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Influence of Thinning and Pruning Regime on Woody Species Density and Abundance

Emma Anyango, Dr. Joyce A. Obuoyo (PhD), Prof. Boniface O. Oindo (PhD).

School of Arts and Social Sciences, Department of Geography and Natural Resources Management, Maseno University.

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ABSTRACT

The revival of forests is gaining prominence, with a focus on common tree species. However, the most affected species by fragmentation are the exotic woody species; therefore attention to forest silvicultural practices is essential. Kenya is acknowledged as one of the nations that value its forest environment greatly, although there are still restrictions on the application of silvicultural regimes there. This is a result of the continued strong demand for wood. It is anticipated that silvicultural regimes would eclipse Kenya's fragmentation tactics. Thus, the goal of this research was to evaluate the influence of thinning and pruning regime on the woody species density and abundance in Kimondi forest, Nandi County, Kenya. This study was centered on *Eucalyptus saligna, Cupressus lusitanica and Pinus patula* as the woody species that are harvested for timber in Kimondi forest. The island biogeography theory served as the basis for this research. The number of woody species per plot, the basal area per plot, the different types of woody species, the total number of each woody species in the study area, the diameter at breast height, soil type, plantation size, soil depth and forest pest were the intervening factors. The study employed a cross-sectional descriptive study design. The study area's species types were observed, observation schedule was filled, 30 sample plots were randomly selected each measuring 20m by 20m, and the number of woody species in each plot counted and recorded as the primary data. To assess the appropriateness of the species chosen, Two-way Analysis of Variance was used. Based on the study's findings, Effect size is 36.098%, hence 36.098% of the variation of the abundance and density of woody species can be explained by the thinning and pruning regime. There was a significant interaction. In thinning and pruning regime, *Pinus patula* was the most abundant with amean and standard deviation of $6.433^{a} \pm 2.37$, *Cupressus lusitanica* had $4.467^{b} \pm 1.74$ while *Eucalyptus saligna* had $3.267^{c} \pm 1.74$. There was a significant difference in the woody species abundance indicated byLSD = 0.711 and p-value = 0.001**. The importance of this research was to raise awareness about the application of silvicultural regimes to enhance the density and abundance of woody species in Kimondi Forest, Nandi County, Kenya, in order to mitigate the consequences of increasing forest fragmentation andspecies extinction

Keywords: Silvicultural regimes, thinning and pruning regime, woody species abundance, woody species density

INTRODUCTION

Worldwide, regeneration is typically essential to maintaining forests and reforesting areas devoid of trees (Zhou *et al.*, 2016). According to Maetzke *et al.,* (2017), regeneration happens through silvicultural regimes ("natural regeneration"), which artificially apply thinning and pruning at various intervals. According to a study by Liu (2019), the inability of Norway spruce and Scots Pinus patula to naturally regenerate in Northern Europe has led to the introduction of a number of regeneration regimes that partially shaded or protected seedlings from harsh environmental conditions. In either scenario, the growing potential of the regeneration and the extent to which its surroundings permit the production of potential determine its productivity. According to Charton (2020), thinning and pruning regimes are necessary for all regeneration models, whether they involve artificial or spontaneous regeneration. Natural regeneration is the process through which forests are regenerated using coppicing, self-sown seeds, or root suckers (Binglin *et al.,* 2020). However, because the majority of broadleaves regenerate through coppicing and pruning, they are insufficient to serve as a reliable indicator of how silvicultural regimes affect the density and abundance of woody species (Binglin *et al.,* 2020). Woody species like *Pinus patula and Cupressus lusitanica* are used for pruning and thinning at various intervals (Gebeyehu, *et al.,* 2021). The majority of these research have shown that appropriate temperature, moisture, and aeration conditions are necessary for the regeneration of woody species, including *Pinus patula and Cupressus lusitanica.* However, the density and abundance of these hardwood species are influenced by their management, which is why it's important to identify the silvicultural regimes that strengthen woody species.

Due to over harvesting, up to 40% of Australia's forests are now fragmented. Agreements have been made to gradually phase out native forest logging in Australia in response to growing environmental concerns about the sustainability of native forestry techniques. Australia is currently pushing plantations as a long-term wood supply solution (Basaglia *et al.,* 2015). Common practices include pruning and thinning, which are done to guarantee the quality of the finished product. By the time they are 13 or 15 years old, up to 70% of trees have been removed (Basaglia *et.al.,* 2015). The thinned logs are usually not suitable for sawn timber applications because of the high rate of defects hence the need to combine both thinning and pruning (Carina *et al.,* 2016). When compared to sawn timber, engineered wood products can lessen the impact of inherent faults and transform them into more uniform structural products with greater strength and less variability in mechanical qualities (Carina *et al.,* 2016). Engineered wood products are typically created by shaping veneers, strands, and flakes using procedures like peeling, chipping, or slicing, then joining them with adhesives to create structural goods with shapes like wood panels (Velamazán *et al.,* 2018). The use of engineered wood products as a competitively priced building material is growing in acceptance (Velamazán *et al.,* 2018). Recently, energy-intensive materials have also been replaced by engineered wood products made from low-value thinned trimmed logs. The significance of the thinning and pruning routine is mentioned by these scholars. The focus of these investigations was on engineered wood products rather than a range of woody species, which is a drawback. Thus, it summarizes the main findings of this study regarding the significance of thinning and pruning *Eucalyptus saligna, Pinus patula,* and Cupressus *lusitanica* trees.

