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Original Article

Distribution, Conservation Status and Effects of Threats on Relative Abundance of Warburgia ugandensis Tree Species. A Case Study of Katimok Forest Reserve, Kenya

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Warburgia Ugandensis, Abundance, Indicators of Threat, Debarking, Conservation.

ABSTRACT

Forest ecosystems provide livelihood opportunities such as medicines, fuelwood, timber, cash income and a reliable supply of groundwater. However, encroachment of forests by human settlement adjacent to conservation areas is associated with overharvesting of forest resources and uncontrolled livestock grazing leading to the destruction and disappearance of useful plant species in forest ecosystems which can significantly affect both biodiversity integrity and ecological functioning. Therefore, this study aimed to investigate the distribution, conservation status, and effects of threats on the relative abundance of *Warburgia ugandensis* in Katimok Forest Reserve, Baringo County in Kenya. Data collection was done using transect lines and quadrat methods. The data on the relative abundance of *Warburgia ugandensis* and indicators of threat were collected from quadrats and sub-quadrats located at 50 m, 350 m and 650 m from the forest edge. In addition, other measures of tree growth such as diameter at breast height (DBH) and heights of mature trees in the study blocks were made. One-way ANOVA was used to analyse the relative abundance of *Warburgia ugandensis,* indicators of threat and growth parameters. Pearson correlation results revealed a significant relationship between debarked and mature *Warburgia ugandensis* ($r = 0.95$; df=2, $P=0.019$), grazing intensities, and number of seedlings/saplings ($r = 0.96$; df=2, $P=0.017$) and other indicators of threats (stumps, defoliated leaves, broken twigs/branches) and the abundance of *Warburgia ugandensis* ($r = 0.97$; df=2, $p=0.015$). Therefore, there is an urgent need to map out the distribution of *Warburgia ugandensis* in the whole country to know where it is abundant in order to draw a national conservation and management plan for the tree species.

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INTRODUCTION

Across the globe, there are tens of thousands of medicinal plants among them being *Warburgia ugandensis* (Sprague) (Marrelli, 2021). The species is indigenous to the African continent and specific countries where the wealth of these species are found include South Africa, the Democratic Republic of Congo, Kenya, Uganda, Ethiopia, and Tanzania (Denis *et al.*, 2018). In Kenya, the species naturally occurs largely in North Rift (Baringo, Nandi, Elgeyo Marakwet, West Pokot, Transzoia Counties, among others) and Central (Nairobi, Kiambu, and Muranga) parts of the country (Denis *et al.*, 2018). It is commonly known as the East African greenheart or Pepper-bark tree and belongs to the family *Canellaceae*. *Warburgia ugandensis*, one among 16 known species in the family, is a perennial evergreen and single-stem aromatic tree. The species is one of the rare, high-value tree species with its parts used in herbal medicine (Abuto *et al*., 2018). According to the usefulness and sustainability of human use, the species is rated second among the top priority tree species in Kenya (Muchugi *et al*., 2012).

As a high-value medicinal tree species, *Warburgia ugandensis* has a wide range of anti-microbial activities (Maobe *et al*., 2013). Some parts of the tree species, specifically stem barks and leaves are used in the management of many disorders and protect against health conditions such as cough, cold, respiratory and odontological ailments among many communities in Kenya (Maroyi, 2014). Apart from using the species for the treatment of diseases, there are other expansive uses ranging from harvesting as livestock feeds, timber, poles, and firewood. These wide ranges of uses have significantly decimated the tree population (Abuto *et al*., 2018). Besides, human-induced factors such as cutting trees to pave the way for settlement, climate change, livestock grazing and urbanisation have also drastically reduced the population of trees in Kenya (Hosonuma *et al*., 2012). In particular, the influence of grazing on plant diversity patterns is dictated by climate. Ecosystems with low precipitation levels and high temperatures are severely affected by grazing, which damages soil characteristics (increased erosion, decreased water infiltration), decreasing already little diversity of plant species, while in the ecosystem with low

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abiotic stress, grazing may stimulates the growth of plants diversity (Centeri, 2022; Teague & Barnes, 2017). However, heavy grazing in forest ecosystems continues to change floristic composition from palatable seedlings, saplings, grasses and sedges to less palatable forbs, either by livestock trampling or browsing on the vegetation (Kikoti & Mligo, 2015). This has worried conservationists (Shanley & Luz, 2003)), that most of the medicinal plants valued for their useful parts such as those widely extracted for their stems or bark face the risk of becoming extinct. Despite these alarming threats to the survival of these medicinal plant species, there are no or little existing conservation plans (Painuli *et al*., 2021).

