A Tree Grows in Kenya: The Status of *Prunus africana* in the Kakamega Forest, Western Kenya

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In partial fulfillment of a Bachelor of Science degree in Environmental Sciences
Brown University, May 2005

Signature Page

This senior honors thesis by Michal Kapitiulnik is accepted by the Brown University Center for Environmental Studies as partially satisfying the requirements for the degree of Bachelor of Science in Environmental Science.

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Abstract

Global deforestation coupled with rapid human population growth has resulted in widespread forest fragmentation and increased pressure on forest products. This has resulted in habitat loss, species endangerment, and loss of ecosystem function. One method of combating these detrimental effects is through agroforestry, which seeks to mirror forest structure by establishing multiple canopies of growth including timber species, medicinal and food crops in one integrated system. In the Kakamega Forest, Western Kenya, human encroachment on the forest for agricultural land and forest products has resulted in wide spread deforestation, with the result that only a small fragment of intact forest remains One species suffering from this increased pressure is *Prunus africana.*

P. africana is a medicinal tree important in both local and global markets. The species is endangered across it's range, mostly due to harvesting of wild populations. In the Kakamega forest, however, the driver of scarcity is unknown. This project seeks to identify causes of scarcity and subsequent tools for successfully propagating *Prunus africana* in agroforestry programs. If *P. africana* can be successfully grown through agroforestry, generating income, it could be an important tool for conserving this species.

1. Introduction

Deforestation is a global problem (FAO, 2003). A growing world population has resulted in increasing demands for goods from forests, including timber and land for agricultural and settlement. This has resulted in heightened forest fragmentation and habitat destruction. It is often areas where biodiversity is at its highest that these detrimental pressures exist. Unfortunately, many of these areas lack the infrastructure and conservation policies to prevent deforestation.

Between 1990 and 2000, there was a 0.2% annual global forest loss comprising 94,000- km^2 loss over this 10-year period. In Africa, there was a 0.8% annual forest loss over this same time period, resulting in a 53,000 km^2 loss. In Kenya, there was a 0.5% annual forest loss, comprising a 930 km^2 loss over ten years (FAO, 2003). While the rate of Kenyan deforestation may seem negligible compared to the continental and global rates, it should be noted that in the year 2000, forest comprised 30% of the country (ICIPE, 2005). Thus, this kind of annual loss would have a significant effect on the ecology of Kenyan forests.

Fragmentation of forests results in a myriad of detrimental effects including species loss, habitat loss, and loss of important ecosystem functions. Many strategies have been implemented to counteract the effects of deforestation. While some of these strategies preclude human involvement, more successful programs acknowledge human dependence on forest systems and engage communities in conservation efforts (Cunningham, 1997). One such approach is the implementation of agro-forestry projects (Cunningham et al, 1993).

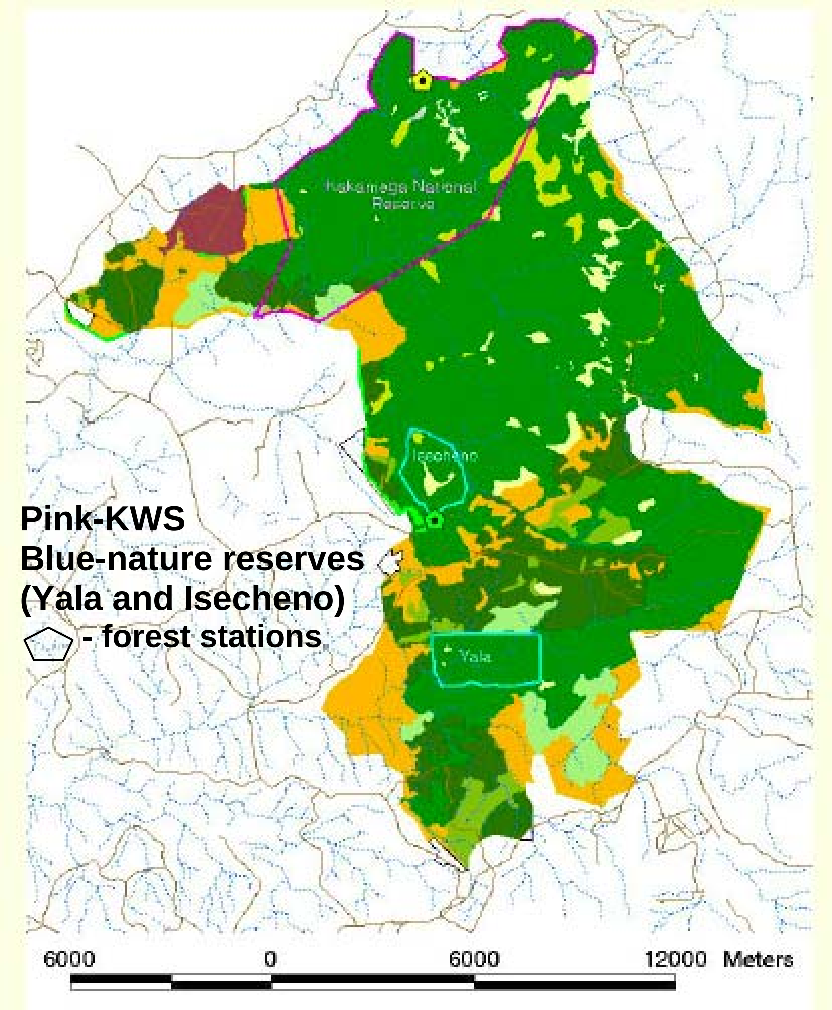
Agro-forestry incorporates trees into the agricultural system, contrary to the homogeneity of modern monoculture systems. In doing so, it seeks to mirror forest ecosystems by establishing multiple plant canopies. Timber species as well as food crops and medicinal plants can be integrated into the same agronomic system. Through this process, patterns of nutrient cycling and soil quality can be conserved. In communities seeking to quell deforestation, agro-forestry can work in a few important ways. First, cultivation of plants that communities previously gathered from the forest can decrease the pressure on wild populations (Cunningham et al, 2002). In addition, ex-situ propagation can be used to increase genetic diversity in a specific area and regenerate wild populations (Cunningham & Mbenkum, 1993). Agro-forestry often promotes sustainable harvesting of medicinal and food products (ICIPE, 2005). In addition, it can be used as a tool for local income generation for communities who live in and around forests, which are often regions where poverty rates and population growth are both very high (ICIPE, 2005).

Kakamega forest is one region where high population growth has resulted in deforestation. The Kakamega forest is an afromontaine forest in western Kenya (fig 1). It is a small fragment of the Guineo-Congolian rainforest that once spanned the equatorial region as well as parts of the western coast of Africa (Earlham University, 1999). Within the forest, land cover is very heterogeneous, resulting in many different forest types (fig 2). As a result, the forest is an area of high biodiversity. Though the forest is small in area, it is species-rich, with over 350 bird species, and over 380 plant species identified (Earlham University, 1999; ICIPE, 2005). In fact, around 20% of all Kenyan plant and animal species are endemic to the forest, including up to 75% of all butterfly species in the country (KIFCON, 1994).

Figure 1: Map of Africa with Location of Kenya and Kakamega (Glenday, 2004)

The Kakamega forest has a very complex land use history, and has been highly influenced by the growth and development of the surrounding communities. The dominant tribe surrounding the forest is the Luhya, one of Kenya's most populous tribes, extending across Kenya's western border into Uganda (KIFCON, 1994). Most of the communities survive by practicing subsistence agriculture, growing mostly maize with a mix of other food crops including bananas, tomatoes, sukuma wiki (collard greens) and sweet potatoes (KIFCON, 1994; ICIPE, 2005). The soil in and around the forest is a moderately fertile clay-loam mixture, and the river system within the forest makes fresh water easily attainable, making agricultural initiatives much more successful than in other regions of the country (Earlham University, 1999).

