the project SFL's effect on forest structure. However, there are other important social effects that are seen thanks to the project (ECO_2LIBRIUM, 2017). The production, distribution and installation of the stoves create job opportunities, and lowered demand for firewood for stove users. This leads to increased livelihood for many people. The project has mainly, so far, employed women (75 %). Women are also, together with children, the ones from the household that for the most part are involved in the firewood collection. Women increase their income or save money and time by employment, reduced need of buying firewood from collectors, or need to collect firewood themselves. From interviews made during the present study, we know that these women can now pay for food, clothes for their children, and pay school fees etc. Further, many girls get the chance to study thanks to the spared time. Poverty is one factor, among several others, that is associated with deforestation (Deininger and Minten, 1999; Geist and Lambin, 2001), and reduction of poverty can favor conservation of forest (Kerr *et al.*, 2004). That suggests that projects such as SFL might reduce deforestation both by lowering the demand for forest resources and increasing peoples' livelihood which perhaps decreases poverty.

5.4 Conclusion

The Kakamega forest is, with no doubt, still experiencing pressure from humans utilizing its resources. However, the installation and usage of energy-efficient cookstoves seem to have some positive impact on the forest's recovery and maturation. The present study shows signs of recovery by decreasing the number of damages found on the preferred group of species and promoting survival of fast-growing pioneer trees to grow larger. The latter in particular creates a climate suitable for shade-tolerant, climax type trees to sprout and establish recruiting trees. Further, utilization of energy-efficient cookstoves preserve important structural components such as woody debris on the forest floor. This is an important effect that gives many organisms the opportunity to establish and spread, and for carbon to be stored.

To conclude, the structure of the Kakamega forest show some signs of recovery and maturation thanks to usage of energy-efficient cookstoves. Therefore, stoves should continue to be installed and utilized. And, future comparative studies (in the same fixed plot locations) are essential to be able to properly assess the cookstoves' effect on forest structure as well as its regeneration and maturation.

5.5 Future studies

The present study is an initiative creating opportunities for other studies to further develop the assessment of energy-efficient cookstoves. The present study deals with difficulties such as no previous results from before the start of the SFL project to compare the present study's results with. The fact that the plots are not spatially independent of each other is an additional factor that might affect the result. All available areas fulfilling the given criteria were sampled. However, the forest is small and the distance between plot locations makes them dependent on each other when using the radius of 3045 m as a buffer when including houses and stoves in the analyses. Another factor making the present study's result difficult to analyze is variations in past management and utilization of the forest (BIOTA, 2004). The forest shows a large variation in successional stages and includes disturbed primary and secondary forest, grasslands, and clearings as well as timber and tea plantations (Bleher *et al.*, 2006; Fisher *et al.*, 2010). Spatial variations like these could create differences in forest structure, perhaps making the effect of the stoves difficult to find.

Since data is now available for comparison, future studies should follow up on the stoves' effect on the structure of the Kakamega forest. Forests dominated by small trees and few large trees are usually undergoing continuous regeneration (BIOTA, 2004) and recruitment of shade-tolerant species (for instance climax type species) is a sign of forest development (Chazdon *et al.*, 2005; Capers *et al.*, 2005). Therefore, the main parameters to observe is the magnitude of increase and decrease of pioneer and climax type individuals among living and damaged trees, as well as their stem diameter distribution. If the number of stoves lower the pressure on the preferred group to use as firewood, which is suggested in the present study, recruiting trees of that type is expected to have grown into larger size classes. Therefore, the number of trees in the preferred size class (DBH 1-19 cm) should increase, as well as the basal area of the stand structure, if the assumptions made in the present study are true. The proportion of living climax type trees should increase, and pioneers decrease, with time if the forest is maturing. In addition, future studies should follow up on the distribution of the forest's structural layers. If the forest is maturing, the complexity of vertical and horizontal structures will increase over time (Budowski, 1970). Finally, future studies should collect information about local peoples' habits in collecting woody materials from the forest. People may still be collecting woody materials for other purposes than firewood, that might mask a potentially larger effect from the stoves than shown in the present study.