Threats facing the existence of important plant species such as *Warburgia ugandensis* are due to procedures of collecting plant materials, a wide spectrum of uses and the unsustainability of harvesting (Williams *et al*., 2013). For instance, debarking is detrimental to the tree species as it allows free passage of pathogens and interrupts the transportation of food materials through vascular cambium, and can result in the death of the tree (Gauthier *et al*., 2015). Debarking removes thick protective stem bark, easing the digestibility of vascular cambium, phloem and xylem by pathogenic organisms (fungi, bacteria) and insects (Gauthier *et al*., 2015). Studies on the effects of debarking on the regrowth of bark and survival of medicinal tree species show that, in most cases, bark recovery is most unlikely, with chances of death being very high (Mohammed *et al*., 2022). Generally, unsustainable harvesting of tree species threatens the genetic diversity of both the *ex-situ* and *in-situ* population of the plant (Wang, 2020). Thus, since most of the previous studies are largely on how important plant species such as *Warburgia ugandensis* are exploited by traditional communities in Kenya, localised assessment of distribution, conservation status and effects of threat on the relative abundance of *Warburgia ugandensis* remains underexplored (Maobe *et al*., 2013; Maroyi, 2014). Therefore, this study aimed to provide well-grounded information on the relative abundance of *Warburgia ugandensis*, its threats in the natural habitats and the effects of these threats on the relative abundance of the species at Katimok Forest Reserve, Baringo County in Kenya.

MATERIALS AND METHODS

Study Area

This study was conducted within four forest blocks adjacent to human settlements of the Katimok forest ecosystem in Baringo County, Kenya. Katimok Forest consists of several separate forest blocks of different sizes and varying in altitude (*Figure 1*). The forest Reserve was gazetted in 1949 and it is currently being managed by Baringo County Government (Jebiwott *et al*., 2020). The elevation of the forest ranges between 2162 m and 2288 m above sea level and it is one of the largest blocks of the larger Kabarnet Forest covering 1,956.59 ha and lies on latitude 00° 61’N - 00° 38’N and longitude 35° 26’E - 35° 48’E. Katimok Forest Reserve receives an annual rainfall of about 1000–1500 mm and mean annual temperatures ranging from a minimum of 10 ^{0}C and a maximum of 30 °C (Ednah *et al*., 2018).

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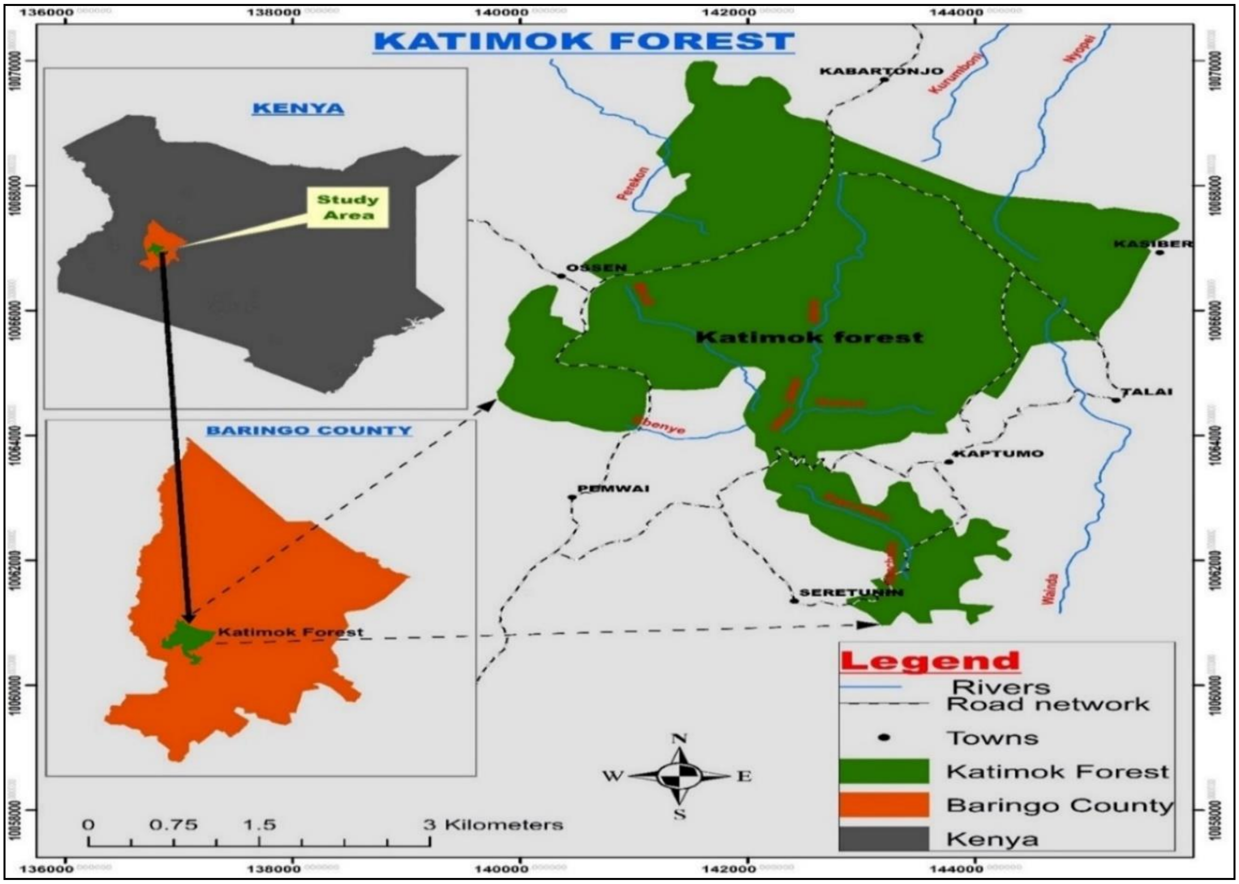
Figure 1: Map of Katimok Forest reserve



