



Responses of *Ocotea usambarensis* to logging on the Southern Slopes of Mount Kilimanjaro, Tanzania

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Abstract

The East African Camphorwood (*Ocotea usambarensis*) population in the montane forests of East Africa has experienced heavy logging. This logging can be attributed to both historical, legal and commercial harvesting of the species under colonial governments and subsequent illegal selective logging. This study assessed the population structure of *Ocotea usambarensis*, as influenced by the historical logging intensity and elevation gradient (1800 – 2500m) on the southern slopes of Mt. Kilimanjaro. The mean stem density and basal area of seedlings, saplings, and adults were compared using the Wilcoxon signed-rank test. The age structure of *Ocotea usambarensis* varied along the elevation gradient and across different logging intensity blocks. The comparison between blocks with different historical logging intensities revealed no significant difference. However, significant variation in stem density and basal area of adults was observed along the elevation gradient. The results further indicated the population distribution of *Ocotea usambarensis* exhibited a reverse J-shaped pattern, with the highest number of seedlings and the lowest number of adults, indicating a positive recovery suggesting a sustainable population. These findings suggest that logging affects mature trees near the park boundary, highlighting the need for increased enforcement and participatory approaches for sustainable conservation of the species in its range areas.

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Introduction

Anthropogenic activities are altering the world's ecosystems, with forest ecosystems and their connectivity being the most important threat of the 21st century. Land use and climate change, deforestation and habitat fragmentation, are some of the most important components of ecosystem change, acting as major drivers of biodiversity loss worldwide (Franklin *et al.*, 2016; Msalilwa *et al.*, 2020; Said *et al.*, 2021). Recent studies have shown that plant species loss is exceeding background extinction rates (Humphreys *et al.*, 2019; Le Roux *et al.*, 2019). The continuous decline and degradation of tropical rainforests is currently on the rise and mainly driven by land-use change such as deforestation (Renner *et al.*, 2022) and the tropical forest ecosystems are experiencing rapid and alarming transformations because of escalating human activities taking place within them (Morris, 2010). This degradation calls for the urgency to address the impacts of ecosystem change on tree population dynamics and species loss. Densely populated areas and its forests surround the montane forest of Kilimanjaro and woodlands experience different ongoing anthropogenic disturbances along the entire elevation gradient (Said *et al.*, 2021; Renner *et al.*, 2022). This rapid population expansion has led to the swift conversion of forests into agricultural lands, extensive logging activities, and increased incidences of forest fires (Richard *et al.*, 2014; Renner *et al.*, 2022). These activities, logging in particular, have led to the over-exploitation forest resources, consequently causing alterations in the local environmental conditions and posing significant challenges for forest recovery (Kleinschroth *et al.*, 2013). The regeneration of commercial timber species, in particular, has become increasingly difficult because of the intricate processes involved (Kleinschroth *et al.*, 2013).

Tropical forests are not only vital for the conservation of biodiversity but also offer a wide array of essential benefits to landscape ecosystems and human societies. They serve as invaluable sources of food, timber, fresh water, medicine, and

recreational opportunities for humans (Percy *et al.*, 2005). Additionally, Forests provide critical habitats for countless other species, contributing to the overall ecological balance (Percy *et al.*, 2005; Mohammed *et al.*, 2021). The presence of forest trees plays a pivotal role in regulating floods, preventing soil erosion, sequestering carbon dioxide, and regulating climate patterns (Percy *et al.*, 2005).

The forest belt of Mount Kilimanjaro (hence fourth Mt. Kilimanjaro), holds immense significance as a crucial water source and provider of various ecosystem goods and services to communities residing in the East African region, particularly in Kenya and Tanzania (Lambrechts, 2002). Encompassing approximately 59% of Mt. Kilimanjaro's area, the forests exhibit a diverse range of vegetation zones, spanning from dry succulent forests at the foothills (800 meters) to tropical montane rainforests (Hemp, 2006b). These forests also include alpine and sub-alpine zones, adding to the rich ecological diversity of the region.

The Mt. Kilimanjaro forest belt comprises of over 900 plant species, and approximately 130 are tree species including *Xymalos monospora*, *Ocotea usambarensis*, *Podocarpus latifolius*, *Ilex mitis* and *Rapanea melanophloeos* (Lambrechts, 2002).

Despite being one of the world's most diverse habitats (Morris, 2010), the forest belt of Mt. Kilimanjaro has been significantly impacted by human activities and disturbances such as wildfires and logging, resulting in a substantial reduction of tree and shrub biomass and overall changes in vegetation structure (Hemp, 2006b; Renner *et al.*, 2022). Among the major human exploitations of forest resources in the moist East Africa mountains, including the Mt. Kilimanjaro forest belt, selective and/or illegal logging has been widely reported (Lambrechts, 2002). Before 1984, the Mt. Kilimanjaro forest belt faced immense pressure from legal selective logging for commercial timber (Rutten *et al.*, 2015b; Renner *et al.*, 2022).