Zhou *et al.* (2012) conducted a study in Saudi Arabia to examine the impact of thinning on several wood quality indices. The study was based on a high initial density plantation of Acacia salicina trees, which was subsequently thinned to promote high individual tree growth suited for saw-timber production. In 1998, the trees were planted at a density of 6400 trees ha-1, with a 1.25 × 1.25 m spacing between each tree (Zhou *et al.,* 2012). Beginning after the population had been there for two and a half years, annual mechanical thinning was carried out until 2003 (You *et al.,* 2015). For the thinned and unthinned stands, respectively, densities of 400 and 3200 trees ha-1 were maintained from 2004 to 2010 (You *et al.,* 2015). In order to measure the wood specific gravity, fiber length, shrinkage behavior, and sapwood-heartwood ratio, and growth-ring width, five randomly chosen trees from each of the two stands were felled in 2010 and disk samples were taken (Syampungan *et al.,* 2016). When comparing the breadth of annual growth rings in a tree-thinned population to growth rings in an unthinned population, the width rose by 155-25%. According to Noguchi *et al.* (2017), the production of sapwood and heartwood at a given height level was 4-5 and 4-6 times higher in the thinned population than in the unthinned population. The influence of thinning on fiber length varied with position across the wood disc's radius, but the length of the fiber did not alter much. However, thinning resulted in a 3.8% fall in the specific gravity of wood, going from 0.523 in the unthinned population to 0.503 in the thinned population (Dang *et al.,* 2018). The study conducted by Dang *et al.,*

(2018) revealed that the tangential shrinkage of wood in thinned trees displayed a distinct fluctuation pattern along the radius, with the highest mean value of 8.24% reported. These studies demonstrate the significant benefits of thinning for woody species' DBH, even though thinning cannot always highlight a woody species' superior quality of wood. Therefore, it is imperative to use both thinning and pruning as silvicultural regimes to promote the abundance of woody species.

According to Deng *et al.,* (2019), species abundance, tree density, and basal area of woody species increased gradually throughout the climatic gradient from north to south in Burkina Faso's protected forests in West Africa. According to Deng *et al.*, (2019), in order for a species to survive in the short- and medium-term, it must have access to a steady supply of moisture through thinning and pruning; be free from extremely high or low temperatures; and have enough light to enable growth and respiration through photosynthesis without placing undue stress on the species. Longer term, there needs to be an adequate supply of vital nutrients and no suffocation (Zeller *et al.,* 2019). Decomposed wind-fallen stem wood offers the best seedbed for germination and survival in an undisturbed forest. Its consistent moisture supply and elevation of seedlings above the general level of the forest floor reduce the risk of suffocation by leaves and snow-pressed minor vegetation. Additionally, such a microsite is less likely to experience flooding Packalen *et al.*, (2020). The microsites obtained from thinning and pruning have several benefits, such as increased light, elevated temperatures in the rooting zone, and enhanced mycorrhizal development (Packalen *et al.,* 2020). These researchers also claimed that 90% of all spruce seedlings of hardwoods were rooted in decaying wood in a survey conducted in the PorcuPinus patula Hills, Manitoba. In general, mineral soil seedbeds are moister and easier to rewet than organic forest floors, making them more responsive than the undisturbed forest floor. In this study, however, the exposure to thinning and pruning during drought seasons needs to be implemented with caution. The effects that dryness or frost cause in the soil are so great that any clear-cut opening that is thinned and pruned without planning would be dubious when done frequently.

Wood values in Africa are affected by stand management practices such as thinning and pruning, particularly in Mount Duro Natural Forest and the surrounding agricultural environment in Nagelle Arsi, Oromia, Ethiopia (Magnago, 2015). It is commonly known that stand management strategies affect softwoods (Boer *et al.,* 2016). According to research by Broome *et al.*, (2017), it is still unclear how hardwoods respond to thinning and pruning in terms of wood characteristics. A. *mangium*, age 20, underwent stand thinning in its seventh year, and its effects were evaluated thirteen years later (Abunie and Dalle, 2019). Anova tests were used to examine the wood samples taken from the kinds of trees that had been felled (Abunie and Dalle, 2019). According to Brown, G. W. *et al.*, (2019), there was no discernible difference in the physical qualities of the wood according to the intensities of thinning and pruning. Onyango *et al.*, (2020) found that the improved basic wood density of a 20-year-old tree varied from 530.50 to 602.00 g cm-3, which was comparatively greater than the density values obtained from plantings with considerably lower ages. Furthermore, Felix *et al.,* (2022) noted that tree density affects the amount of timber produced overall, the frequency of competition-induced death, and the quantity and quality of individual tree timber. This study was conducted in Kenya's Arabuko Sokoke forest. The abundance of woody species can also be boosted by pruning, but at the expense of probably slower growth. As a result, stand density can be managed by thinning and selecting an initial planting density. These differences make it more instructive to investigate how the application of both thinning and pruning affects the density and abundance of woody species.