Figure 2: Map of Kakamega Forest (Glenday, 2004)



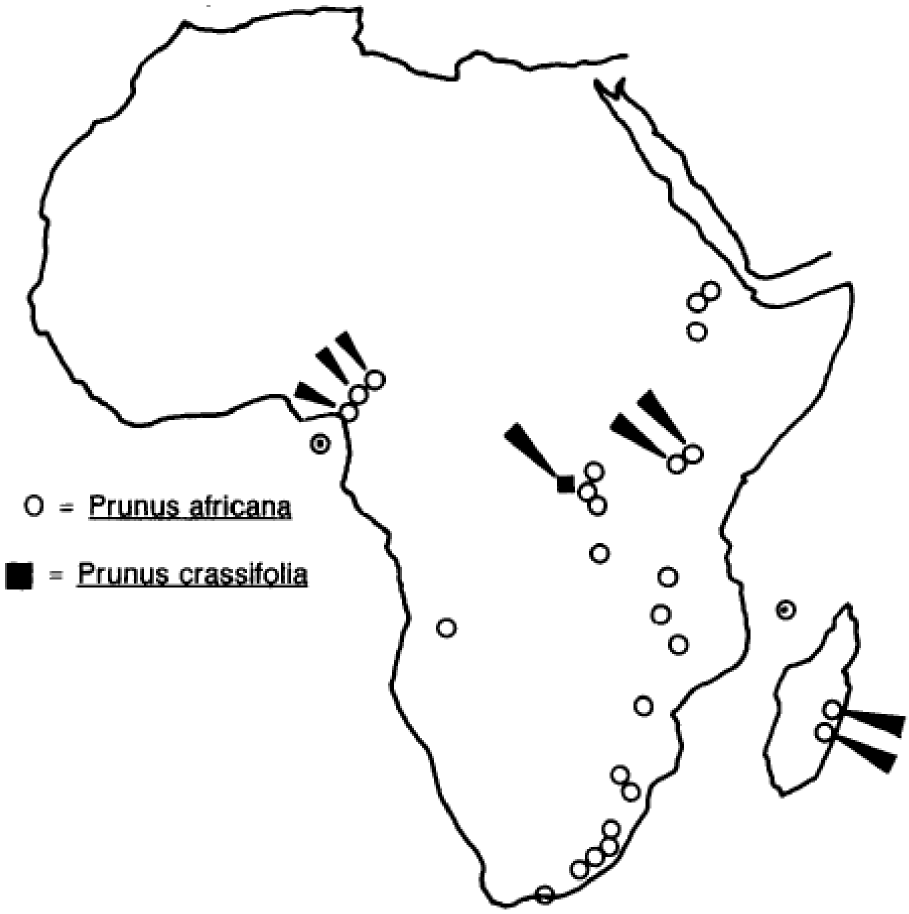
The promise of agricultural success has long resulted in dense settlement surrounding the Forest, making this area have one of the fastest growing populations in the country, with a 2.8% annual growth rate (Earlham University, 1999). With the steady increase in human population has come a corresponding increase in demands on the forest, Local populations rely on forest products for religious, medicinal, building, grazing, fuelwood, charcoal production, and water needs. Where once these extractive uses did not interfere with the natural regeneration of the forest, they now result in widespread species endangerment, as well as loss of ecosystem function.

Some NGOs have intervened to try and merge conservation issues with income generation and environmental education for local communities. International Centre of Insect Physiology and Ecology (ICIPE) and the Kenya Forestry Research Institute (KEFRI) have collaborated to initiate agro-forestry projects that emphasize the cultivation of medicinal plants that have been traditionally gathered from the forest (ICIPE, 2005). These plants are then processed by ICIPE into powder, salves and other forms, and sold in markets around the forest as well as in neighboring towns and as far away as Nairobi.

Two medicinal plants have been integrated into such programs with great success: *Ocimum kilamscharium* and *Mondia whytei*. Many farmers around the Kakamega forest are raising *Ocimum* . ICIPE purchases the raw plant material from farmers and processes it into a medicinal salve, Naturub™, which is then sold at local and regional markets. *Prunus africana* is another important medicinal species that inhabits the forest. Attempts to incorporate this tree into afro-forestry projects have failed thus far (Cunningham, 1993)

Prunus africana (Hook f.), also known as *Pygeum africanum*, or African Stinkwood, is a large evergreen tree from the Rosaceaea family. It is found in the montaine forests of Cameroon, Kenya, Zaire, and Madagascar (fig 3). It is an upper canopy tree that can grow as high as thirty meters (Hall et al, 2000). *Prunus* bark contains three active constituents including phytosterols, which are anti-inflammatory agents (Hall et al, 2000; Longo, 1981). It takes fifteen years for the bark to develop the active ingredients necessary for medicinal use (Longo, 1981). Traditional medicinal uses of the bark include the treatment of stomach aches, urinary and bladder infections, chest pain, malaria, and kidney disease.

Figure 3: Distribution of Prunus africana (Cunningham, 1993)



The international market for *Prunus* bark is focused on it use as a treatment of prostate gland hypertrophy and the closely related but more serious condition benign prostatic hyperplasia (Hall et al, 2000; Cunningham & Mbenkum, 1993). Prostate enlargement currently affects r >50% of men over the age of 50. The market for prostrate treatments, especially herbal remedies, is growing every year. Global demand rose from 2,800 Mg (tonne) in 1995 to 3,100 Mg in 1997 (Anonymous, 2000). The over-the-counter value of retail trade in the United States alone is approximately $220 million a year (Cunningham et al, 2002). The bark of *Prunus africana* is exported from Africa to Europe, mainly France, where it is processed and then distributed globally (Cunningham & Mbenkum, 1993). The demand of the market and the limited geographic distribution of *Prunus africana* has resulted in widespread endangerment due to over-harvesting Cunningham & Mbenkum, 1993; Hall et al, 2000).

In response to the growing scarcity, *Prunus africana* was declared endangered under CITES II (the convention on trade in endangered species) (Cunningham et al, 1997), and listed as vulnerable by the IUCN (IUCN, 2002). As a result, all imports and exports of *Prunus* must be declared. In addition, exporting countries must demonstrate that the source of the *P. africana* was harvested in a "sustainable" manner. Unfortunately, monitoring trade is difficult because *P. africana* is exported in many forms, including bark, bark extract, capsules, and tonic (Hall et al, 2000). In addition, a lack of regulatory infrastructure within forests where *P. africana* thrives lessens the efficacy of harvesting limitations.

Within the Kakamega forest, no large scale bark harvesting is currently occurring. In fact, there is no knowledge of the potential for a widespread *P. africana* bark market. (Fashing, 2004). *P. africana* has been found to play a key role in forest ecology. It is the primary food source for Colobus monkeys, the dominant primate species in the forest. Studies have shown that the tree is scarce throughout the forest (Fashing, 2004; Tsingalia, 1989). Attempts to propagate *P. africana* seedlings in nurseries as well as attempts to integrate them into agroforestry projects have largely failed.

In this study, I will address three main questions, as well as a number of sub-questions: 1) What is the distribution of *P. africana* in the Kakamega forest? More specifically, what is the density of seedlings/ saplings/trees across different management units? 2) Does herbivory influence seedling survival of *P. africana*? More specifically, what is the relationship between woodiness and insect damage? What is the proportion of woody vs. non-woody seedlings that have insect damage? 3) Does removal of insect herbivory increase seedling survival? More specifically, what is the survival of netted vs. non-netted seedlings? All of these questions are targeted at gaining a better understanding of the conditions under which *P. africana* can be successfully incorporated into agroforestry projects as a tool to combat scarcity and increase local income to farmers near the forest.