However, in the early 2000s, the declining population of forest trees in the Mt. Kilimanjaro forest belt prompted the Tanzanian government to impose restrictions on legal tree harvesting. Since then, the government has been implementing measures to combat forest degradation, including the annexation of the Mt. Kilimanjaro forest belt as part of Kilimanjaro National Park in 2005 (Agrawala *et al.*, 2003) to enhance efficient enforcement of conservation laws and protection of the available natural resources.

Ocotea usambarensis, a dominant and vital species in moist forests below 2500 a.s.l (Willan, 1965; Kleinschroth *et al.*, 2013), continues to face threats from illicit loggers due to its valuable timber (Richard *et al.*, 2014). An aerial survey conducted in 2002 revealed the presence of about 2,100 stumps of logged *Ocotea usambarensis* trees (Lambrechts, 2002). Twenty years later, information about *Ocotea usambarensis* population structure remains elusive. The lack of information about the population status of Mt. Kilimanjaro's flagship forest tree species jeopardizes efforts to manage the forest belt as a source of water, tourist attraction, and carbon sequestration and climate regulation.

Previous studies on Mount Kilimanjaro and other moist mountains in East Africa provide valuable insights into the regeneration dynamics of woody species like *Ocotea usambarensis* in response to elevation and disturbance gradients. (Kleinschroth *et al.*, 2013) study in Mt. Kenya on *Ocotea usambarensis* regeneration patterns following historical logging sheds light on its adaptability to disturbances. The research revealed that selective logging impacts both the population structure and regeneration of *Ocotea usambarensis*. Despite the species' tolerance to shading, post-logging recovery is still influenced by additional factor such as soil compaction and root damage. (Rutten *et al.*, 2015a) study on vegetation structure across different habitats on Mt. Kilimanjaro also contributes to our understanding of *Ocotea usambarensis* regeneration under varied circumstances.

Their findings showed that selective logging exerts long-lasting effects on forest structure and composition, particularly in terms of stem density. The study underscored the significance of considering factors beyond logging, such as elevation, human influence, and non-timber forest product (NTFP) harvesting, in comprehending forest dynamics. (Renner *et al.*, 2022) focused on the natural regeneration of woody species, including *Ocotea usambarensis*, across elevation and disturbance gradients, highlighting the complex interaction between environmental factors and regeneration processes. Our study builds on existing literature by investigating the population structure of *Ocotea usambarensis* on the southern slopes of Mt. Kilimanjaro.

Our hypothesis examines the stability of the *Ocotea usambarensis* population despite human disturbances, specifically logging. Historical logging serves as the first blocking criterion in this study, with elevation as the second criterion. Plots within the range of 1800 m to 2200 m are categorized as Low Montane Forest (LMF), while we classify those between 2200 m and 2500 m as Middle Montane Forest (MMF) (Hemp, 2006a; Rutten *et al.*, 2015b). To test our hypothesis, we focused on the following objectives: (i) Determining the stem density and basal area of *Ocotea usambarensis* seedlings, saplings, and adult individuals across blocks with varying logging intensity and elevation gradients; (ii) Comparing stem density, basal area of *Ocotea usambarensis* between blocks with high and low logging intensity, as well as along the elevation gradient. The results from this study are essential for assessing the forest's health and its role in sustaining the mountain and other tropical forest ecosystems.

Materials and methods

Study area

The study was conducted in the montane forest belt on the southern slope of Mt. Kilimanjaro, in Northern Tanzania. Mt. Kilimanjaro is located approximately 300 km south of the Equator, straddling the border between Tanzania and Kenya. Its geographic coordinates range between latitude 2°45' and 3°25' South and longitude 37°00' and 37°43' East (Fig. 1).