Several freshly planted forests—Kobujoi, Kimondi, Tinderet, Kapchorua, North Nandi, and Cerengonia—have recently been established in Nandi County. According to Wekesa (2018), 99% of the species in gazette forests are native, while 1% are exotic. For this reason, it is necessary to acclimate tothese silvicultural regimes. As per Feyisa *et al.*, (2018), silvicultural regimes are preferred in Kimondi Forest because broadcast burning is not a recommended method for preparing sites for natural regeneration. This is because it rarely exposes enough mineral soil to be sufficiently receptive, and the charred organic

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surfaces are not a good seedbed for spruce. Seed features, light, oxygen, soil reaction (pH), temperature, moisture, and seed enemies are the minimum number of variable elements that can affect a seed's ability to germinate (Wekesa, 2018). In the Kimondi Forest, moisture, thinning, and pruning affect the density and quantity of woody species (Peterson, 2021). According to Yu *et al.*, (2022), a burned surface may become too hot for optimal germination, delaying germination until fall and increasing the risk of unhardened seedlings dying throughout the winter. Additionally, they may interact with silviculture treatments to affect the growth and survival of early seedlings. Research must be conducted to validate early seedling performance as well as long-term development and yields, as nurseries create and produce new stock types in response to manager needs and in conjunction with them (Yu *et al.*, 2022). When medium and large stock types are compared, there is a significant, albeit limited, impact of stock type on the size of black and white spruce at the juvenile stage; however, these slight differences have no effect on the estimated merchantable volume produced at rotation age Pukkala (2023). Numerous studies have demonstrated that on these rich, thin-humus sites, mechanical site preparation does not enhance seedling growth. Consequently, other factors than growth and yield, such as the availability of seedlings, the cost of production and planting, or operational limitations, should be taken into account when choosing a medium- or larger-sized stock type for reforestation projects and applying mechanical site preparation in ecosystems similar to the one under study. These studies have primarily concentrated on spruce seedlings, but they do not provide a comprehensive understanding of the many sorts of seedlings from other woody species. Thus, the necessity for a long-term forest regeneration strategy where the kind of seedlings planted and their planting technique can be taken into account to determine the impact on the abundance of woody species arises.

MATERIALS AND METHODS

STUDY AREA

Nandi County, Emgwen, and Aldai Sub Counties are home to Kimondi Forest Station, which is situated in the South Nandi Forest Reserve. It is surrounded by the counties of Kakamega and Vihiga. It is located in the Rift Valley at latitudes 0018' N and 0032 N and longitudes 37005 E and 37023' E. The elevation is between 1700 and 2000 meters above sea level. It is located 4 km from Kapsabet town along the Kapsabet-Chavakali road, west of Kapsabet town and south of the main Kapsabet-Kaimosi route. It is reachable from Kisumu by the 75-kilometer Chavakali-Kapsabet route. 5,435.5 hectares make up this forest today after 741.8 hectares were cleared for habitation. 1,339.95 ha of plantations and 4,095.55 ha of wild forest make up this area.

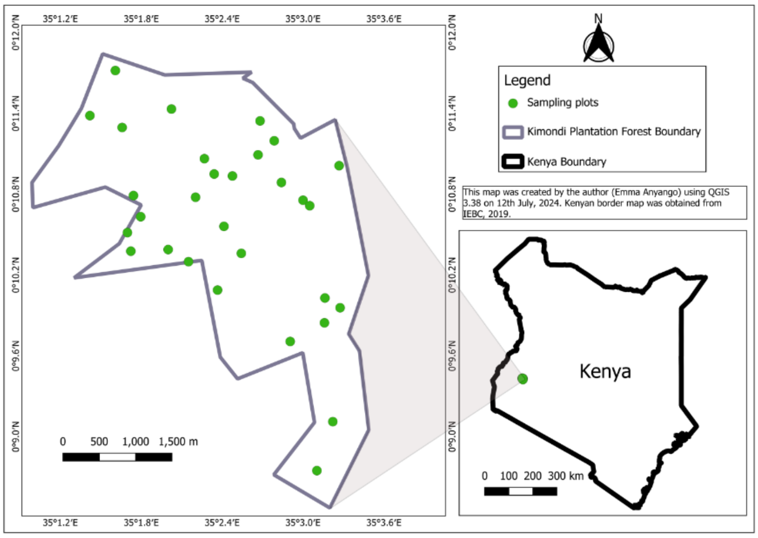

Figure 2: Map of Kimondi Forest

STUDY SITE

The topography of Kimondi Forest Station, which is a component of South Nandi Forest, has a significant impact on soils, climate, and biodiversity. This is due to the high abundance of terrain that results from its construction during the Cainozoic era. The average annual rainfall of Kimondi is between 1600 and 1900 mm. Although the region experiences bimodal rainfall, it is often moist all year round. Temperatures in the region vary from 18 to 240C. The Kimondi Forest Station's rainfall trend varies greatly; in 2013, 4260.4 ml of rainfall was recorded, the greatest amount ever. The average annual rainfall of Kimondi is between 1600 and 1900 mm. Although the region experiences bimodal rainfall, it is often moist all year round. Temperatures in the region vary from 18 to 240C. The Kimondi Forest Station's rainfall trend varies greatly; in 2013, 4260.4 ml of rainfall was recorded, the greatest amount ever.

FIELD SAMPLING

The study population is Kimondi Forest. Proportionate random sampling was used to select woody strata in the forests. In total sample of 30 plots each measuring 20m by 20m were established randomly which represented a sample of the 5,435.50ha occupied by the closed-canopy forest. This entailed one plot per 180ha of the forest.