2. Methods

2.1 Study Area

The Kakamega National Forest is located in the Western Province (0.28º N and 34.8º E. It is a montaine forest, located approximately 1600m above sea level, has an average annual rainfall of 2,000 mm, and temperature ranges between 11º and 26º C in both the rainy (April-November) and the dry season (December-March). The forest lies in the Lake Victoria Basin, and is an important watershed for rivers that flow into Lake Victoria such as the Isiukhu and Yala.

The forest is governed by two separate management bodies: the Forest Department (FD) and the Kenya Wildlife Service (KWS). The majority of the forest (approximately 200 km^2) is managed by the Forest Department. This area was established as a National Forest in 1933, and affords free entrance to the public. Within this area limited extractive use is permitted, including deadwood and grass collection and licensed cattle grazing. In the past, some licensed commercial logging of plantations was also permitted, though currently there is a country-wide logging ban which prohibits such activity. KWS governs only approximately 40 km^2 of the northern area of the forest, which was designated a National Reserve in 1986. There is only one legal entrance into this area, through the forest station. Within this portion of the forest there is a policy of allowing no extraction of natural resources or biota.

2.2. Data Collection

2.2.1 Plot Stratification

As mentioned before, the land cover of the Kakamega forest is very heterogeneous (fig 2). Plots were stratified based on land cover type, age, and managing agency. This was done using land cover maps from 1975-2000 obtained from the Kenya Department of Remote Sensing and Resource Survey (DRSRS). These maps were created by DRSRS using aerial photography as well as Landsat TM satellite images (Rogo et al., 2003). The maps identified three types of tree cover: indigenous forest, hardwood timber plantation, and softwood timber plantation. Field observations as well as Forest Department registry records resulted in the addition of a fourth forest class: mixed indigenous plantation.

In addition to land-use cover, plots were further stratified according to age. ‘Young plots were identified as areas that had regenerated or been planted between 1986 and 2000 (< 14 years old in 2000), while ‘old’ plots were present before 1986 (> 14 years old in 2000). Indigenous forest plots were also classified according to the management body: Kenya Wildlife Service (KWS) or Forest Department (FD). It should be noted that within the indigenous forest classification an ‘old’ plot would contain vegetation of many ages, due to forest successional patterns as well as local disturbances. In addition, both ‘old’ and ‘young’ plots represent a range of stand ages. For example, registry data indicates that while some hardwood plantations were established 50 years ago, others may be only 25 years old (Kakamega Forest Department, 2003, Glenday, 2004).

A total of 95 plots were sampled. The number of plots sampled in each sampling class was roughly proportional to the amount of forest area covered by each class. In addition, heterogeneity of indigenous forest structure (as opposed to plantations) was also considered (table 1).

Table 1:Plot stratification

Strata	# of ‘old’ plots	# of ‘young’ plots	Total # of plots
Forest Department Indigenous Forest (IF-FD)	32	11	43
Kenya Wildlife Service Indigenous Forest (IF-KWS)	14	5	19
Mixed Indigenous Plantation (MI)	4	6	10
Softwood Timber Plantation (SW)	5	5	10
Hardwood Timber Plantation (HW)	6	7	13

Within the indigenous forest areas, established footpaths and roads were used as transects. Perpendicular distances between 0 and 500m from the path were randomly generated, and plots subsequently established. Plantation blocks were identified using DSRS maps as well as the Kakamega Plantation Registry (Kakamega Forest Department, 2003). Plots were established at random within each block. All plot locations were recorded using a GPS unit. These locations were then geo-referenced using the 2000 land cover map created by DRSRS. When ground-truthing did not match with the map classification, the cover class was determined by the ground assessment.

2.2.2 Plot data

For each plot a 20x20m square was cut using machetes, and corners identified using compasses and measuring tape. Within each 20x20m area, all adult *Prunus africana* trees were identified, and their DBH was measured. Qualitative information about bark condition, branching, and insect damage was also noted. A nested 10x10m square was cut in the bottom right corner of the plot. In this area all *Prunus africana* saplings with a height> 50 cm were identified. Their height, # leaves, and average leaf length were measured. In addition, the presence or absence of insect damage as well as woodiness was noted. Five 1x1m sub-plots were placed at the four corners and center of the 10x10m plot. Within these sub-plots all seedlings and saplings (of all heights) were identified. Their height, # leaves, and average leaf length were measured. As in the 10x10m plot, woodiness and insect damage were also recorded.

As mentioned above, a handheld GPS unit was used to mark plot locations. In addition, the altitude and slope of each plot was also determined. Within each plot, dominant trees, shrubs, and herbs were identified. In addition, conditions such as number of canopies (1-3), density of vegetation (low, medium or high), ground level light (qualitative scale from 1-5), depth of leaf litter, and color of soil were recorded. Path presence within a plot (or nearby) was also recorded, and potential path use (such as fuelwood collection, hunting, grass collection, and cattle grazing) was noted. Human disturbance within (or near) each plot (such as logging, fuelwood gathering, plant or bark harvesting, grass collection, charcoal pits, grazing, and hunting) was also recorded.

2.2.3 Herbivory Data

In addition to data collected on wild populations of *Prunus africana*, an experimental study of herbivory was also conducted. Two hundred ninety eight seedlings, germinated from seeds collected within the Isecheno Nature Reserve, and grown in the Kakamega Environmental Education Program (KEEP) nursery, were used in the study. All of the seedlings had been germinated at the same time (approximately 1 month prior to the study), and given the same water and light treatments (full sunlight, periodic watering). In addition, all of the seedlings were potted in plastic bags of the same size (though some were black and some clear), using the same soil. It should be noted that 'healthy' seedlings (those without extensive insect damage) were selected for use in this study.

Seedlings were randomly divided into nine subgroups of 33 and Wire-mesh screening placed over six of the subplots, The netting was sewn together using wire thread to construct 1.5x 0.5x1m nets,. Seedlings divided into 8 rows, with poles separating the rows and four poles at the corners to hold the net in place. Shallow trenches were dug around each net and approximately 4 cm of the bottom of the nets were buried to keep herbivores from crawling under. Three control subplots were arranged in the same manner (8 rows, poles separating rows, and four stakes) but had no netting applied.

Every three months the height, number of leaves, and average leaf length for each seedling was recorded, over a nine-month period. In addition, every two weeks the total number of leaves, and the number of those leaves with insect damage was also recorded for each plant. Death and re-sprouting of seedlings, as well as the presence of any insects, was also noted. All of the sub-plots were located in the same geographic area, thus there was no spatial replication.

2.3 Statistical Analysis

2.3.1 Field data

Student T-tests (assuming unequal variances) were performed to identify whether there were significant differences in the density of *Prunus africana* across the land classes. First of all, densities in the indigenous forest were compared to those in the plantations. In addition, *Prunus africana* densities in indigenous forest managed by KWS and the FD were compared. Finally, the densities of the old and young plots of each class were compared. All analyses were executed separately for seedling, sapling and tree densities. Data were also analyzed in R 2.1.0 (R Core Development Team, 2005), using the STATS package. Density measurements were transformed to log + 1. Single factor and mixed model ANOVAs were used. F values for the mixed model ANOVA were calculated by hand (Sokal and Rohlf 1981).

2.4.2 Herbivory data

Student T-tests (assuming unequal variances) were performed to ensure that there was not a significant difference in the seedlings (measured by number of leaves) that were netted and those that were not. In addition, student t-tests were performed to assess differences in insect damage (measured by proportion of leaves with insect damage) between the netted and non-netted subplots over time. It should be noted that dead seedlings were identified as being completely damaged by insects (proportion insect damage=1). In addition, ANCOVA was used to determine differences in regression lines between netted and non-netted treatments over time.