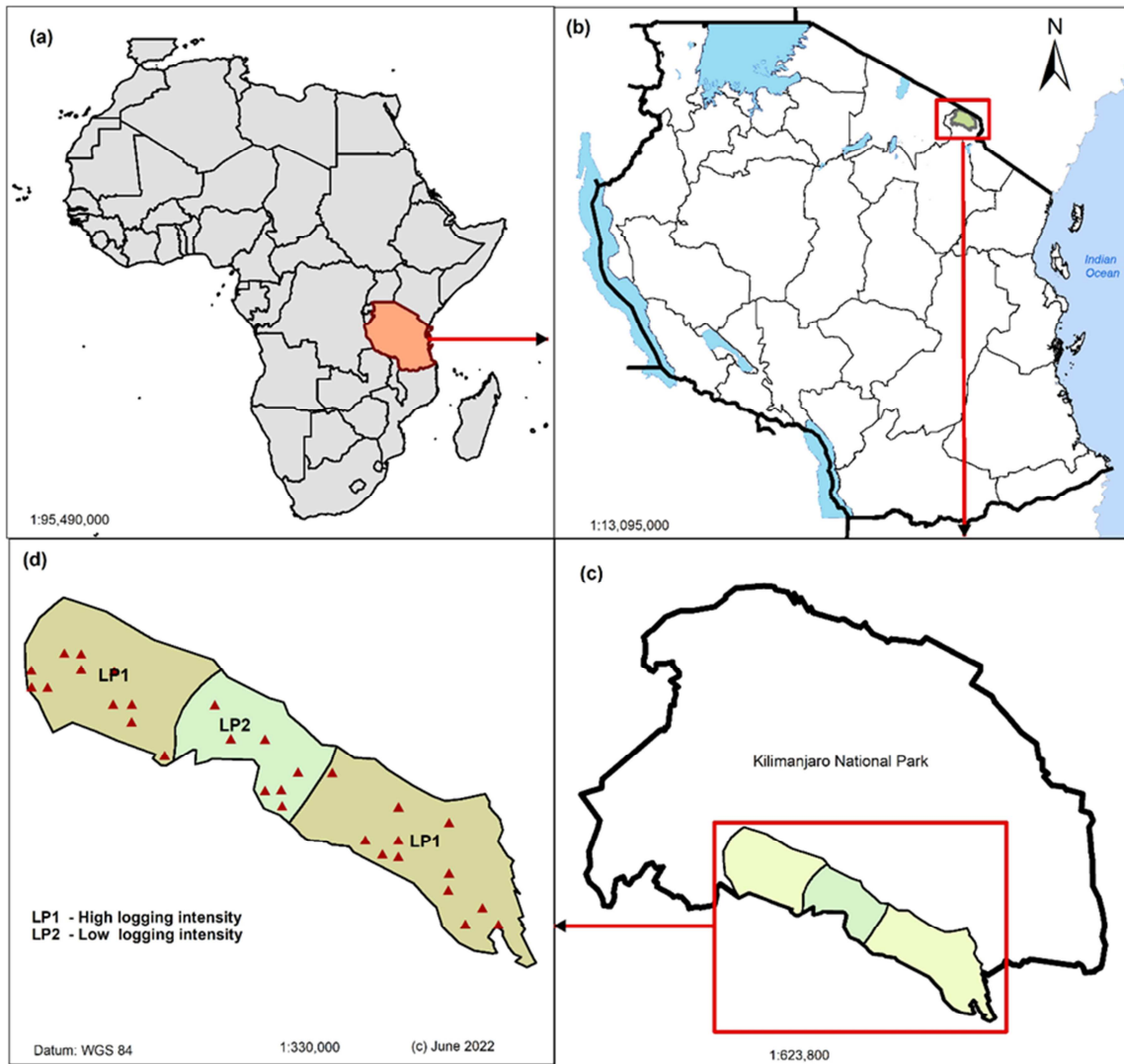


Fig. 1. Map of the study area on the southern slopes of Mt. Kilimanjaro

(Lambrechts, 2002) The region experiences a bimodal climate characterized by two distinct rainy seasons each year: the long rains occurring from March to June and the short rains taking place between November and December. The northern lee slopes of the mountain receive considerably less annual rainfall compared to the southern slopes. The amount of rainfall varies significantly along the elevation gradient, resulting in the presence of distinct ecological zones (Kikoti and Mligo, 2015).

Sampling strategy and assessment of population structure

The study area was divided into two blocks namely High logging intensity (HLI) and Low logging

intensity (LLI) (Fig. 1) based on the aerial survey results by Lambrechts *et al.* (2002) The blocks were further divided into 143 grid cells with an area of 1km² each. Arc map software was utilized to randomly select 30 grid cells, equivalent to 20% of the total number of grid cells (Bailey, 1994; Msalilwa *et al.*, 2019, 2020) in each block.

In each selected sample grid cell, we establish one concentric circular plot with nested subplots, each featuring an area of 500m² for adults, 25m² for saplings, and 1m² for seedlings (following the approach outlined by (Mueller-Dombois, 1974) and (Paudel and Mandal, 2019)). This configuration resulted in 30 study plots for our research. The sampling plots were categorized based

on their location: those between altitudes 1800m and 2200m were classified as Low Montane Forest (LMF), and we categorized those between 2200m and 2500m as Middle Montane Forest (MMF) (Hemp, 2006a; Rutten *et al.*, 2015b). Within each plot, all trees were marked, enumerated, identified, and their heights were recorded.

Trees were categorized based on (Mwavu and Witkowski, 2009) classification which asserts that seedlings are trees with a diameter <2cm and a height of less than 1m, saplings comprise trees with a diameter between 2 and 10 cm, and adult trees with a Diameter of Breast Height (DBH) > 10cm. DBH for adult trees was measured at 1.3m height of a stem from the ground (Msalilwa *et al.*, 2020). For this study, root suckers and coppices were all considered seedlings given, they fit the above-mentioned criteria. *Ocotea usambarensis* has poor sexual reproduction, hence its propagation is mainly asexually from roots and stumps (Hermansen, 1985). Therefore, the assessment of both sexual and asexual propagation provides a clear picture of the species' population structure.