In each plot, all woody species with diameter at breast height (DBH) ≥ 10 cm measured at 1.3 m above the ground was be counted and identified this was done to avoid counting the saplings. The relevance was to sample out the targeted woody species likely to be utilized for timber and other wood related activities. The identification was done with the help of an expert from the Kenya Forest Service.

The total number of species in a plot was established using the species/area relationship curve:

S=cAz

(Where S is species number, A is area of forest, and c and z are constants), (Brooks *et al,* 1999).

DATA COLLECTION

Information that is gathered directly from first-hand sources is referred to as primary data. The study area's woody species was observed, 30 sample plots were used each measuring 20m by 20m, and the number of woody species in each plot was counted and recorded as the primary data collection methods. A basic count of the woody tree species in the vicinity of the sampled forests is one of the primary data that was collected from the field. It also includes the size of the forest sampled. Data used in this study was obtained between March 2024 and June 2024. This is because timber is best harvested during spring (March, April, May) and summer (June, July and August) months when the sap is flowing to prevent damage of the tree when leaves have fallen off the hard wood trees. These methods was appropriate for the data collection because the data to be collected could be obtained by measurement (sample plots 20m by 20m each, height of trees to be counted), counting (number of woody species) and observation (the woody species density – closeness or openness). Observation schedules were used to assess the extent of the use of silvicultural regimes in the forest and how it was have influenced woody species abundance. Data on woody Species abundance was collected by identifying a specific woody species within the sampled area and counting them in the whole of the sampled areas in the two forests to get the abundance of each of the tree species in Kimondi forest. Woody species richness and abundance was used to calculate the quantity of woody species. As the woody species was counted in the plots, the intervening variables such as Soil type, Soil depth, Forest pest, Spacing of woody species and amount of graded timber from the number of coppices was recorded per plot. This is to aid in analysis of how these variables have influenced the quality and quantity of the woody species

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Independent variable is silvicultural regimes attributes e.g. ecological thinning and pruning. The dependent variables were woody species density and abundance. The instruments for data collection was include measuring tape for measuring the sampled area in the Kimondi forest. String was used to demarcate the quadrants. Data was collected within the randomly selected 30 study sites within the study site. The experimental study plots were determined via species –area curves so that further increases in plot size would not capture additional species. This approach captures most species that would be considered. Measurements for trees include DBH which was obtained from previous botanical survey data. The study sites were based on their location in the forests. The plots were established from the forest. To assess the influence of silvicultural regimes on Kimondi Forests, the number of individuals of all woody species was counted and recorded in the sampled areas. Secondary data was appropriate in sourcing for the maps of the forests.

Measures of the Influence of thinning and pruning regime on the woody species density and abundance

Two way anova test was used to analyze the relationship between thinning and pruning regime,unthinned and unpruned regime, the number of woody species per plot and density of each woody species. Results was presented in tables containing mean and standard deviation of abundance and density, least significant difference, p value<= 0.05 the superscripts letters indicate the significant difference in the means.

DATA

THINNING AND PRUNING REGIME VS WOODY SPECIES ABUNDANCE AND DENSITY

PLOT NO.	longitude	latitude	**THINNING AND PRUNING REGIME:**				**UNTHINNED AND UNPRUNED WOODY SPECIES**				**Total no. of woody species in the plot**
			No. of species	No. of individual *Eucalyptus saligna*	No. of Individual *Pinus patula*	No. of Individual *Cupressus lusitanica*	No. of species	Number of individual *Eucalyptus saligna*	Number of Individual *Pinus patula*	Number of Individual *Cupressus lusitanica*	
A	35.03902	0.182496	3	2	6	2	3	3	1	8	47
B	35.04733	0.181449	3	3	8	5	3	1	2	7	45
C	35.05	0.179258	3	1	12	3	3	2	1	3	46
D	35.04444	0.184867	3	2	9	6	2	1	0	7	48
E	35.03944	0.168141	3	3	9	3	3	3	2	3	49
F	35.05446	0.183529	3	3	8	4	3	1	3	9	49
G	35.03671	0.179624	3	4	5	1	3	2	4	4	42
H	35.04127	0.182255	3	3	6	4	3	3	3	8	45
I	35.02365	0.189722	3	4	6	1	3	2	1	4	41
J	35.02871	0.17295	3	3	5	4	3	1	1	6	40
K	35.03333	0.17315	3	1	10	4	3	1	4	3	46
L	35.05271	0.167159	3	3	3	4	3	3	1	12	51
M	35.04237	0.172681	3	2	7	6	3	3	1	5	44
N	35.02904	0.179832	3	5	11	5	3	2	5	10	62
O	35.02829	0.175252	3	2	4	6	3	2	8	3	44