3. Results

3.1. Distribution of Prunus africana

3.1.1 Seedling Density

Overall, seedling density throughout the Kakamega forest was very low. More than 70% of the plots measured contained no *Prunus africana* seedlings. Only 10% contained more than 1 seedling (fig. 4). In spite of this overall low density trend, approximately 16% of the indigenous forest plots contained between 1 and >100 seedlings. In addition, 60% of softwood plantation plots contained 1-10 seedlings, 50% of mixed plantation plots contained 1-100 seedlings, and 26% of hardwood plantations contained 1-10 seedlings (fig. 5).

Figure 4: Histogram of overall seedling density

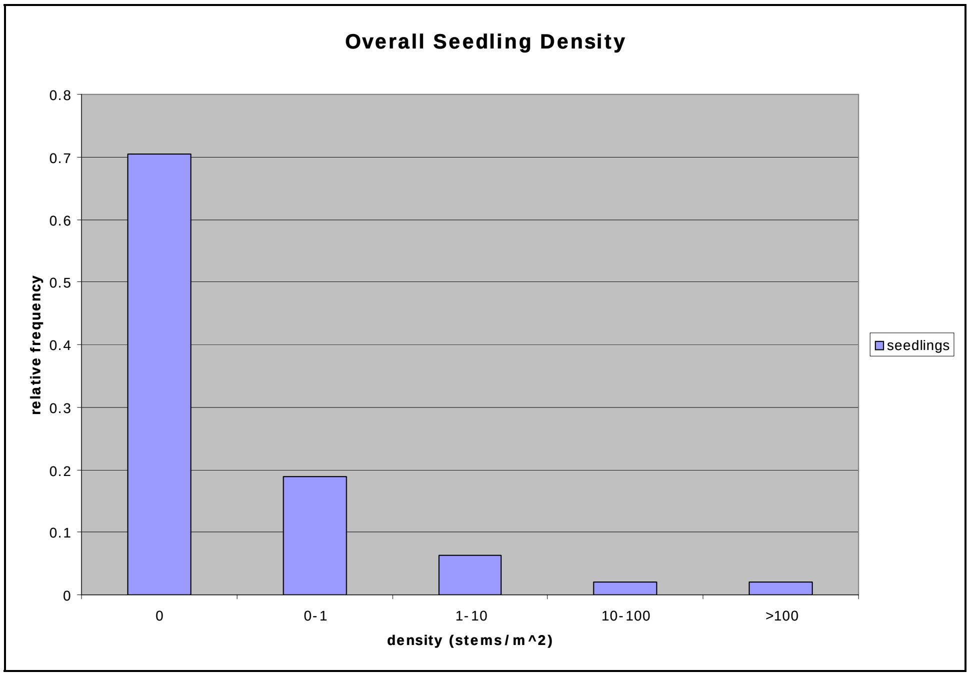


Figure 5: Histogram of seedling density across strata

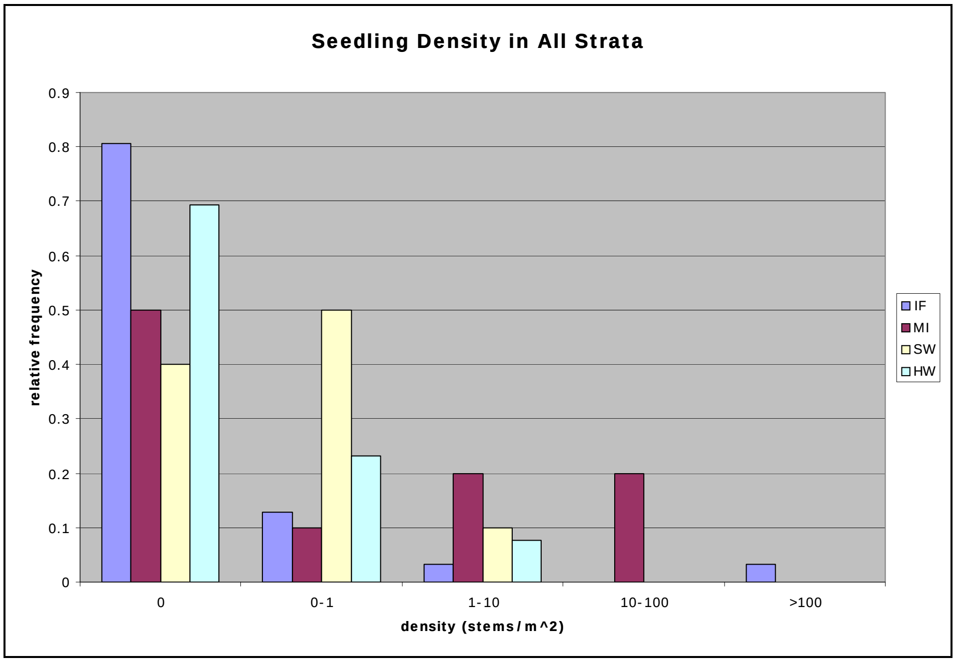


Table 2: Effect of land cover class (LCC; Indigenous Forest or Plantation.) on seedling, sapling, and tree density from single factor ANOVA.

	Source of variation	**df**	**SS**	**MS**	**F**	***P***
Seedling	LCC	1	.75	.75	1.0071	.3182
	Error	93	69.29	0.745		
Sapling	**LCC**	**1**	**.00025**	**.00025**	**4.130**	**.04497**
	Error	93	.00056	.00006		
Tree	LCC	1	.00001	.00001	2.161	.1449
	Error	93	.00059	.000006		

Table 3: Effect of Management Body (KWS or FD) and Forest Age on seedling, sapling and tree density from mixed model 2-way ANOVA.

	Source of Variation	**df**	**SS**	**MS**	**F**	**P**
Seedling	**Management Body (MB)**	**1**	**1.097**	**1.097**	**1.3396**	**<.0001**
	Plot Age (PA)	1	.414	.414	.5056	.4799
	MB + PA	1	0.162	0.162	0.1983	0.6578
	Error	58	47.51	0.819		
Sapling	**Management Body (MB)**	**1**	**.0000036**	**.000004**	**2.82**	**0.0344**
	Plot Age (PA)	1	.0000006	.0000006	0.3644	0.5484
	MB + PA	1	.0000013	.0000013	0.8097	0.3719
	Error	58	.0000919	.0000016		
Tree	Management Body (MB)	1	0.000000002	0.000000002	0.0028	0.8406
	Plot Age (PA)	1	0.0000031	0.0000031	1.811	0.1836
	MB + PA	1	0.0000007	0.0000007	0.4206	0.519258
	Error	58	0.0000981	0.0000017		

For seedling density, there was no significant difference between plantation and indigenous forest plots and no significant difference between FD and KWS plots (fig 6). Single-factor ANOVA of the effect of land-cover class (indigenous forest or plantation) indicated no significant difference in seedling density between indigenous forest and plantation plots (P>0.05). (Table 2) However, mixed model two-way ANOVA of the effect of management body (FD or KWS) and forest age (young or old) on density indicated significantly higher density in FD indigenous forest plots than KWS (P<0.0001; Table 3). Mixed model ANOVA of the effect of strata (KWS-IF, FD-IF, MI, SW, HW) and plot-age on density indicated that young (< 14 years old) FD indigenous forest plots had significantly higher seedling density than all other strata (Table 4)