The main tree species in Katimok Forest Reserve were *Vitex keniensis (*Turrill*)*, *Olea africana (*subspecies *europaea***)**, *Syzygium guineense* (Bambara: *Kokisa*), *Prunus africana (*Hook f.) Kalkman and *Osyris tenuifolia (*Monodora tenuifolia Benth) (Jebiwott *et al*., 2020). There were exotic plantations in Katimok Forest Reserve that comprised tree species such as *Pinus patula (schiede ex schltdl. & Cham)*, *Eucalyptus saligna var. protrusa* (Blakely & McKie)*, Grevillea robusta (*A. Cunn. ex R.Br.) and *Cupressus lustanica* (*C. lindleyi*) (Jebiwott *et al*., 2020). There were exotic plantations in Katimok Forest Reserve that comprised tree species such as *Pinus patula (schiede ex schltdl. & Cham)*, *Eucalyptus saligna var. protrusa* (Blakely & McKie)*, Grevillea robusta (*A. Cunn. ex R.Br.) and *Cupressus lustanica* (*C. lindleyi*) (Jebiwott *et al*., 2020). The exotic plantations were established in the early 1970s as reforestation measures after the eviction of illegal settlers. Katimok Forest Reserve is a habitat for wildlife such as the helmeted Guinea fowl (*Numida meleagris*), Angola colobus (*Colobus angolensis*), Kirk's dik-dik (*Madoqua kirkii*), Cape hare (*Lepus capensis*), Olive baboon (*Papio anubis*) and common quail (*Coturnix coturnix*) (Jebiwott *et al*., 2016).

Soil types and distribution in Katimok Forest Reserve and surrounding areas are greatly influenced by the topography. Steep slopes within the forest have well-developed soils from volcanic rocks. The soils in steep slopes have deep to shallow depths with the bedrock being either basaltic or pyroclastic (Ednah *et al*., 2018). Due to extreme weather conditions in the area, the soils weather creates sandy, dark or clay loam soils. The colour of the soils in Katimok Forest Reserve varies from red