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P	35.05083	0.178576	3	4	7	5	3	2	6	3	41
Q	35.02764	0.188253	3	3	7	7	3	2	6	5	44
R	35.04842	0.161782	3	2	4	5	3	1	2	5	45
S	35.05265	0.164091	3	6	3	6	3	3	7	5	53
T	35.03373	0.190536	3	4	5	3	3	2	6	4	41
U	35.05458	0.16595	3	2	9	6	3	2	3	1	45
V	35.03781	0.184398	2	3	6	0	3	3	5	5	45
W	35.04469	0.189063	3	4	8	6	3	3	3	1	57
X	35.04644	0.186605	3	6	3	5	2	2	3	0	41
Y	35.0268	0.195298	3	6	5	7	3	1	4	5	52
Z	35.03584	0.171655	3	4	4	3	3	1	4	6	47
AA	35.05368	0.151863	3	4	7	11	2	0	5	10	63
AB	35.02993	0.177212	3	4	5	4	3	2	4	2	45
AC	35.05171	0.145801	3	3	5	5	3	2	1	8	47
AD	35.04022	0.17602	3	2	6	3	3	4	4	3	41
TOTAL				98	193	134		60	100	155	1406

TWO WAY-ANOVA SUMMARY TEST FOR ABUNDANCE

Df Sum Sq Mean Sq F Value Pr(>F)

Species 2 196.7 98.34 23.26 1.11e-09***

Regime 1 67.2 67.22 15.90 9.81e-05***

Species regime 2 108.3 54.17 12.81 6.43e-06***

Residuals 174 735.5 4.23

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Signif. codes: 0`***’0.001`**’ 0.01 `*’0.05 `.’ 0.1``1

DENSITY

PLOT NO.	longitude	latitude	**DENSITY.**		
			Density of *Eucalyptus saligna*	Density of *Pinus patula*	Density of *Cupressus lusitanica*
A	35.03902	0.182496	0.0125	0.0175	0.025
B	35.04733	0.181449	0.01	0.025	0.03
C	35.05	0.179258	0.0075	0.0325	0.015
D	35.04444	0.184867	0.0075	0.0225	0.0325
E	35.03944	0.168141	0.015	0.0275	0.015
F	35.05446	0.183529	0.01	0.0275	0.0325
G	35.03671	0.179624	0.015	0.0225	0.0125
H	35.04127	0.182255	0.015	0.0225	0.03
I	35.02365	0.189722	0.015	0.0175	0.0125
J	35.02871	0.17295	0.01	0.015	0.025
K	35.03333	0.17315	0.005	0.035	0.0175

L	35.05271	0.167159	0.015	0.01	0.04
M	35.04237	0.172681	0.0125	0.02	0.0275
N	35.02904	0.179832	0.0175	0.04	0.0375
O	35.02829	0.175252	0.01	0.03	0.0225
P	35.05083	0.178576	0.015	0.0325	0.02
Q	35.02764	0.188253	0.0125	0.0325	0.03
R	35.04842	0.161782	0.0075	0.015	0.025
S	35.05265	0.164091	0.0225	0.025	0.0275
T	35.03373	0.190536	0.015	0.0275	0.0175
U	35.05458	0.16595	0.01	0.03	0.0175
V	35.03781	0.184398	0.015	0.0275	0.0125
W	35.04469	0.189063	0.0175	0.0275	0.0175
X	35.04644	0.186605	0.02	0.015	0.0125
Y	35.0268	0.195298	0.0175	0.0225	0.03
Z	35.03584	0.171655	0.0125	0.02	0.0225
AA	35.05368	0.151863	0.01	0.03	0.0525
AB	35.02993	0.177212	0.015	0.0225	0.015
AC	35.05171	0.145801	0.0125	0.015	0.0325
AD	35.04022	0.17602	0.015	0.025	0.015
TOTAL			0.395	0.7325	0.7225

ANOVA SUMMARY FOR DENSITY

Df Sum Sq Mean Sq F Value Pr(>F)

Species 2 0.002458 0.0000522 23.56 6.64e-09***

Residuals 87 0.004539 0.0000522

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Signif.codes: 0`***'0.001`**' 0.01 `*'0.05 `.' 0.1``1

DATA ANAYSIS AND RESULTS

RESULTS

Thinning and Pruning regime had the highest abundance of woody species with an estimate of 745 individual woody species in the sampled pots out of the total counted woody species which were 1,406 in the 12,000m^{2}. The most abundant species in this regime was *Pinus patula* which had 193 species thinned and pruned and 100 unthinned and unpruned, contributing to 20.84% of woody species in this regime.The relationship between the thinning and pruning regime and woody species density and abundance was also compared to the relationship between unthinned and unpruned woody species and woody species abundance and density in Kimondi Forest was determined and the results presented in table 2.0.

Table 2.0: Two-way ANOVA test results indicating Mean and standard deviation of abundance of the three woody species across two regimes in Kimondi Forest. Means were followed by different superscript letters

down the columns which were generated to show significant difference at p <= 0.05. Means were separated using Fishers Least Significant Difference.

Silvicultural regimes	**Woody species**	**Mean ± sd abundance**	**Regime mean**
Thinned and pruned	*Eucalyptus saligna*	$3.267^{c} \pm 1.74$	$4.722^{a} \pm 2.35$
	Pinus patula	$6.433^{a} \pm 2.37$	
	Cupressus lusitanica	$4.467^{b} \pm 1.74$	
Unthinned and unprunned	*Eucalyptus saligna*	$2.000^{d} \pm 1.41$	$3.500^{b} \pm 2.51$
	Pinus patula	$3.333^{c} \pm 2.01$	
	Cupressus lusitanica	$5.167^{b} \pm 2.85$	
		LSD = 1.125 p-value = 0.000***	LSD = 0.711 p-value = 0.001**

The findings of Table 2.0 shows that *Pinus patula* was the most abundant with a mean and standard deviation of $6.433^{a} \pm 2.37$, which is 46.06% of woody species that were pruned and thinned in this regime. *Cupressus lusitanica* had an abundance of mean and standard deviation of $4.467^{b} \pm 1.74$, which is 31.16% of the woody species that were thinned and pruned. *Eucalyptus saligna* was the least abundant with a mean and standard deviation of $3.267^{c} \pm 1.74$ resulting to 22.78% of the woody species that were pruned and thinned in the plots.