6. Acknowledgement

I would like to show my gratitude to my Swedish (Karl-Olof Bergman) and Kenyan (PhD Anton Espira and Christopher Amutabi Kefa) supervisors for their guidance, mentoring, and provision of required material for GIS during my project. I thank my co-supervisor Lars Westerberg for his guidance throughout the statistical analyses and my examiner Tom Lindström for his helpful feedback during the writing process.

I am grateful to Eco2librium Company Ltd for providing material, financial and technical support. I want to thank all staff members from Eco2librium for their support throughout my stay in Kenya, especially Solomon Atswenje and Copeland Musumba for their participance and species knowledge during data collection. I am very grateful for Anton Espira providing room and board during my stay in Kenya. I also want to thank Dr. Humphrey Agevi as my representant for the Department of Biological Science at Masinde Muliro University of Science and Technology (MMUST) for making this study possible.

I appreciate the Kenya National Commission and Technology (NACOSTI), the Kenya Forest Service (KFS) and the County government of Kakamega County for issuing the permits allowing my fieldwork to be conducted.

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8. Appendix 1

Appendix 1. List of all species identified, to species or genus level, and measured (Diameter at Breast Height) among living trees and trees found damaged (as stumps or with cut branches).

Family	Species	Status (Living/Damaged)	Life form (Shrub/Tree)	Succession type
Leguminosae	Acacia abyssinica	L	T	Pioneer
Cornaceae	Alangium chinense	L/D	T	Climax
Mimosaceae	Albizia grandibracteata	L/D	T	Climax
Mimosaceae	Albizia gummifera	L	T	Climax
Sapotaceae	Aningeria altissima	L/D	T	Climax
Moraceae	Antiaris toxicaria	L/D	T	Climax
Sapotaceae	Bequeartiodendron oblanceolatum	L/D	T	Climax
Sapindaceae	Blighia unijugata	L/D	T	Climax
Euphorbiacaea	Bridelia micrantha	L/D	T	Pioneer
Flacourtiaceae	Casaeria battiscombei	L/D	T	Climax
Flacourtiaceae	Casaeria gladiiformis	L	T	Climax
Rhizophoraceae	Cassipoureae ruwensorensis	L/D	T	Climax
Ulmaceae	Celtis africana	L/D	T	Climax
Ulmaceae	Celtis gomphopylla	L/D	T	Climax
Ulmaceae	Celtis mildbreadii	L/D	T	Climax
Ulmaceae	Chaetachme aristata	L/D	S/T	Climax
Sapotaceae	Chrysophyllum viridifolium	L	T	Climax
Rutaceae	Clausena anisata	L	S/T	Pioneer
Boraginaceae	Cordia africana	L/D	T	Climax
Fabaceae	Craibia brownii	L/D	T	Climax
Euphorbiacaea	Croton megalocarpus	L/D	T	Climax
Euphorbiacaea	Croton sylvaticus	L/D	T	Climax
Sapindaceae	Deinbollia kilimandscharica	L/D	T	Climax
Ebanacea	Diospyros abyssinica	L/D	T	Climax
Putranjivaceae	Drypetes gerrardii[1,2,3,4,5]	L/D	S/T	Generalist
Boraginaceae	Ehretia cymosa	L/D	T	Climax
Meliaceae	Ekebergia capensis	L	T	Climax
Rutaceae	Fagaropsis angolensis	L	T	Pioneer
Moraceae	Ficus asperifolia	L/D	S/T	Climax
Moraceae	Ficus cyathistipula	L	T	Climax
Moraceae	Ficus exasperata	L/D	T	Climax
Moraceae	Ficus lutea	L/D	T	Climax
Moraceae	Ficus natalensis	L	T	Climax
Moraceae	Ficus sansibarica[1,2,4,6,7]	L	T	Neither
Moraceae	Ficus sur	L/D	T	Climax
Moraceae	Ficus sycomorus[1,2,4,6,7,8]	L	T	Neither
Moraceae	Ficus thonningii	L	T	Climax
Moraceae	Ficus vallis- choudae	L	T	Climax
Moraceae	Ficus sp.	L	-	-
Flacourtiaceae	Flacourtia indica	L/D	S/T	Pioneer
Apocynaceae	Funtumia africana	L/D	T	Climax
Guttiferae	Harungana madagascariensis	L/D	T	Pioneer
Rubiaceae	Heinsenia diervilleoides	L/D	T	Climax