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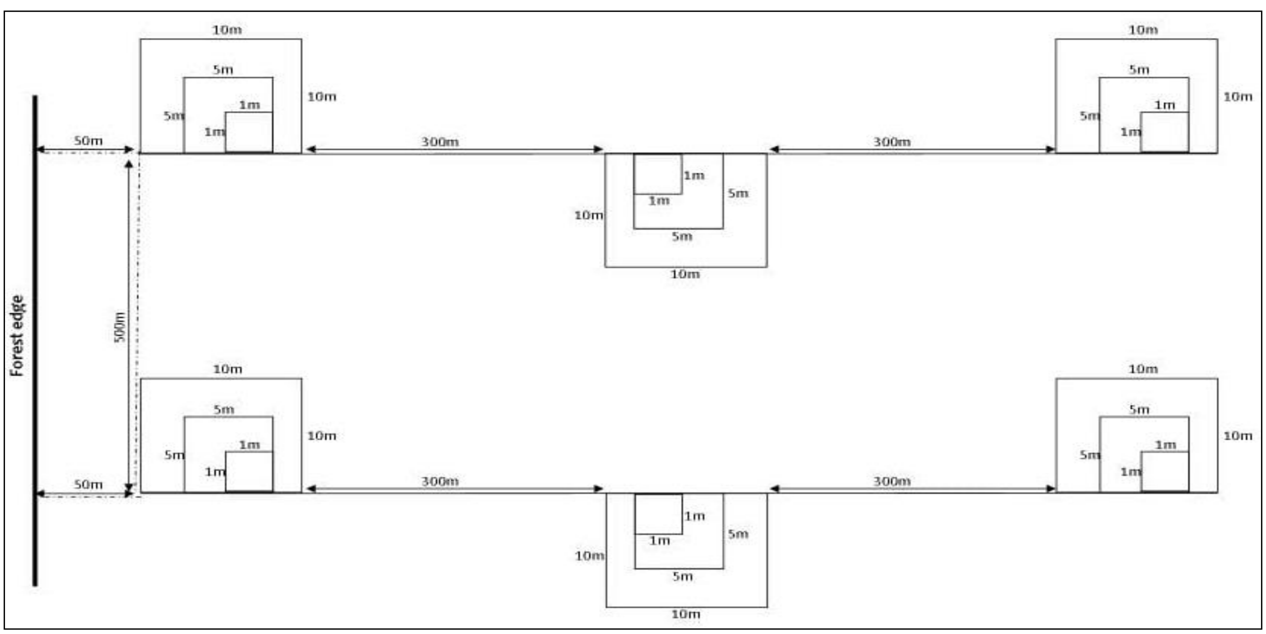
to brown depending on the mineral contents. However, the soil type in the study blocks of the forest remained largely the same. Soils in the forest and its neighbouring areas are fertile, supporting the cultivation of maise, beans, millet, and sorghum. Other agricultural practices in the area included the rearing of cattle, sheep, goats and beekeeping. The main streams that flow from Katimok Forest Reserve are Jaban, Perekon and Goisoi.

Data Collection

A preliminary survey was conducted to establish the section of the forest blocks where *Warburgia ugandensis* populations were located as well as the proximity of human settlement to the forest reserve. A preliminary survey aids in acquiring better data, use time and other resources efficiently and effectively (Khuc, 2021). This was followed by an ecological survey entailing the use of transect lines and quadrat methods in order to collect data on the relative abundance of *Warburgia ugandensis* and indicators of threat on the growth parameters (*Figure 2*). To establish the influence of human settlements on the abundance of the species as well as indicators of threat, quadrats were classified into three different distances from the forest edge, i.e., near (50 m from the forest edge), away (350 m from forest edge), and distant (650 m from forest edge). Two transect lines were laid at a distance of 500 m apart in each forest block. Along the transect lines, quadrats and sub-quadrats were nested for the collection of data on every size-class distribution of *Warburgia ugandensis*. The size-class distribution refers to the mature trees, saplings, and seedlings of the plant species. The mature trees were defined as woody plants with a diameter at breast height ≥ 2.5 cm and a height ≥1. 5 m (Eyasu *et al*., 2020). The saplings were young woody plants with a root collar diameter < 2.5 cm and a height of 50–150 cm, while the seedlings were the woody plants with a root collar diameter < 2.5 cm and height from 1–50 cm (Atsbha e*t al*., 2019). The mature *Warburgia ugandensis* tree species were identified, counted, and recorded within 10 m × 10 m quadrats. Also, within the 10 m × 10 m quadrats, all the debarked *Warburgia ugandensis* species were identified, counted, and recorded. Within each of the quadrat, a 5 m × 5 m sub-quadrat and a 1 m × 1 m sub-quadrat were laid out for the collection of data on saplings and seedlings, respectively.

Figure 2: Transect layout per forest block



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The selected indicators of threats included the number of cow dung, the number of debarked mature trees and other indicators such as stumps, defoliated leaves, and broken twigs/branches. Data on other indicators of threats was collected in all the quadrats and sub-quadrats while enumeration of the number of cow dung was done in the 5 m × 5 m sub-quadrats. The identification of the distribution of cattle dung has been established to be an appropriate method to get a clear understanding of the performance of ecological processes and grazing intensity (Sheidai-Karkaj *et al.*, 2022). Other growth parameters such as diameter at breast height (DBH) and heights of all the mature *Warburgia ugandensis* trees were measured and recorded. The use of growth parameters such as the diameter at breast height (DBH) and tree height (H) have been found to be commonly used measures of tree growth (Sumida *et al*., 2013). Diameter at breast height and heights were measured using diameter tape and a Suunto clinometer, respectively. The DBH was taken at 1.3 m height on a straight tree trunk.