Moreover the total unthinned and unprunned woody species were the least in with a 22.41% of the woody species counted while thinned and pruned woody species were 57.72%. There were more unthinned *Cupressus lusitanica* with a mean and standard deviation of $5.167^{b} \pm 2.85$, which is 11.02% of the total woody species, *Pinus patula* had a mean and standard deviation of $3.333^{c} \pm 2.01$, which is 7.11% while the least number of unthinned and unprunned *Eucalyptus saligna* $3.267^{c} \pm 1.74$, which is 4.27% of the total woody species counted. There was a high significant difference at P-value = 0.000***.

PLATE 4; A PLANTATION OF PINUS PATULA, CUPRESSUS LUSITANICA AND EUCALYPTUS SALIGNA ALONG BUFFER ZONE OF NYAYO TEA IN KIMONDI FOREST

The abundance of woody species in the thinned and pruned regime was higher with a mean and standard

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deviation of 4.722[a] ± 2.35 while the unthinned and unpruned regime had a mean and mean deviation of 3.500[b] ± 2.51. There was a significant difference in the woody species abundance indicated by L.S.D = 0.711 and p-value = 0.001**.

Table 3.0 Mean and standard deviation of species density of three tree species in Kimondi Forest. Means followed by different superscript letters down the column are significantly different at p <= 0.05. Means were separated using Fishers Least Significant Difference

Woody species	**Mean ± sd density**
Eucalyptus saligna	0.0132[b] ± 0.00629
Pinus patula	0.0244[a] ± 0.00795
Cupressus lusitanica	0.0241[a] ± 0.00789
	LSD = 0.00381 p-value = 0.000

The results in table 3.0 indicate that thinning and pruning regime produce denser *Pinus patula* with a mean and standard deviation of 0.0244[a] ± 0.00795 representing 39.55% of species under this regime and *Cupressus lusitanica* species with a mean and standard deviation of 0.0241[a] ± 0.00789 representing 39.06% of the woody species in this regimes. *Eucalyptus saligna* that were thinned and pruned and those not thinned and pruned had a mean and standard deviation of 0.0132[b] ± 0.00629 representing 21.39% of the woody species in this regime. There was a significant difference in the densities of the woody species as indicated in the Figure 3.1.

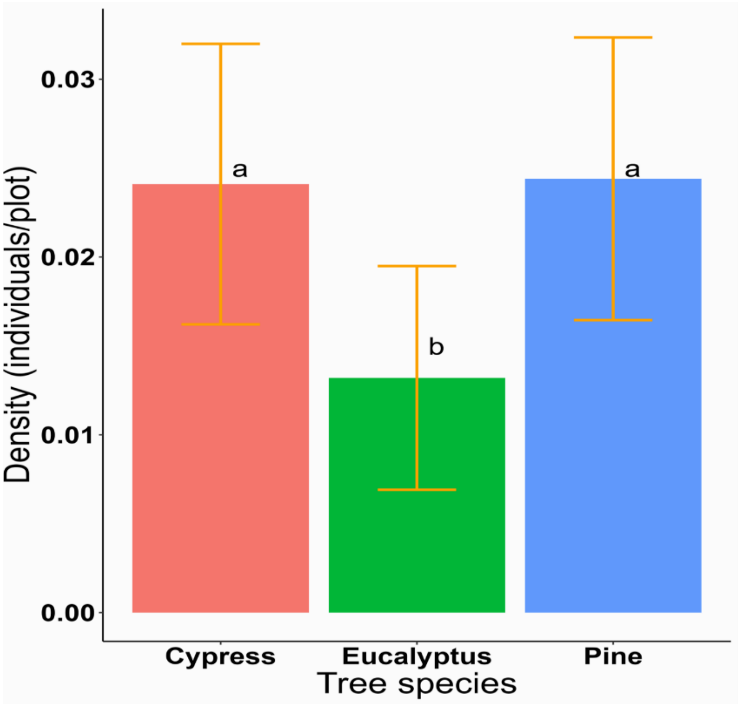

Fig. 3.1 A bar graph with Anova summary of the densities of *Cupressus lusitanica, Eucalyptus saligna* and *Pinus patula.*

Figure 4.1 shows that the quality of *Pinus patula and Cupressus lusitanica* is higher when they are both thinned and pruned. *Eucalyptus saligna* had the best quality of wood harvested as showed by the mean; hence this regime is the least preferred for this particular species.

PLATE 3: A PLANTATION OF *PINUS PATULA* SPECIES.

Overall species in these regimes were 68.04% of the total species in the areas where data was collected. Thus, it is a regime that produced more abundant and dense *Cupressus lusitanica* and *Pinus patula.*

Table 4.2 shows Two-way Anova summary of the interaction between the regimes and woody species density and abundance.