DBH class distribution and age prediction

The individual tree stems were categorized into four (4) DBH classes, 1= 1-10 cm, 2=11-30 cm, 3=31-60 cm, and 4=>60 cm. The categorization helped in identifying the differences in the age distribution of adults in the study area. Age prediction was done following (Willan, 1965) where it was indicated that *Ocotea usambarensis* has a girth growth rate of approximately 30cm (1ft) per ten years and a height growth rate of 90cm per year. In each DBH class, both mean stem density (stems ha⁻¹) and basal area (m²/ha) were computed.

Data analysis

The density of seedlings, saplings, and adult stems was calculated by dividing the total number of stems by the sampled area, as described in Equation 1. This value was then converted to the number of individuals in each plot per unit area of 1 ha (stems per hectare) following the method outlined by (Woldie and Tadesse, 2020). Additionally, the basal area of the enumerated stems was computed using

the approach described by (Mohammed *et al.*, 2021) as shown in Equations 1 and 2.

$$\text{Stem density} = \frac{\text{Total number of stems}}{\text{Area sampled (m}^2\text{)}} \quad (\text{Eq. 1})$$

$$\text{Basal area} = \frac{\pi}{4} (\text{DBH})^2 \quad (\text{Eq. 2})$$

Data for each growth stage were initially summarized using descriptive statistics, including means and standard errors. This preliminary summary was conducted using Microsoft Excel before proceeding with further analyses. To compare the mean stem densities and basal areas of seedlings, saplings, and adult trees between the two blocks (HLI & LLI) and along the elevation gradient (LMF & MMF), we conducted an unpaired two-sample Wilcoxon signed-rank test using R (version 4.0.3). Before conducting the Wilcoxon signed-rank test, a normality test was performed in R (version 4.0.3) using the Shapiro-Wilk test, following the approach outlined by (Mohammed *et al.*, 2021).

Results

Growth stages distribution of Ocotea usambarensis in blocks with different historical logging intensities

Stem densities

Seedling density was higher in both the High Logging Intensity (HLI) and Low Logging Intensity (LLI) blocks compared to other growth stages. However, the mean stem densities (stems per hectare) of all growth stages were higher in the LLI block for Adults (72.50 ± 21.02), Saplings (311.11 ± 208.46), and Seedlings (11,111.11 ± 6,549.90) than in the HLI block for Adults (51.82 ± 13.78), Saplings (266.67 ± 79.68), and Seedlings (10,454.55 ± 3,255.18) (Fig. 2).

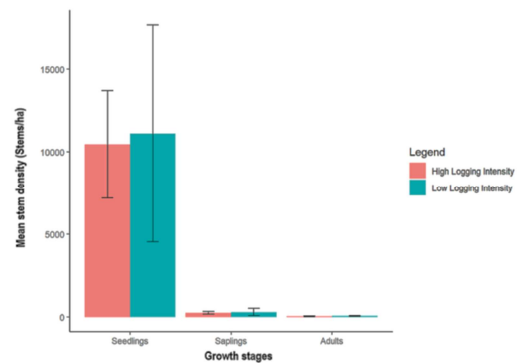


Fig. 2. Mean stem density (stems/ha) of seedlings (N=30), saplings (N=30) and adults (N=30) across different logging intensities

Our analysis revealed that there were no significant differences in the mean stem densities of all growth stages between the High Logging Intensity (HLI) and Low Logging Intensity (LLI) blocks, including adults ($W = 67, p = 0.33$), saplings ($W = 101.50, p = 0.72$), and seedlings ($W = 102, p = 0.90$) (Fig. 3A).

Basal area

The basal area for adult trees was computed in m^2/ha . The results revealed that adult trees in the Low Logging Intensity (LLI) block had a higher mean basal area ($21.1 m^2/ha$) compared to the High Logging Intensity (HLI) block ($9.45 m^2/ha$). However, the differences in mean basal areas (m^2/ha) of all growth stages between the HLI block (Adults: 9.45 ± 3.08 , Saplings: 1.12 ± 0.34 , Seedlings: 2.5 ± 1.68) and the LLI block (Adults: 21.10 ± 6.66 ,

Saplings: 1.02 ± 0.67 , Seedlings: 1.60 ± 1.01) were not significant (Adults; $W=58, p = 0.16$; Saplings: $W=103.5, p = 0.65$; Seedlings: $W = 102.50, p = 0.88$) (Fig. 3B).

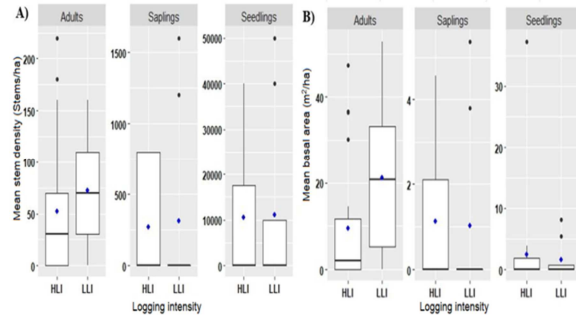


Fig. 3. Boxplots showing comparison of mean stem densities (stems/ha) (A) and mean basal area (m^2/ha) (B) between High and Low logging intensities blocks ($N=30$)