Figure 6: 95% Confidence Interval for Mean Seedling Density across Strata

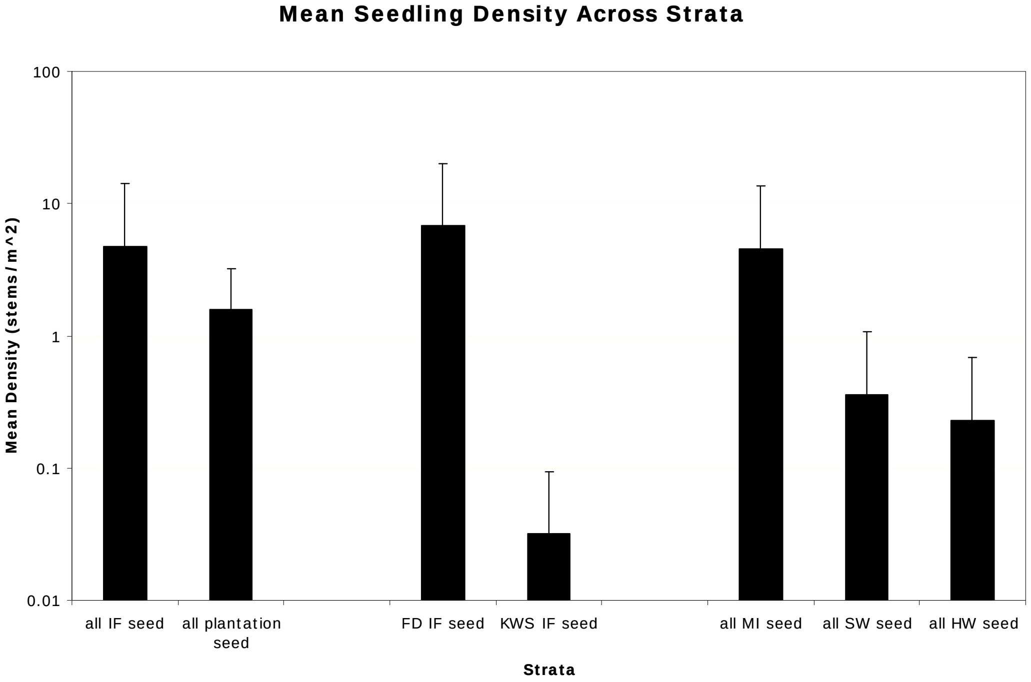


Figure 7: 95% Confidence Interval for Mean Seedling Density in Young vs. Old Plots

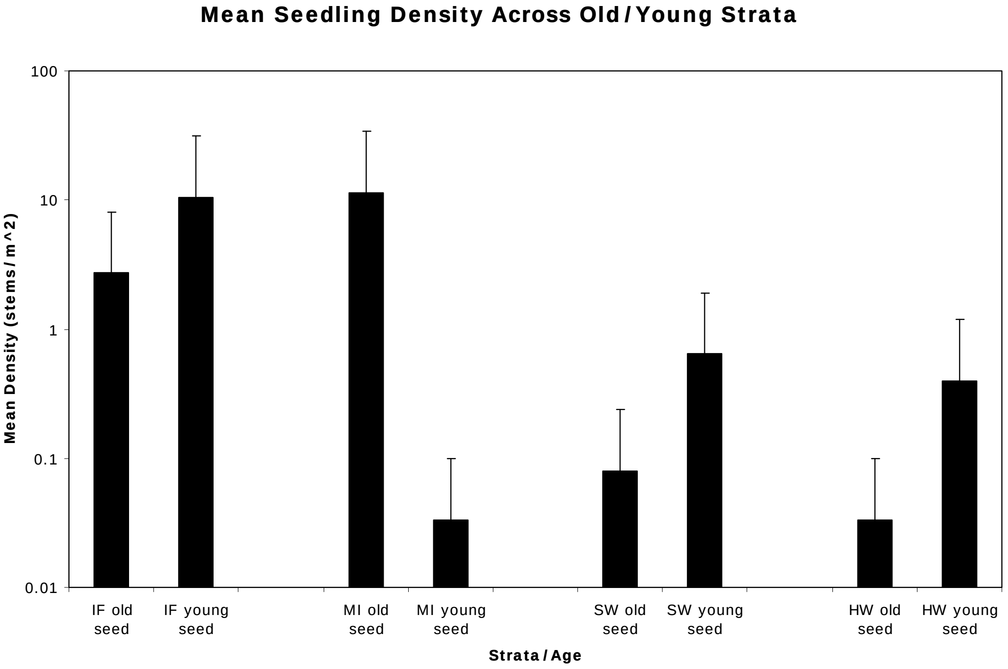


Table 4: Effect of Strata and Plot Age on seedling, sapling, and tree density from mixed model ANOVA.

	Source of Variation	**df**	**SS**	**MS**	**F**	*P*
Seedling	Strata[=]	4	5.47	1.367	0.432	0.71430
	Plot Age (PA)[==]	1	0.102	0.102	0.1668	0.684007
	Strata + PA	**4**	**12.643**	**3.161**	**5.1839**	**0.000873**
	Error	85	51.827	0.610		
Sapling	**Strata**	**4**	**0.00048**	**0.00012**	**3.545**	**0.0055**
	Plot Age (PA)	1	0.00015	0.00015	2.6399	0.10791
	Strata + PA	4	0.00048	0.00012	2.1647	0.07985
	Error	85	0.00047	0.000055		
Tree	**Strata**	**4**	**0.000061**	**0.000015**	**7.74**	**<<0.001**
	Plot Age	1	0.00000015	0.00000015	0.0232	0.87934

	(PA)					
	Strata + PA	4	0.0000079	0.00000198	0.3112	0.86979
	Error	85	0.0005398	0.00000635		

[=] Strata refers to either KWS-Indigenous Forest, FD-Indigenous Forest, Mixed Indigenous Plantation, Softwood Plantation, or Hardwood Plantation.

[==] Plot age is either young (> 14 years) or old (<14 years)

3.1.2 Sapling Density

Overall, *Prunus africana* sapling density was even lower than seedling density. In over 90% of the plots, there was not even 1 sapling (with height > .5m; fig. 8). Student T-tests indicated significantly higher mean sapling density in plantation plots than in indigenous forest plots (P=.005). There was no significant difference between FD and KWS plots, however. Single-factor ANOVA of the effect of LCC on density also indicated a significant difference between indigenous forest and plantation plots (Table 2). Mixed-model two-way ANOVA of the effect of management body and plot age on density found that KWS had significantly higher sapling densities than FD plots (P<0.05; Table 3). Mixed model ANOVA of the effect of strata and plot age found that SW plantations had significantly higher seedling density than all other strata (P<.01; Table 4).