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Sample	143.008	1	143.008	46.351	4.62E-10	3.923
Columns	151.875	1	151.875	49.225	1.64E-10	3.923
Interaction	230.5224	1	230.5224	8.170	0.005049	3.923
Within	357.900	116	36.1			
Total	**883.307**	**119**				

Effect size is 36.098%, hence 36.098% of the variation of the abundance and density of woody species can be explained by the thinning and pruning regime. There was a significant interaction showed by the p-value of 0.005.

DISCUSSION

This quantitative decline in species abundance and density in the unthinned and unpruned regime is a clear indicator that thinning and pruning regime is a silvicutural regime that results to increase in quantity and quality of timber from *Pinus patula* and *Cupressus lusitanica* respectively. Further, *Eucalyptus saligna* species has least abundance and density when thinned and pruned. Moreover the increase abundance and density of *pinus patula* and *Cupressus lusitanica* was attributed too good fertile soils in the region, although the soil nutrient gradient needs to be leveled up for suitable pH to be realized. Uses of these species were mainly construction and cottage industry which is the target for timber harvesting from Kimondi forest. It is evident that despite the threat the local community was causing to the woody species most of them were properly managed. There is therefore need that when using the thinning and pruning regime, intercropping of leguminous species with *Eucalyptus saligna, Pinus patula and Cupressus lusitanica* plantations also has an advantage of replenishing the loss of soil nutrient to ensuring the sustainability of woody species cultivation hence the abundance and density will also be boosted.

Eucalyptus saligna plantations in the study area are older than those of the *Cupressus lusitanica* and *pinus patula* plantations, and this may partly explain why the densities of the *Eucalyptus saligna* plantations are low, significantly so, than those of the *Cupressus lusitanica* and *pinus patula* plantations Thus, it is a regime that produced more abundant and dense *Cupressus lusitanica* and *Pinus patula*.

Comparing *Eucalyptus saligna* to *Pinus patula* and *Eucalyptus saligna*, the densities of the plantations in Ngangao were the lowest, according to similar research conducted by Beleke T. (2015) in Nyangao and Chawia, Tanzania. The lower values of dbh and basal area suggest that the Eucalyptus saligna plantations in Ngangao are used to a larger extent,accordingtoWekesa et al.,(2018).The density of the *Cupressus lusitanica* plantations in Chawia was comparable to that of the *Pinus patula* forest, but this is explained by the fact that the *Cupressus lusitanica* plantations contain a comparatively high proportion of species other than Cupressus lusitanica, especially *pinus patula*, as this study also demonstrates.

These results also corroborate research by Kiruki, H.M. (2018), which showed that when silvicultural regimes are implemented, the quality and spacing of final species have the greatest impact on the value and returns of woody species. This is in line with the theoretical framework of this study which indicated that the number of species is higher on larger, less isolated islands and lower on smaller, more isolated islands hence as the plantation forest increases in size, more dense *pinus patula* and *Eucalyptus saligna* will be harvested through this regime because they are not isolated. The unthinned and unprunned woody species were mainly not mature enough for the silvicutural regime to be applied hence the lower mean and standard deviation densities and abundance.

Furthermore, Kiruki, H.M. (2018) discovered in his research that *Eucalyptus saligna* density decreases with thinning and pruningregime. Furthermore, according to De Avila, A. *et al*.,(2012), the Widespread of *Eucalyptus saligna* has sparked debate regarding the species' high water consumption as well as the detrimental effects that pruning and thinning of the plant has on the biodiversity of *pinus patula* and *Cupressus lusitanica*. Abunie. A. A. and G. Dalle (2019), have also voiced concerns about the negative impacts of planting *Eucalyptus saligna* close to water sources due to the drying up of rivers, streams, and springs. Nevertheless, farmers continue to grow *Eucalyptus saligna* because of its fast growth and good economic returns when it is only thinned.

When correctly subjected to silvicultural regimes, *Pinus patula* trees in Kenya are among the most lucrative trees for commercial tree growers, according to research by Aciar, (2017). Growing for its fencing posts, charcoal, fuel, furniture, fodder, mulch (the dried pinus patulas), soil stability, tanning, dye, construction poles, landscaping, and boat building, it is one of the fastest growing commercial trees in the nation. Thus, the ideal regime is required to sustain its growth and prevent the possibility of extinction.

These findings are in agreement with those of Ares A., Neill A. R. and Puettmann K. J. (2010), who reported that after 16 years of plantations in Australia, the depth of the soil under Eucalyptus saligna plantations (05 cm) has decreased the concentration of inorganic phosphorus from an early concentration of 34 to 2.3 µgg1; thus, an appropriate silvicultural regime is required to increase the quantity and quality of this element in the soil. According to Balenovićh. I. *et al.,* (2011), Eucalyptus saligna species can immobilize phosphorus, rendering it unavailable for plant uptake and resulting in a drop in phosphorus density. Assèdé, E.S.P. *et al*., (2021) made a similar suggestion in Ethiopia, endorsing Balenovićh. I. *et al.*, (2011).

Additionally, Binglin P. *etal*., (2020), reported that they discovered, through the use of ANOVA tests in their research, that when *Cupressus lusitanica* and *pinus patula* are thinned and pruned, their abundance and density increase, in contrast to *Eucalyptus saligna*, which demonstrated a significant decrease in the volume of wood harvested. The study's thinning and pruning regimewas carried out during the rainy season to expedite the stands' healing; hence, the LSD = 0.00381 p_value = 0.000*** indicates that the proportion of woody species in this regime was notably greater than that of other regimes.