Table 1. Stem density and basal area in relation to DBH classes along different logging intensities blocks

| Blocks | Approximated age | High logging intensity | | Low logging intensity | |
|-------------|------------------|------------------------|-------------------------|-----------------------|-------------------------|
| DBH classes | Years | Density (Stems/ha) | Basal area (m^2/ha) | Density stems/ha | Basal area (m^2/ha) |
| 1-10 | 10< | 12072.73 | 3.76 | 16600 | 3.28 |
| 11-30 | 3-10 | 17.27 | 0.61 | 2.5 | 0.02 |
| 31-60 | 10-20 | 22.73 | 3.17 | 20 | 4.52 |
| >60 | >20 | 11.82 | 5.67 | 45 | 16.55 |

DBH class distribution along different logging intensities

The population of *Ocotea usambarensis* demonstrates significant fluctuations in the density (stems/ha) and basal area (m^2/ha) across distinct age categories and logging intensities. Generally, the younger age categories (1-10 and 11-30 years) display reduced densities and basal areas, particularly in the HLI block. Conversely, in the older age categories (>60 years), there is a notable increase in both density and basal area, especially within a block characterized by low logging intensity (LLI) (Table 1).

Growth stages distribution of camphorwood across an elevation gradient

Stem densities

The mean stem densities (stems per hectare) for all growth stages were observed to be higher in the Middle Montane Forest (MMF) for Adults ($87.1 \pm$

17.10), Saplings (371.4 ± 148.00), and Seedlings ($12,666.7 \pm 4,727.50$) compared to the Lower Montane Forest (LMF) for Adults (31.30 ± 12.60), Saplings (200.00 ± 81.60), and Seedlings ($8,750 \pm 3,637.20$) (Fig. 4).

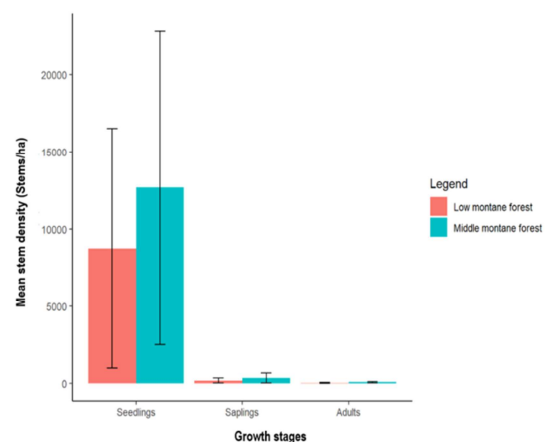


Fig. 4. Mean stem density (stems/ha) of seedlings ($N=30$), saplings ($N=30$) and adults ($N=30$) along the elevation gradient

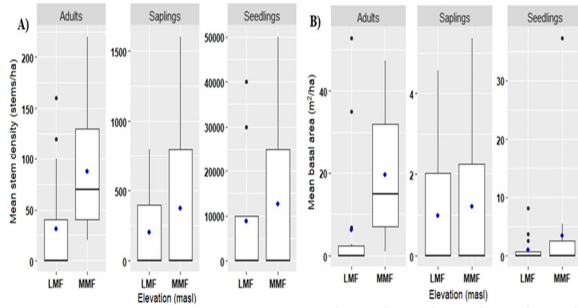


Fig. 5. Boxplots showing comparison of mean stem densities (stems/ha) (A) and mean basal area (m²/ha) (B) between Middle montane forest (MMF) and Lower montane forest (LMF) zones (N=30)

However, there was a significant variation in the mean stem density (stems per hectare) of adults along the elevation gradient ($W = 41, p = 0.002$). In contrast, for other growth stages such as saplings ($W = 99, p = 0.53$) and seedlings ($W = 111, p = 0.70$), the differences were not significant (Fig. 5A).

Basal area

The mean basal area (m²/ha) for adults was found to be higher in the Middle Montane Forest (MMF)

(19.63 ± 4.01) compared to the Lower Montane Forest (LMF) (6.37 ± 3.78). Furthermore, there was a significant difference in the mean basal area (m²/ha) for adults along the elevation gradient ($W = 34, p = 0.001$). However, the mean basal area of Seedlings (3.50 ± 2.45) in MMF and (1.05 ± 0.54) in LMF did not show a significant variation ($W = 110.5, p = 0.68$). Similarly, there was no significant variation in the mean basal areas (m²/ha) of saplings between MMF (1.22 ± 0.49) and LMF (0.98 ± 0.40) ($W = 106.5, p = 0.80$) (Fig. 5B).

DBH class distribution along the elevation gradient

Significant variations in stem density and basal area of *Ocotea usambarensis* across distinct diameters at breast height (DBH) classes were revealed. Specifically, low montane forest (LMF) exhibits generally lower stem density and basal area when compared to middle montane forest (MMF) (Table 2). The results contribute valuable insights into the structural characteristics and dynamic processes of forest ecosystems along elevation gradients.