Data Analysis

After data collection and compilation, Analysis of Variance (One Way ANOVA) was used to compute the difference in the abundance of *Warburgia ugandensis* species and indicators of threat with distance from the human settlement in the various study blocks. Similarly, the differences in diameter at breast heights and heights of the various study blocks were analysed using One Way ANOVA. Further data analysis which entailed a comparison between the variables was evaluated using the Spearman correlation coefficient using SPSS version 28.0.1 correlational techniques. The correlational analysis was done in order to establish the effect of the different grazing pressures on the abundance of saplings and seedlings as well as the effects of threats on the population of the tree species in the study block with distance from human settlement. Descriptive statistics tools that included tables and charts were used to present data. All the statistical significances were considered at 95% confidence levels.

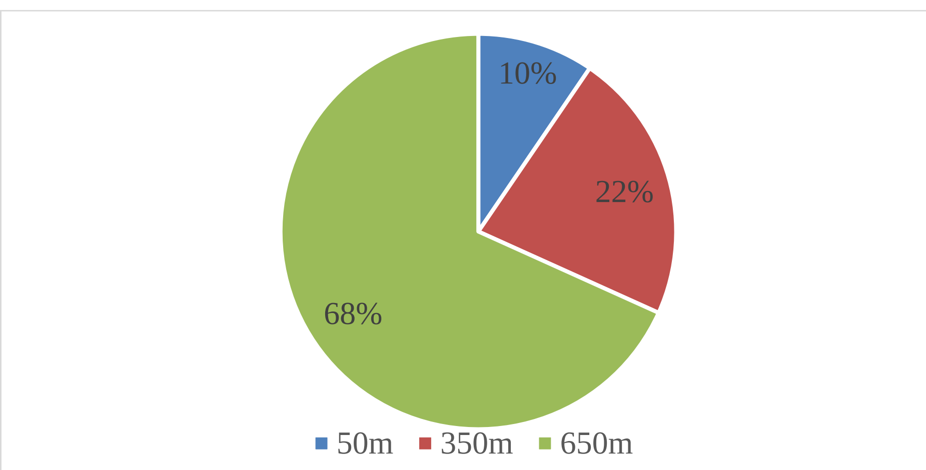
RESULTS AND DISCUSSIONS

Distribution and Conservation Status of *Warburgia ugandensis*

Distribution

The distribution was disaggregated with respect to different distances from the forest edge. The rate of occurrence of *Warburgia ugandensis* species was highest in quadrats which were 650 m away from the forest edge at 68%, while the occurrence in quadrats at 350 m and 50 m away from the forest edge was 22% and 10%, respectively (*Figure 3*).

Figure 3: Distribution of *Warburgia ugandensis* with distance from the forest edge



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According to the Analysis of Variance (One Way ANOVA), there was a significant positive relationship between the abundance of *Warburgia ugandensis* and the distance from the forest edge ($F_{(2,9)} = 1.44$, p=0.028).

Table 1: Abundance of *Warburgia ugandensis* with distance from the forest edge

Distance						
	50 m		**350 m**		**650 m**	
Study block	**Mature trees**	**Saplings/ Seedlings**	**Mature trees**	**Saplings/ Seedlings**	**Mature trees**	**Saplings/ Seedlings**
Ossen	1	0	1	1	2	5
Talai	1	0	2	0	1	2
Saimo	1	0	2	0	1	2
Kabartonjo	3	0	4	4	7	23
Totals	6	0	9	5	11	32

The quadrats which were placed far away from human settlements had a relatively higher number of *Warburgia ugandensis* (*Table 1*). These results concur with other findings (Vuyiya *et al*., 2014) that human settlement leads to a reduction in tree density and uneven distribution patterns of trees. Similarly, it is consistent with other studies which reported that tree density, dispersion patterns and size class distributions varied with the level of human threats in the forest, specifically less disturbed areas having more tree diversity and abundance than disturbed areas (Glasby *et al*., 2019; Gutiérrez & Trejo, 2022) Furthermore, other studies also show low tree recruitment and spread of species in intensely disturbed forests (Encina *et al*., 2022; Chapagain *et al*., 2021).