Figure 8: 95% Confidence Interval for Mean Sapling Density across Strata

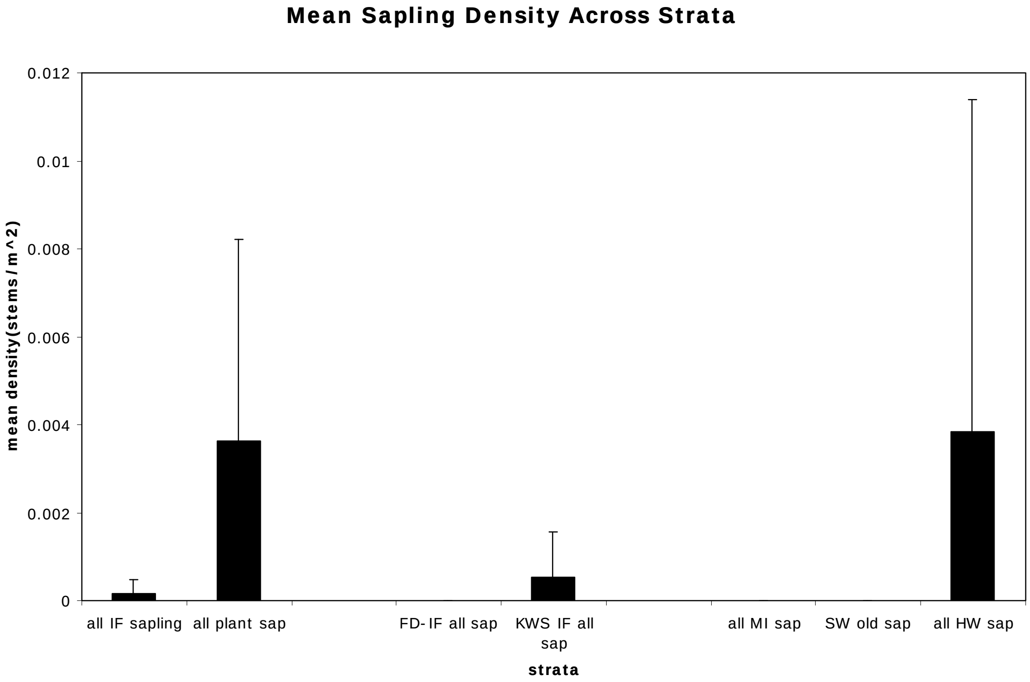
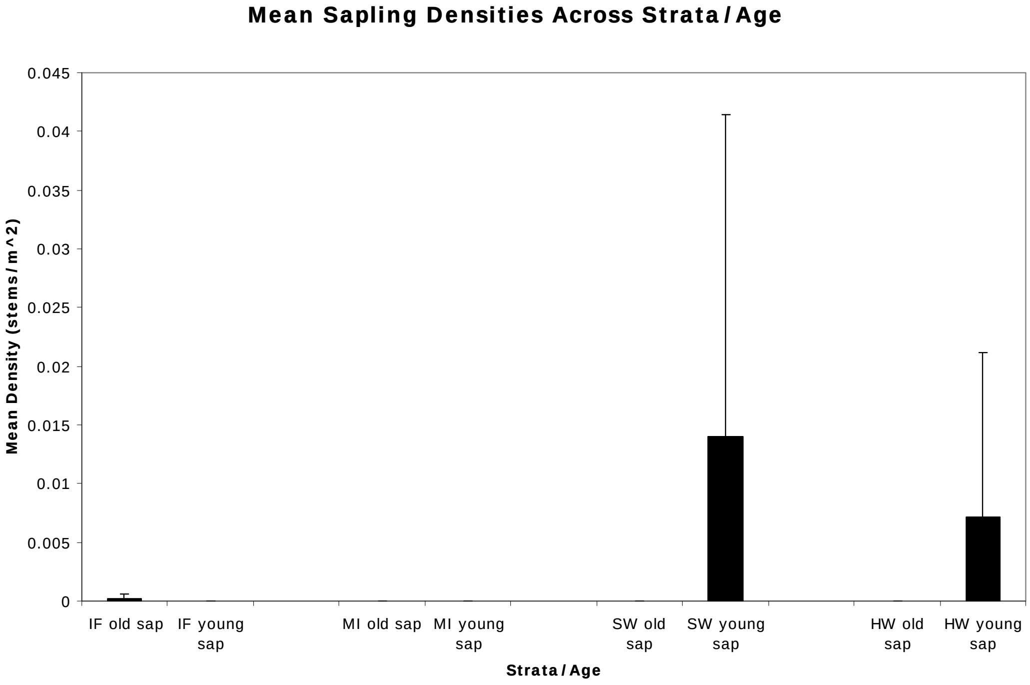


Figure 9: 95% Confidence Interval for Mean Sapling Density in Young vs. Old Plots



3.1.3 Tree Density

As in the seedling and sapling classes, overall tree density in the Kakamega Forest was very low. Over 85% of the plots contained no *P. africana* trees (fig. 11) and none of the softwood plantation plots contained any *P. africana* trees. Twenty percent of mixed-indigenous plantation plots contained 1 *Prunus Africana* tree. Approximately 10% of indigenous forest and hardwood plantation plots also contained 1 *P. Africana* tree, and approximately 17% of hardwood plantation plots contained 4-40 trees. Student T-tests indicated significantly higher mean tree densities in plantations than indigenous forests (P=.029). However, single-factor ANOVA of land-cover class indicated that the difference between overall density (as opposed to mean density) is, in fact, not significant (Table 2). Mixed-model two-way ANOVA of effect of management body indicated no difference in tree density between KWS and FD (Table 3). Mixed-model ANOVA of effect of strata and plot age indicated significantly higher tree density in hardwood plantations than in all other strata (p<<.001; Table 4).

Figure 10: Histogram of Overall Tree Density (dbh > 5 cm)