Appendix 1. Continued.

Family	Species	Status (Living/Damaged)	Life form (Shrub/Tree)	Succession type
Meliaceae	Khaya anthotheca[1,2,4,7,9,10]	L/D	T	Climax
Bignoniaceae	Kigelia africana	L/D	T	Climax
Meliaceae	Lepidotrichilia volkensis	L/D	T	Climax
Sapindaceae	Lepisanthes senegalensis[1,4,11]	L/D	T	Pioneer
Rhamnacea	Maesopsis eminii	L/D	T	Pioneer
Sapotaceae	Manilkara butugi	L/D	T	Climax
Euphorbiacaea	Margaritaria discoidea	L/D	T	Pioneer
Bignoniaceae	Markharmia lutea	L/D	T	Climax
Moraceae	Morus mesozygia	L/D	T	Climax
Loganiance	Nuxia congesta	L/D	T	Climax
Ochnaceae	Ochna holstii[2,4,12]	L/D	S/T	Climax
Oleaceae	Olea capensis	L/D	T	Climax
Salicaceae	Oncoba routledgei[4,13]	L	T	Climax
Flacourtiaceae	Oncoba spinosa	L/D	S	Climax
Rubiaceae	Oxyanthus speciosus	L	S	Climax
Pittosporaceae	Pittosporum mannii	L/D	S/T	Climax
Araliaceae	Polyscias fulva	L/D	T	Pioneer
Verbenecea	Premna angolensis	L/D	T	Climax
Rosaceae	Prunus africana	L/D	T	Climax
Myrtaceae	Psidium guajava[4,14]	L/D	S/T	Pioneer
Apocynaceae	Rauvolfia caffra	L/D	T	Climax
Flacourtiaceae	Rawsonia lucida	L/D	S/T	Climax
Violaceae	Rinorea brachypetala	L/D	S/T	Climax
Capparaceae	Ritchiea albersii	L	S/T	Climax
Rubiaceae	Rothmannia longiflora	L	S/T	Climax
Euphorbiacaea	Sapium ellipticum	L/D	T	Climax
Bignoniaceae	Spathodea campanulata	L/D	T	Pioneer
Oleaceae	Strombosia scheffleri	L/D	T	Climax
Loganiance	Strychnos usamberensis	L/D	T	Climax
Sapotaceae	Synsepalum cerasiferum[4,11,13,15]	L/D	T	Climax
Myritiaceae	Syzygium guineense	L/D	T	Climax
Rutaceae	Teclea nobilis	L/D	T	Climax
Ulmaceae	Trema orientalis	L/D	T	Pioneer
Meliaceae	Trichilia emetica	L/D	T	Climax
Harmamelidaceae	Trichocladus ellipticus	D	T	Climax
Moraceae	Trilepisium madagascariense	L/D	T	Climax
Flacourtiaceae	Trimeria grandifolia	L/D	S/T	Climax
Meliaceae	Turraea holstii	L/D	T	Climax
Annonaneae	Uvariopsis congolensis	L	T	Climax
Rubiaceae	Vangueria apiculata	L/D	S/T	Pioneer
Rutaceae	Zanthoxyllum gillettii	L/D	T	Climax

All species have been identified and confirmed with reference to Beentje (1994)[1] apart from species marked with specific reference. These species have been confirmed with reference to given source in combination with personal communication[4]. A list of the references is given below.

8.1 Appendix references

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