Relative Abundance

There was a total of 50 tree species found growing in different forest blocks with *W. ugandensis* (*Table 2*).

Table 2: The relative abundance of tree species in Katimok Forest.

No	Species name	Number	Relative abundance (%)
1	*Podocarpus falcatus*	31	10.13
2	*Podocarpus latifolia*	24	7.84
3	*Vangueria madagascariensis*	24	7.84
4	*Warburgia ugandensis*	22	7.19
5	*Prunus serotine*	21	6.86
6	*Prunus africana*	18	5.88
7	*Teclea nobilis*	18	5.88
8	*Paveta cataractum*	14	4.58
9	*Paveta alveriana*	13	4.25
10	*Bersama abyssinica*	10	3.27
11	*Asparagus racemosus*	10	3.27
12	*Ehrectia cymosa*	8	2.61
13	*Polyscius kikuyuensis*	8	2.61
14	*Guinea guidonia*	8	2.61

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No	Species name	Number	Relative abundance (%)
15	*Euclea divinorum*	7	2.29
16	*Zyzgium guinea*	6	1.96
17	*Olea africana*	5	1.63
18	*Ekerbergia capense*	5	1.63
19	*Dombeya torrida*	4	1.31
20	*Garcinia burchani*	4	1.31
21	*Flacourtia india*	3	0.98
22	*Albisia coriara*	3	0.98
23	*Vitex keniensis*	2	0.65
24	*Tarchonanthus camphoratus*	2	0.65
25	*Camelia sinensis*	2	0.65
26	*Celtis africana*	2	0.65
27	*Heteromorpha trifoliolata*	2	0.65
28	*Trimeria grandifolia*	2	0.65
29	*Vangueria volkensii*	2	0.65
30	*Cordia abysinica*	2	0.65
31	*Vepris nobilis*	2	0.65
32	*Croton megalocarpus*	2	0.65
33	*Aethiopica olinia*	2	0.65
34	*Aconthera schimperi*	2	0.65
35	*Antiaria toxicaria*	1	0.33
36	*Croton urucarana*	1	0.33
37	*Osyris tenuifolia*	1	0.33
38	*Fraxinus pensilvanica*	1	0.33
39	*Phylocosmus africanus*	1	0.33
40	*Dovyalis abyssinica*	1	0.33
41	*Maytenus undata*	1	0.33
42	*Calodendrum capense*	1	0.33
43	*Vanguera infausta*	1	0.33
44	*Berberis darwanii*	1	0.33
45	*Ficus tonegi*	1	0.33
46	*Schinus mole*	1	0.33
47	*Pittosporum viridiflorum*	1	0.33
48	*Tarchonanthus camphoratus*	1	0.33
49	*Croton microstachus*	1	0.33
50	*Garania livingstonei*	1	0.33
	Grand Total	306	100.00

The most prevalent species were *Podocarpus falcatus* comprising 10.13% of all the species, followed by *Podocarpus latifolia* 7.84%, *Vangueria madagascariensis*, and *Warburgia ugandensis* with 7.84% and 7.19% respectively. The study showed that some of the trees growing alongside *Warburgia ugandensis* were relatively taller than *Warburgia ugandensis* and with a wider canopy shading *W. ugandensis* saplings and sprouts, compromising their growth and establishment.

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Population Structure

Structure-based on DBH in Different Forest Blocks

The measurements of diameter at breast height (DBH) of identified trees in the study blocks showed a huge variation. The sizes of trees varied with distance from the human settlement (*Table 3*). At 350 m and 650 m the trees were having a mean DBH of 42.09 cm and 47.89 cm, respectively. The least diameter at breast height was measured at 50m, having a mean DBH of 22.31cm.

Table 3: *Warburgia ugandensis* mean DBH

Forest Block	50 m	350 m	650 m
Ossen	34.55	61.91	68.77
Talai	29.61	59.42	65.55
Saimo	20.74	36.47	42.32
Kabartonjo	4.32	10.56	14.93
Mean	22.31	42.09	47.89

There was a significant difference in the measurement of diameter at the breast height of *Warburgia ugandensis* trees and the distance from the human settlement ($F_{(2,9)}$ =1.58, p=0.025). The finding is similar to a study in the Mt Kenya region which reported the diameter at breast height of *Warburgia ugandensis* ranging between 8 cm and 26 cm (Kairu *et al.*, 2013). Equally, the result is similar to a study by Denis (2018), which found that *W. ugandensis* can grow up to a diameter at a breast height of 0.7 metres. Generally, previous studies show that tree growth is determined by age and conditions of growth such as geological characteristics, climatic variables and human activities, among others (Zhang *et al.*, 2016; Fan *et al.*, 2020). Since all the study blocks experienced similar weather patterns and geological characteristics, the variation in DBH can be attributed to the age of trees and varying levels of human or livestock disturbances at different distances.