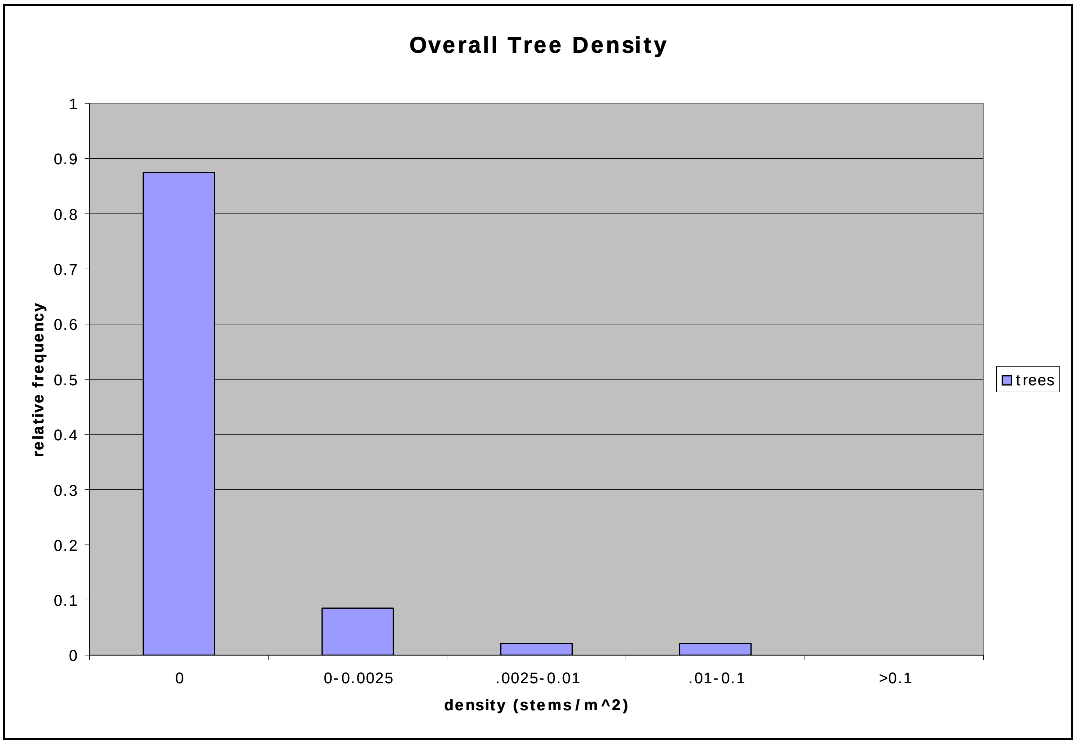


Figure 11: Histogram of Tree Density across Strata

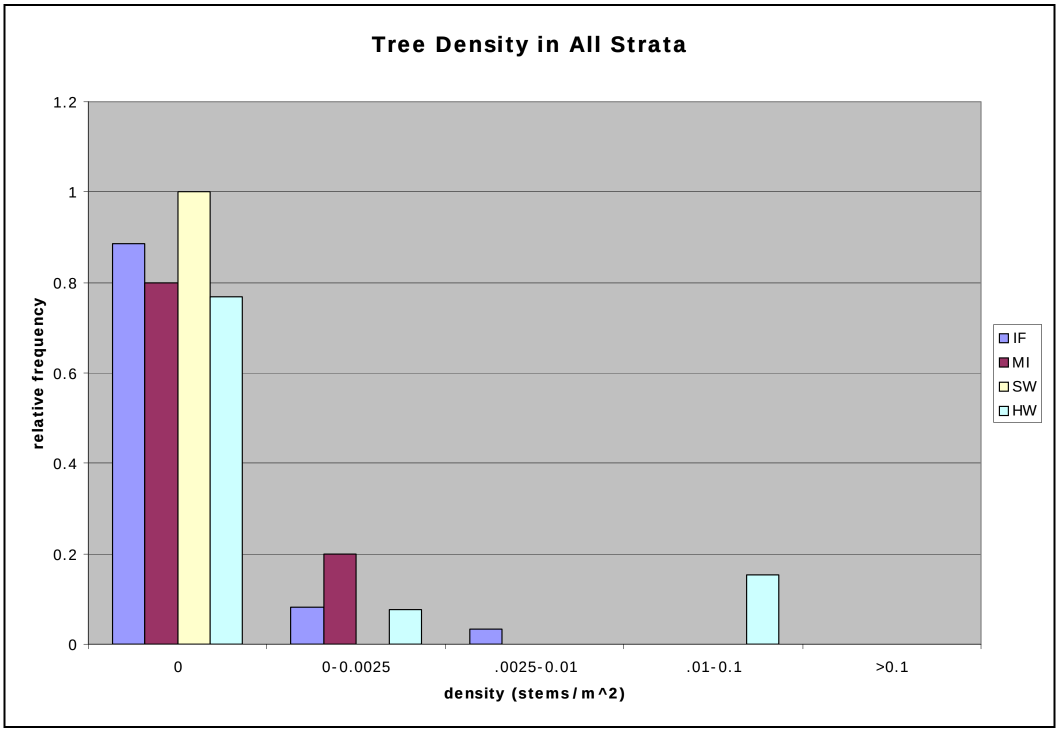


Figure 12: 95% Confidence Interval for Mean Tree Density across Strata

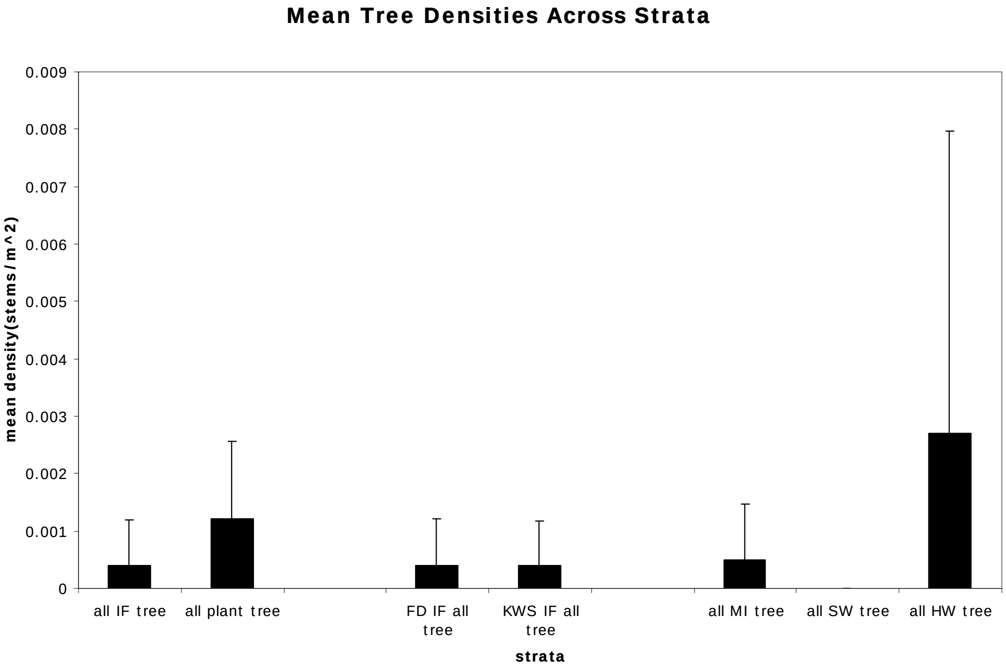
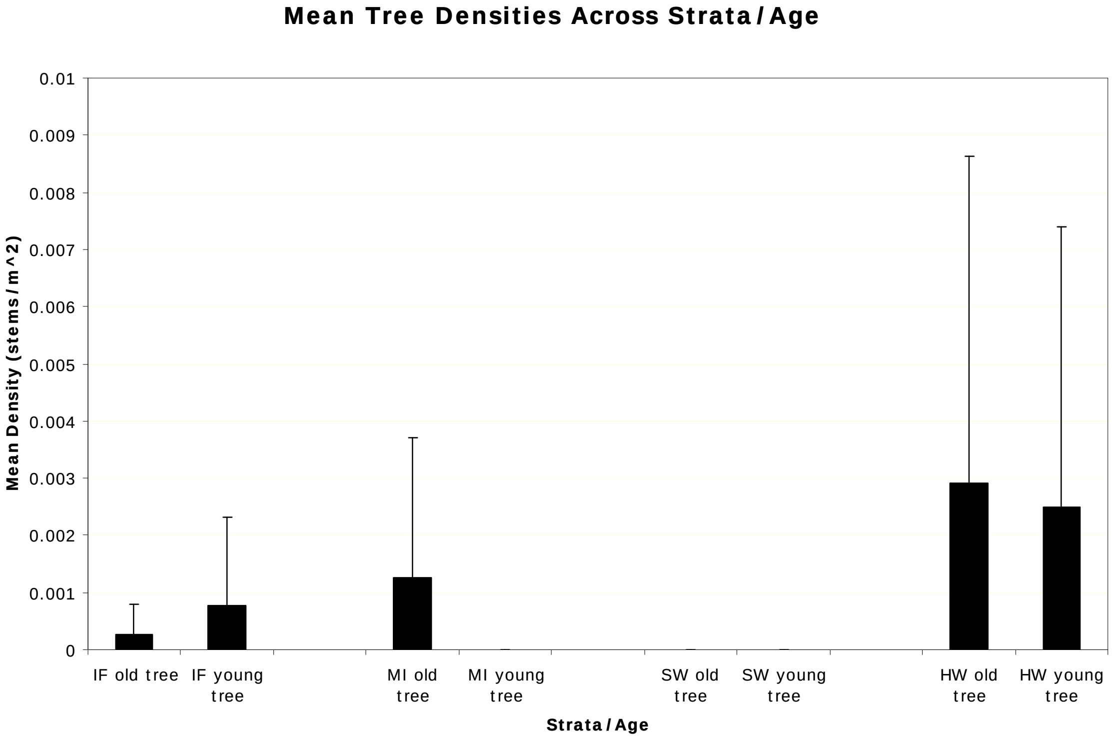


Figure 13: 95% Confidence Interval for Mean Tree Density in Young vs. Old Plots



3.2 Insect Damage

The relationship between insect damage and woodiness was examined in seedlings. Only 35% of non-woody seedlings exhibited insect damage, whereas over 85% of woody seedlings showed insect damage. A chi-squared test for this relationship gave a χ^2=49.3 (Tables 5a, 5b). This resulted in a significantly higher presence of insect-damage in woody stem seedlings than non-woody-stem seedlings with $P<<0.001$.