Table 2. Stem density and basal area in relation to DBH classes along different elevation gradients

| Elevation gradient | Approximated age | Lower montane forest (LMF) | | Middle montane forest (MMF) | |
|--------------------|------------------|----------------------------|--------------------------------|-----------------------------|---------------------------------|
| DBH classes | Years | Density (Stems/ha) | Basal area(m ² /ha) | Density (Stems/ha) | Basal area (m ² /ha) |
| 1-10 | 10< | 8950 | 2.02 | 18228 | 5.47 |
| 11-30 | 3-10 | 11.25 | 0.13 | 15.71 | 0.82 |
| 31-60 | 10-20 | 5 | 0.82 | 44.29 | 6.63 |
| >60 | >20 | 15 | 5.42 | 27.14 | 12.18 |

Discussion

Growth stages distribution of Ocotea usambarensis in blocks with different historical logging intensities

The growth stages within the blocks with different logging intensity histories exhibited minimal variation with a higher density of junior adults with DBH between 11-30cm and 31-60cm. The forest's recovery has been evident despite the logging disturbance, demonstrating a high potential for regeneration and increased recruitment. Under good bio-physical conditions, forest patches with moderate disturbance are expected to have higher regeneration potential a finding which was also observed in studies done by (Koirala, 2004) and (Renner *et al.*, 2022).

Improved light penetration plays a key role in enhancing seed germination and the development of the understory (Renner *et al.*, 2022). The population structure of *Ocotea usambarensis* was observed to be stable a finding which denotes that the logging impact to the *Ocotea* forest was not significant because *Ocotea usambarensis* is a long-lived species. Also, in 2005, the Mt. Kilimanjaro forest belt was incorporated into Kilimanjaro National Park, resulting in improved enforcement of conservation laws and more effective protection of natural resources. A decrease in selective illegal logging cases in the Mt. Kilimanjaro forest belt was also reported by (Rutten *et al.*, 2015a). We observed a higher density

of *Ocotea usambarensis* trees 20 years old or younger, a finding which also suggests annexation of the Mt. Kilimanjaro forest belt (approximately 17 years of strict protection) has reduced illegal extraction of *Ocotea usambarensis* thus allowing saplings of the species to grow further. However, more mature adults with DBH equal to or more than 60cm were observed in blocks with lower logging intensity. This indicates that the block has reached a climax state, where recruitment is expected to be lower due to canopy cover hindering the growth of seedlings and saplings in the understory (Condit *et al.*, 1998).

Nonetheless, the study observed higher densities of *Ocotea usambarensis* seedlings compared to its other growth stages across all the study blocks. This could be due to the low survival rates of *Ocotea usambarensis* seedlings, which face competition from the light-demanding pioneer species like *Macaranga kilimandscharica*, *Hagenia abyssinica*, and *Agarista salicifolia* (Bussman, 2001; Renner *et al.*, 2022). In particular, *Macaranga kilimandscharica*, as an early successional species, exhibits a growth rate 50% higher than that of *Ocotea usambarensis*, failing *Ocotea usambarensis* seedlings and saplings to survive due to limited/low light intensity (Bussman, 2001; Koirala, 2004).

Growth stages distribution of Ocotea usambarensis across an elevation gradient

The mean stem density and basal area of adult *Ocotea usambarensis* varied significantly between the plots found in lower and higher altitudes. This indicates that selective illegal logging decreases as the elevation increases, with more logging activity concentrated at lower altitudes. Similar findings were reported by (Richard *et al.*, 2014) who observed a higher presence of anthropogenic disturbances near or along the boundaries of forest reserves compared to higher altitudes located further away. Forest patches in proximity to human settlements are more susceptible to human exploitation, as illegal logging often serves as a primary source of income in many communities (Koirala, 2004; Richard *et al.*, 2014) and individuals

can easily navigate to and from the forest, evading forest rangers. Lower altitudes also experience prolonged periods of drought and higher rainfall seasonality, which significantly affects soil moisture content. Soil moisture content is a crucial factor for the regeneration of woody species following anthropogenic disturbances (Renner *et al.*, 2022).

We further noted significant differences among different (DBH) classes along the elevation gradient. The mean stem density of *Ocotea usambarensis* with DBH classes 31-60cm and greater than 60cm was higher in the higher altitudes than in lower altitudes. This suggests that illegal logging in the Mt. Kilimanjaro forest belt primarily targets adult trees with a DBH exceeding 30cm for timber production. Furthermore, there were no significant differences in stem densities for seedlings and saplings along the elevation gradient, indicating that the current logging practices specifically target adult *Ocotea usambarensis* trees.

Population distribution of Ocotea usambarensis

The population distribution of *Ocotea usambarensis* exhibited a reverse J-shaped pattern, with a higher number of seedlings compared to saplings and adults. Similar findings were reported by (Paul *et al.*, 2019) in their study comparing population structures of disturbed and undisturbed mixed broadleaved forests in India. The reverse J-shaped pattern indicates a stable population with robust reproductive and recruitment capabilities (Ahmed *et al.*, 2017; Msalilwa *et al.*, 2020; Balemlay and Siraj, 2021) suggesting a favorable regeneration status for *Ocotea usambarensis* (Paul *et al.*, 2019).