Warburgia ugandensis Height in Different Forest Blocks

There was a huge variation in the mean heights of *Warburgia ugandensis* and distance from human settlements. The tallest tree heights were recorded at 350 m and 650 m, having a mean height of 13.97 m and 18.60 m, respectively. At 50 m shorter trees heights were recorded, registering a mean height of 9.13 m (*Table 4*).

Table 4: *Warburgia ugandensis* mean heights

Forest Block	50 m	350 m	650 m
	Mean heights of trees at different lengths from the forest boundary		
Ossen	7.41	8.63	13.32
Talai	6.64	10.39	21.75
Saimo	11.46	12.98	19.73
Kabartonjo	9.77	17.60	20.71
Mean	9.13	13.97	18.60

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There was a significant difference in the heights of the tree species and distance from human settlements ($F_{(2, 9)}$ = 9.04, p= 0.007). The results are consistent with previous studies (Anne *et al*., 2014) that the tree species can grow from a height of 5-30 m tall and with another that observed growth from 4.5 m to 40 m in height (Denis *et al*., 2018). However, the variation in heights in different blocks can be attributed to age and different extent of human or livestock disturbances since all blocks experienced relatively similar weather patterns, soil characteristics and rainfall patterns. The difference in the height of the tree species could be partly explained by degradation in the form of illegal logging of tall and big trees, which has undoubtedly affected the structure near human settlements. This is in line with the study by Bentsi (2022) that found that basal area, height and diversity of tree species are influenced by the tree age and human anthropogenic activities.

Threats on Relative Abundance of *Warburgia ugandensis*

The Relation of Debarked to Mature Trees and Distance from Settlements

The findings revealed that there is a significant difference in the number of debarked trees and distance from the forest edge ($F_{(2, 9)}$ = 3.5, p= 0.008). Hosea (2020) found that debarking decreases with an increase in distance from human settlements. Furthermore, previous studies (Musila *et al*., 2014) have cited continued human encroachment in the forest to extract bark for use in traditional medical treatments, especially in areas where the important plant resource is close to human settlements.

Table 5: Mean Debarking and Mature trees

Distance	Debarked trees			Mature trees		
	Mean	Standard Deviation	Max	Mean	Standard Deviation	Max
50 m	1	0	1	1.5	1	3
350 m	0.75	0.25	1	2.25	1.58	4
650 m	0.25	0.25	1	2.75	8.25	7

The correlation results of debarking and mature trees indicated a significant relationship between the variables (r = 0.95; df =2, p=0.019). We therefore reject the null hypothesis that all the population means are equal. The results showed that the number of mature trees drops when the levels of debarking are relatively higher. Conversely, when the magnitude of debarking becomes comparatively lower, the abundance of mature trees rises. The finding is consistent with previous studies which indicated that debarking makes trees susceptible to infestation by insects, decay of stem and subsequent death (Nndwammbi *et al*., 2018). Debarking interferes with the exchange of materials leading to the eventual death of the trees (Beltrán *et al*., 2021). Bark harvesting can have a highly negative impact on tree species as it alters the structure, reproduction and physiological continuity of mature plants, thus threatening their survival (Beltrán *et al*., 2021). Besides, recovery patterns and survival of trees after debarking are dependent on the intensity of debarking, season of debarking, and the size of the trees (Nndwammbi *et al*., 2018). Destructive harvesting practices such as the full-ring barking of medicinal plant species have led to the drastic decline of the population of these plants of socioeconomic importance (Guedje *et al*., 2016).

Relationship between Cow Dung Presence and Seedlings/Saplings

The finding revealed that there is a significant difference between the number of cow dung with distance from the forest edge ($F_{(2,9)}$ = 3.79, P=0.04). The quadrats near the forest edge had a

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comparatively higher number of cow dung. The results are consistent with another study (Jamil *et al*., 2022) which showed livestock grazing intensity being higher closer to human settlement than in locations far away from human settlement. Likewise, another study (Tyrrell *et al*., 2017) showed that livestock frequently grazes at the edge of conservation areas as opposed to deep inside. Moreover, a comparison between mean cow dung and seedlings/saplings was made (*Table 6*).