The reduced density of *Eucalyptus saligna* under this regime is also a result of the insufficient funding available to only support the expensive thinning regime, which lowers the quantity and quality of *Eucalyptus saligna* under this regime (FAO and UNEP, 2020). Similar to this, the accumulation of plant residues in the upper portion of soil depth and their rate of decomposition may have contributed to an increase in the quantity and quality of *pinus patula* and *Cupressus lusitanica* under this regime in the planted forest (Keyser TL (2012).

Conversely, the decline in abundance and density of *Eucalyptus saligna* could be ascribed to the effect of continuous cultivation that aggravates organic matter oxidation and insufficient inputs of organic substrates from the farming system in the neighboring communities due to residue removal and presence of water erosion in some of the areas that are steep in the study area. These results are consistent with those of Velamazán M *et al*., (2017), who stated that the reduced amount and quality of *Eucalytus saligna* was also caused by the massive harvesting of these species, which lowered the quality of the wood by changing the pH of the soils, which results in low microbiological activity. Venter. Z. S. *et al.*, (2018) also noted that *Eucalyptus saligna's* composition is skewed as a result of thinning and pruning. In addition, Wang. Y. *et al.*, (2020) discovered that pruning and thinning *Eucalyptus saligna* reduces both its quantity and quality. This was discovered in Koga, Ethiopia. Generally, planted forests that have applied thinning and pruning regime have shown notable increase in abundance and density of woody species particularly the different types of *Pinus patula* trees (Wekesa. C. *et al*., 2018).

For many years, *Cupressus lusitanica* species have been cultivated in New Zealand to replace natural timber. Lumber output has increased for various high value applications due to the advent of portable sawmills (Omoro. L.M.A., 2010). Deng. C. *et al*., (2020), recently concluded a study comparing the wood quality traits of common Cupressus lusitanica species to assess how well they performed in usage. It was clear that the Cupressus lusitanica boosted the amount and quality of timber through thinning and pruning as well as pruning regime. In a study conducted in the cloud forests of the

Eastern Arc Mountains, Taita Hills, Kenya, byOmoro, M.A. and Pelikka, A.P. (2010), differences in species diversities were evaluated using a oneway ANOVA, and Tukey's HSD and Duncan's tests were used for even and uneven numbers of samples, respectively, to separate the means. In comparison to *Cupressus lusitanica* and *eucayptus*, *Pinus patula* also had a greater number of regenerated species, including species linked to low disturbance levels as *Syzygium guineense, Rapanea melanophloeos,* and *Xymalos monospora*.

These findings indicate that Thinning and pruning regime shows a significant difference in the species abundance and density. The high density and abundance of *Cupressus lusitanica* and *pinus patula* could be accounted for by the higher mean and standard deviations levels unlike that of *pinus patula* in a planted forest. The density of *Pinus patula* and *Cupressus lusitanica* was significantly influenced by age and tree height. It increased with age and was lowest at age 4 years and highest at age 10 years. There were significant differences ($p < 0.05$) in basic density between *Pinus patula, Cupressus lusitanica* and *Eucalyptus saligna*. The basic density of *pinus patula* and *Cupressus lusitanica* were also closely related while that of *Eucalyptus saligna* thinned and pruned were distinctly different. This study has answered the research question effectively on the influence of thinning and pruning regime on density and abundance of woody species in Kimondi forest. The findings were that thinning and pruning increases the abundance and density of *Pinus patula* and *Cupressus lusitanica* as compared to *Eucalyptus saligna* species.

CONCLUSION

Thinning and Pruning regime had the highest abundance of woody species with an estimate of 745 individual woody species in the sampled pots out of the total counted woody species which were 1,406 in the 12,000m^2. *Pinus patula* was the most abundant with a mean and standard deviation of $6.433^a \pm 2.37$, which is 46.06% of woody species that were pruned and thinned in this regime. *Cupressus lusitanica* had an abundance of mean and standard deviation of $4.467^b \pm 1.74$, which is 31.16% of the woody species that were thinned and pruned. *Eucalyptus saligna* was the least abundant with a mean and standard deviation of $3.267^c \pm 1.74$ resulting to 22.78% of the woody species that were pruned and thinned in the plots. The abundance of woody species in the thinned and pruned regime was higher with a mean and standard deviation of $4.722^a \pm 2.35$ while the unthinned and unpruned regime had a mean and mean deviation of $3.500^b \pm 2.51$. There was a significant difference in the woody species abundance indicated by LSD = 0.711 and p-value = 0.001**

RECOMMENDATIONS

It is further recommended that when using the thinning and pruning regime, intercropping of leguminous species with *Eucalyptus saligna*, *Pinus patula* and *Cupressus lusitanica* plantations also has an advantage of replenishing the loss of soil nutrient to ensuring the sustainability of woody species cultivation hence the abundance and density will also be boosted.

AREAS FOR FURTHER RESEARCH

The study recommends the following areas for further research:

- The dynamics of trees growth and physiological processes to silvicultural regimes.
- A qualitative research on perceived societal relevance of seedling and sapling species composition

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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