The observed reverse J-shaped population distribution can be attributed to several factors, including disturbances such as selective logging of adults and competition for limited resources (such as light, water, and minerals) among species, which significantly impact seedlings (Hitimana *et al.*, 2004). This could also explain the population dynamics of *Ocotea usambarensis*, as selective logging combined with other human disturbances create favorable

conditions for *Macaranga kilimandscharica* to outcompete *Ocotea usambarensis* seedlings and saplings (Bussman, 2001).

Conclusion

A thorough understanding of forest tree species' population structure is paramount for effective conservation planning and management. This study specifically focused on the population structure of *Ocotea usambarensis*, providing vital insights into the management of the Mt. Kilimanjaro forest belt, which plays a crucial role in tourism, watershed management, climate regulation, and carbon sequestration. While the reversed *J*-shaped population distribution suggests the overall sustainability of the forest belt's tree population, it is evident that adult *Ocotea usambarensis* trees, especially those near the park boundary, remain vulnerable to exploitation. Addressing this issue necessitates increased community participation in forest protection and management through conservation education and awareness campaigns. This will impart to the local communities a sense of ownership, thus enhancing compliance with the park's conservation strategies. These efforts will contribute to the conservation of the Mt. Kilimanjaro forest belt, ensuring its long-term sustainability and the provision of its valuable ecosystem services.

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References

- Agrawala S, Moehner A, Hemp A, Van Aalst M, Hitz S, Smith J, Meena H, Mwakifwamba SM, Hyera T, Mwaipopo OU.** 2003. Development and climate change in Tanzania: Focus on Mount Kilimanjaro. Organisation for Economic Co-operation and Development (OECD).
- Ahmed E, Ali S, Addisu A.** 2017. Structure and regeneration status of woody plants in the Hallidegieh wildlife reserve, North East Ethiopia. *International Journal of Biodiversity and Conservation* **9**(6), 200–211. DOI: 10.5897/ijbc2017.1085.
- Andrade GS, Rhodes JR.** 2012. Protected areas and local communities: An inevitable partnership toward successful conservation strategies? *Ecology and Society* **17**(4). DOI: 10.5751/ES-05216-170414.
- Bailey KD.** 1994. *Typologies and taxonomies*. Thousand Oaks, CA. SAGE Publications, Inc. DOI: 10.4135/9781412986397.
- Balemlay S, Siraj M.** 2021. Population structure and regeneration status of woody species in Kenech Forest, Southwest Ethiopia. *International Journal of Forestry Research* **2021**. DOI: 10.1155/2021/6640285.
- Bussman R.** 2001. Succession and regeneration patterns of East African mountain forests: A review. *Systematic and Geography of Plants* **71**(2), 959–974.
- Condit R, Sukumar R, Hubbell SP, Foster R. B.** 1998. Predicting population trends from size distributions: A direct test in a tropical tree community. *The American Naturalist* **152**(4), 495–509.
- Franklin J, Serra-Diaz JM, Syphard AD, Regan HM.** 2016. Global change and terrestrial plant community dynamics. *Proceedings of the National Academy of Sciences of the United States of America* **113**(14), 3725–3734. DOI: 10.1073/pnas.1519911113.
- Hemp A.** 2006a. Continuum or zonation? Altitudinal gradients in the forest vegetation of Mt. Kilimanjaro. *Plant Ecology* **184**(1), 27–42. DOI: 10.1007/s11258-005-9049-4.
- Hemp A.** 2006b. Vegetation of Kilimanjaro: Hidden endemics and missing bamboo. *African Journal of Ecology* **44**(3), 305–328. DOI: 10.1111/j.1365-2028.2006.00679.x.