Table 5a: Observed Values of Chi-Squared Test for relationship between woody stem and insect damage

	Presence of Woody Stem	**No Woody Stem**	**Total**
Presence of Insect Damage	489	266	755
No Insect Damage	6	41	47
Total	495	270	802

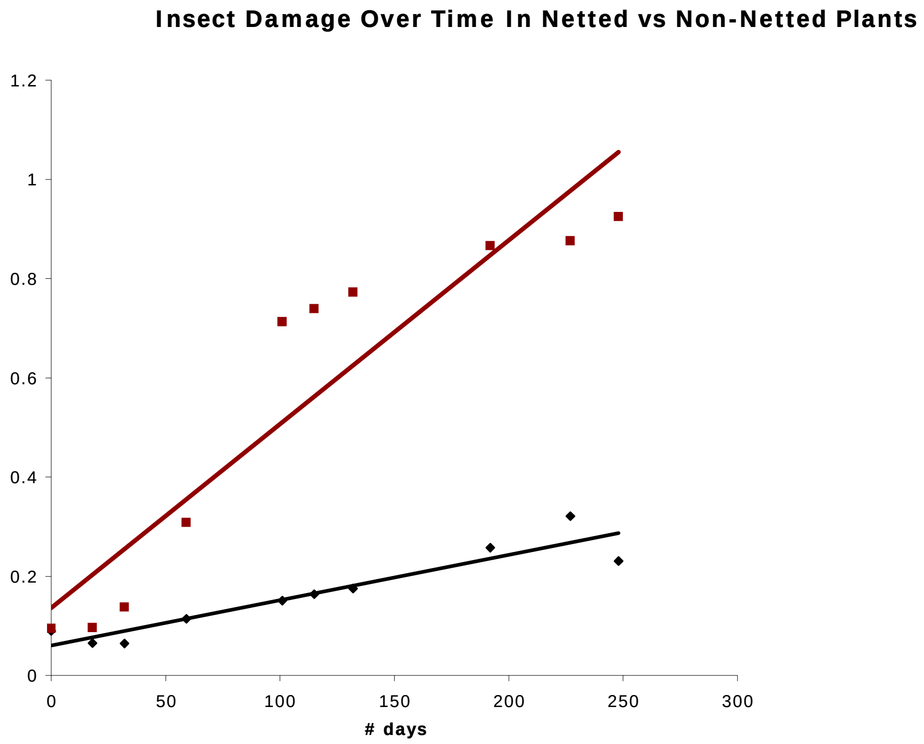
Table 5b: Chi-Squared Values

χ^2	Df	P
49.3	1	<<0.001

3.3 Herbivory Study

Student T-tests indicated that the number of leaves as well as the proportion of leaves with insect damage for netted and non-netted plants was not significantly different (P>0.05) when the study began. ANCOVA was used to determine difference in regression lines of insect damage over time for each treatment. The relationship between duration of exposure and average proportion of insect damage is significantly greater in non-netted plants than in netted plants (P<.001; Fig. 14). Over time, non-netted plants experience significantly more insect damage than those under nets.

Figure 14: Regressions for Insect Damage over Time in Netted and Non-netted Seedlings



4. Discussion

This study proposed to answer a series of questions about the status of *P. africana* in the Kakamega forest. In this section I will discuss the answers my research provided to the following questions: 1) What is the distribution of *P. africana* in the Kakamega forest? More specifically, what is the density of seedlings/ saplings/trees across different management units? 2) Does herbivory influence seedling survival of *P. africana*? More specifically, what is the relationship between woodiness and insect damage? What is the proportion of woody vs. non-woody seedlings that have insect damage? 3) Does removal of insect herbivory increase seedling survival? More specifically, what is the survival of netted vs. non-netted seedlings? All of these questions are targeted at gaining a better understanding of the conditions under which *P. africana* can be successfully incorporated into agro-forestry projects as a tool to combat scarcity and increase local income to farmers near the forest.

4.1 Distribution of Prunus africana

Data analysis suggests that overall, there is low density of *Prunus africana* in the Kakamega forest for all age classes (seedlings, saplings, and trees). Yet there is some variance in density among strata and management type, which has interesting implications. First of all, it seems that plantations are an important habitat for seedling recruitment as well as for saplings and trees. Softwood plantations, for example, are a critical habitat for saplings. This could be a result of increased light availability in softwood plantations due to the fact that there tends to simpler canopy structure to these forests. Tree density is higher in plantations than indigenous forest, which is likely a result of plantings by the forest department. Hardwood plantations had significantly higher tree densities than all other strata, because some of these plots were *P. africana*-only plantations

The significance of plantations as habitat for all age classes is important to note, because while there is currently a country-wide logging ban, it is anticipated that this ban will eventually be lifted, making *P. africana* even more vulnerable to habitat fragmentation and subsequent decreases in population size and genetic diversity. It is also interesting that for seedlings and saplings there are higher densities in FD indigenous forest than KWS indigenous forest, despite the fact that enforcement of management rules is stricter in KWS land. This could be a result of decreased light availability in KWS plots due to thicker canopies, which result from extraction limitations.

4.2 Drivers of and Solutions to Scarcity

Field observations and past research (Fashing, 2004; Tsingalia, 1989) indicate that human harvesting is not driving the scarcity of *P. africana* within the forest. This is not to say that the effects of logging, fuel-wood extraction, and other anthropogenic stresses are not indirectly influencing this scarcity. While specific herbivores have not been identified, insect damage seems to play a key role in survival past the seedling stage. In order for agroforestry projects to succeed, special care must be taken to protect seedlings from detrimental effects of herbivory.

Netting, for example significantly increases the survival rate of seedlings, making large-scale projects more feasible for farmers. Netting provides low-cost, high-return protection for seedlings. There are some important limitations to incorporating *P. africana* into these projects, however, such as the long-maturation time of *P. africana (*15 years). When coupled with other medicinal, food, and timber species, however, agroforestry of *P. africana* becomes more economically feasible. By mixing short-term and long-term economic returns, farmers are better able to commit to agroforestry programs. In addition, intercropping with other species can protect from widespread herbivory attacks.

4.3 Obstacles to Agroforestry

Disseminating information about ideal ways to grow *P. africana* to farmers— and encouraging communication between farmers— is a challenge due to a lack of basic infrastructure around the forest (roads, etc). ICIPE and KEFRI could address this problem by leading educational workshops. The implementation of monitored pilot workshop programs could provide farmers with assistance in procuring materials and educational support for successfully growing *P. africana*, much like the pilot *Ocimum* and *Mondia* programs did.

Creating a market consistent with CITES II restrictions creates an obstacle that must be overcome. Because small scale farmers do not have the funding to generate the scientific data necessary to that proving sustainable harvesting, as required under CITES II, it would be difficult for the farmers to gain approval to export their products. NGOs such as ICIPE could serve as 'middle-men', with farmers selling raw materials to NGOs who would then process and export the *P. africana*'s medicinal products. This system has worked in the case of *Ocimum*, where ICIPE buys the plant material from farmers and processes it into Naturub,™ a popular medicinal salve for chest congestion. There is also a vibrant local market for *P. africana* which could be taken advantage of by farmers independent of NGOs. This could catalyze local income generation by allowing farmers to engage in economic activity within their communities.

In addition to serving as a tool for local income generation, agroforestry projects could be used for future ex-situ propagation of *P. africana* which themselves could be useful for the regeneration of forest populations.

4.4 Future research

Future projects should focus on monitoring the survival of transplanted netted and non-netted plants into forest gaps. This kind of investigation could gauge the efficacy of agroforestry projects in regenerating forest populations. In addition, the threshold that woody seedlings must pass under nets before they can survive in the open should be further examined. This examination would provide information on how much extra effort needs to be put into netting, which would contribute to the success not only of the agroforestry projects themselves, but to the regeneration work as well. Further research should also focus on identifying specific herbivores that prey on *P. africana.* This research could identify possible effects of large-scale planting of exotic tree species within a forest system.

Acknowledgments

I would like to thank Steve Hamburg for his enduring patience and guidance throughout this long process. Also, a big thank you to all of the elite members of “Team Thesis” for all of the dictation and cola-flavored candy. A special thanks to Carmichael’s associate for the arsenal of soft tacos and Dr. Peppers as well. Thanks to my MIA banda-mates, Lauren McGeoch and Julia Glenday, and to Patrick Luteshi, Bonface Shimenga, and Winstone Opondo of Kakamega Environmental Education Program (KEEP) for all their help and soccer routines. Thanks to my family for all of the long-distance phone calls and air-mail gluten-free cakes. This work could not have been done without the support of the Luce Fellowship Program and the RAB Grant.

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