Table 6: Mean cow dung and seedlings/saplings

Distance	Cow dung			Saplings/seedlings		
	Mean	**Std Dev.**	**Max**	**Mean**	**Std Dev.**	**Max**
50 m	6.75	4.25	9	0	0	0
350 m	4.25	24.25	9	1.25	3.58	4
650 m	0.5	0.33	1	8	102	23

The results indicated a significant relationship between the presence of cow dung and mean saplings/seedlings (r=0.96; df=2, p=0.017). We therefore reject the null hypothesis that all the population means are equal. This implied that the number of saplings and seedlings increased with the declining presence of cow dung since livestock either browse or trample on them. This study (Yedidya Ratovonamana & Ganzhorn, 2013) indicated that livestock grazing in a forest degrades the ecosystem by altering the floristic composition and other research. Roberts *et al*. (2021) have also shown that seedlings and saplings are mostly damaged by trampling and grazing. In addition, overgrazing adversely affects the composition of the plant population and reduces their capacity to regenerate (Abdelsalam, 2021). The unregulated and prolonged periods of grazing in forests cause excessive trampling and often at times result in alien weeds and grasses (Schieltz & Rubenstein, 2016).

Other Indicators of the Threat and Abundance of *Warburgia ugandensis*

Other indicators of threat studied included stumps, defoliated leaves, and broken twigs/branches. The study found that there is a significant difference between other indicators of threats and the abundance of *Warburgia ugandensis* at a distance from the forest edge. ($F_{(2,9)}$ = 0.728; p=0.05). Sites closer to human settlements had a relatively more number of other indicators of threats. The study corroborates with other findings (Vuyiya *et al*., 2014), which showed a different extent of human disturbances (illegal logging, charcoal burning) on tree species at a distance from human settlement. Furthermore, during logging activities in forests, the felled trees may injure neighbouring trees or fall on smaller trees causing damage (Tavankar & Bodaghi, 2011). Additionally, the relationship between other indicators of threats and *Warburgia ugandensis* was established. The relation between other indicators of threat and abundance of *Warburgia ugandensis* in the different quadrats is shown below (*Table 7*).

Table 7: Mean of Other indicators and mean of *Warburgia ugandensis*

Distance	Other indicators			Mature trees/Saplings/seedlings		
	Mean	**Std Dev**	**Max**	**Mean**	**Std Dev**	**Max**
50 m	6.75	4.25	9	1.5	1	3
350 m	4.25	24.25	9	3.5	9	8
650 m	0.5	0.33	1	9.75	168.25	30

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Pearson's correlation analysis revealed a significant relationship between other indicators of threat and abundance of *Warburgia ugandensis* species (r =0.97; df=2, p=0.015). We therefore reject the null hypothesis that all the population means are equal. The results revealed that the *Warburgia ugandensis* population was higher in quadrats far from human settlements. On the contrary, the counts of other indicators of threats where fewer as human settlements from the study site becomes distant. The finding is similar to a study by Boyd (2013), which showed that the risk of pest and disease introduction has changed over time, with rising occurrence of genetic re-assortment leading to novel disease threats and the potential role of climate change that negatively affects plant population. Another study cited that the increased prevalence of non-native pests and diseases adds to the challenges of tree-based landscapes already burdened by native pests and diseases (Graziosi *et al*., 2020). Generally, alteration in the abundance of species is influenced by many factors, although anthropogenic activities (indicated by stumps, broken branches/twigs) are the most prominent, negatively affecting the population of the tree species (Singh *et al*., 2022).

CONCLUSION

There was a clear variation in the abundance of *Warburgia ugandensis.* The abundance of *Warburgia ugandensis* increased towards the core of the forest. Contrary to the increasing abundance of *Warburgia ugandensis,* the number of debarked trees, the presence of cow dung and other indicators of threat decreased from the forest edge to the core. This indicated that human-induced activities from communities living adjacent to the forest and unmanaged livestock grazing in the forest were reduced with distance into the forest. This meant that the threats affecting the growth of *Warburgia ugandensis* declined from the forest fringes to the core and correspondingly, the abundance of *Warburgia ugandensis* increased with distance from human settlement. Therefore, due to the threats posed by human encroachment and uncontrolled grazing activities to *Warburgia ugandensis* in the forest, the species should be protected and monitored by the Kenya Forest Service (KFS). Furthermore, it is imperative to map out the distribution of *Warburgia ugandensis* in the whole country to establish abundance and draw a national conservation and management plan for the species.

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Conflict of Interest

There were no declared conflicts of interest.

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