- Hermansen J.** 1985. Catchment forestry in Tanzania.
- Hitimana J, Kiyiapi JL, Njunge JT.** 2004. Forest structure characteristics in disturbed and undisturbed sites of Mt. Elgon Moist Lower Montane Forest, western Kenya. *Forest Ecology and Management* **194**(1–3), 269–291.
DOI: 10.1016/j.foreco.2004.02.025.
- Humphreys AM, Govaerts R, Ficinski SZ, Nic Lughadha E, Vorontsova MS.** 2019. Global dataset shows geography and life form predict modern plant extinction and rediscovery. *Nature Ecology and Evolution* **3**(7), 1043–1047.
DOI: 10.1038/s41559-019-0906-2.
- Kikoti IA, Mligo C.** 2015. Impacts of livestock grazing on plant species composition in montane forests on the northern slope of Mount Kilimanjaro, Tanzania. *International Journal of Biodiversity Science, Ecosystem Services and Management* **11**(2), 114–127. DOI: 10.1080/21513732.2015.1031179.
- Kleinschroth F, Healey JR, Gourlet-Fleury S.** 2013. Regeneration of the East African timber tree *Ocotea usambarensis* in relation to historical logging. *Forest Ecology and Management* **291**, 396–403.
DOI: 10.1016/j.foreco.2012.11.021.
- Koirala M.** 2004. Vegetation composition and diversity of Piluwa micro-watershed in Tinjure-Milke region, east Nepal. *Himalayan Journal of Sciences* **2**(3), 29–32. DOI: 10.3126/hjs.v2i3.227.
- Lambrechts C.** 2002. The Threats to Mt. Kilimanjaro. (February).
- Le Roux JJ, Hui C, Keet JH, Ellis AG.** 2019. Recent anthropogenic plant extinctions differ in biodiversity hotspots and coldspots. *Current Biology* **29**(17), 2912–2918.e2.
DOI: 10.1016/j.cub.2019.07.063.
- Mohammed EMI, Adam YOM, Elamin HA.** 2021. Tree population structure, diversity, regeneration status, and potential disturbances in Abu Gadaf natural reserved forest, Sudan. *Environmental Challenges* **5**(August), 100366.
DOI: 10.1016/j.envc.2021.100366.
- Morris RJ.** 2010. Anthropogenic impacts on tropical forest biodiversity: A network structure and ecosystem functioning perspective. *Philosophical Transactions of the Royal Society B: Biological Sciences* **365**(1558), 3709–3718.
DOI: 10.1098/rstb.2010.0273.
- Msalilwa UL, Munishi PKT, Treydte AC.** 2019. Emerging issues and challenges associated with conservation of the African baobab (*Adansonia digitata* L.) in the semi-arid areas of Tanzania. *Journal of Biodiversity and Environmental Sciences* **15**(5), 76–91.
- Msalilwa UL, Munishi PKT, Treydte AC.** 2020. Demography of baobab (*Adansonia digitata* L.) population in different land uses in the semi-arid areas of Tanzania. *Global Ecology and Conservation* **24**, e01372. DOI: 10.1016/j.gecco.2020.e01372.
- Mueller-Dombois R.** 1974. Aims and methods of vegetation ecology.
- Mwavu EN, Witkowski ETF.** 2009. Population structure and regeneration of multiple-use tree species in a semi-deciduous African tropical rainforest: Implications for primate conservation. *Forest Ecology and Management* **258**(5), 840–849.
DOI: 10.1016/j.foreco.2009.03.019.
- Paudel P, Mandal RA.** 2019. Comparing growing stock using circular, square, and rectangular plot shapes in inventory (A study from community forests in Chitwan District, Nepal). (October).
DOI: 10.32474/OAJESS.2019.04.000177.

- Paul A, Khan ML, Das AK.** 2019. Population structure and regeneration status of rhododendrons in temperate mixed broad-leaved forests of western Arunachal Pradesh, India. *Geology, Ecology, and Landscapes* **3**(3), 168–186.
DOI: 10.1080/24749508.2018.1525671.
- Percy S, Arico S, Reid W, Mooney H, Cropper A, Capistrano D, Lee M, Ash N.** 2005. Millennium Ecosystem Assessment Business and Industry Synthesis. A Report of the Millennium Ecosystem Assessment. Available at: <http://www.alexandrina.org/CSSP/Event/>.
- Renner M, Hemp A, Ensslin A, Rutten G, Fischer M.** 2022. Natural regeneration of woody plant species along an elevational and disturbance gradient at Mt. Kilimanjaro. *Forest Ecology and Management* **520**, 120356.
DOI: 10.1016/j.foreco.2022.120356.
- Richard J, Madoffe SS, Maliondo SMS.** 2014. Assessment of factors for declining regeneration and death of East African camphor in moist mountainous forest of Tanzania. *Journal of Tropical Forest Science* **26**(4), 495–502.
- Rutten G, Ensslin A, Hemp A, Fischer M.** 2015a. Forest structure and composition of previously selectively logged and non-logged montane forests at Mt. Kilimanjaro. *Forest Ecology and Management* **337**, 61–66. DOI: 10.1016/j.foreco.2014.10.036.
- Rutten G, Ensslin A, Hemp A, Fischer M.** 2015b. Vertical and horizontal vegetation structure across natural and modified habitat types at Mount Kilimanjaro. *PLoS ONE* **10**(9).
DOI: 10.1371/journal.pone.0138822.
- Said M, Mtei K, Lyimo J, Mbaga T.** 2021. Predicting land use/cover changes and its association to agricultural production on the slopes of Mount Kilimanjaro, Tanzania. *Annals of GIS* **27**(2), 189–209. DOI: 10.1080/19475683.2020.1871406.
- Willan RL.** 1965. Natural regeneration of high forest in Tanganyika. *East African Agricultural and Forestry Journal* **31**(1), 43–53.
DOI: 10.1080/00128325.1965.11662025.
- Woldie BA, Tadesse SA.** 2020. Composition and structure of woody vegetation in community compared to state forests in Tehuledere District, South Wollo, Ethiopia. *Journal of Sustainable Forestry*, **39**(8), 757–783.
<https://doi.org/10.1080/10549811.2020.1772826>.