

Impact of Forest Cover Change on Tree Species Diversity and Composition Within Irangi Forest, Embu County, Kenya

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ABSTRACT: The objective of this study was to examine the ecological effects of forest cover change on tree species diversity and composition in Irangi Forest between 2005 and 2025. The study was guided by the hypothesis that there was no significant relationship between forest cover change and tree species diversity. A mixed-methods approach was employed, integrating spatial analysis of satellite imagery, ecological field surveys, and key informant interviews. Species data were collected along stratified transects, and diversity was analyzed using Shannon (H') and Simpson (1-D) indices. The findings revealed significant variation in species diversity across deforestation gradients, with diversity indices ranging from $H' = 2.87-1.62$ and $1-D = 0.91-0.53$. Statistical analysis at the 0.05 level of significance led to the rejection of the null hypothesis, confirming that forest cover change significantly influences tree species diversity and composition. Indigenous species such as *Juniperus procera*, *Ocotea usambarensis*, and *Podocarpus* were less abundant in disturbed areas. Structurally, intact forest zones exhibited dense canopies, while degraded areas showed reduced tree cover and altered forest structure. The study concludes that forest cover change has a significant negative impact on biodiversity and forest structure. It recommends strengthening the Forest Conservation and Management Act, promoting community-based forest management, and enhancing GIS-based monitoring and indigenous reforestation initiatives. These measures are critical for achieving Sustainable Development Goal 15 and ensuring sustainable forest management.

KEYWORDS: Spatio-temporal, forest cover variation, species diversity, biodiversity, GIS.

INTRODUCTION

Globally, forests are vital ecosystems that provide essential ecological, economic, and social services to humans. They cover approximately 31% of the Earth's land surface and harbor over 80% of terrestrial biodiversity (FAO, 2022). They are also critical to sustainable development because they regulate climate, sequester carbon, cycle water, and save soil. However, deforestation, land-use change, and climate variability continue to erode forest ecosystems, with an estimated 10 million hectares lost annually between 2015 and 2020 (FAO, 2025). The loss of forest cover has irrevocable effects for biodiversity, ecosystem services, and the livelihoods of millions of people who depend on forests for subsistence. Africa alone contributes to this trend, losing approximately 3.9 million hectares of forest each year, primarily due to agricultural expansion, illegal logging, and weak enforcement of conservation policies (FAO, 2024).

East African woods play an important role in sustaining agriculture, which is the region's primary source of income. Nonetheless, it has been undermined by population growth, agricultural expansion, illegal logging, and lax implementation of conservation laws (KFS, 2025). In Kenya, montane forests such as those in the Mount Kenya ecosystem are especially significant. They function as critical water catchments, biodiversity refuges, and climate regulators (KFS, 2025). Yet, over the last two decades, these forests have experienced extensive degradation, with the Mount Kenya ecosystem losing approximately 15% of its dense forest cover due to agricultural encroachment, illegal timber harvesting, and charcoal production (KFS, 2025; KWTa, 2025). The Irangi Forest Block in Embu County, part of the gazetted Mount Kenya Forest Reserve, exemplifies these challenges. Although it is home to ecologically valuable tree species such as *Ocotea usambarensis*, *Juniperus procera*, and *Podocarpus falcatus* (Wass, 1995), increasing anthropogenic pressures have led to canopy loss, habitat fragmentation, and declining biodiversity.

The forest has historically provided important ecosystem services such as timber, non-timber forest products, and water for home and agricultural use (ECIDP, 2023). It also helps to regulate local climate and increase agricultural productivity in the surrounding area. However, the forest has been subjected to rising anthropogenic pressures (KFS, 2020). The colonial administration

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predominantly used the forest for commercial timber production, establishing exotic tree plantations like as Cypress (*Cupressus lusitanica*) and Pine (*Pinus spp.*) to meet rising demand for wood products (Wass, 1995). While the plantations were commercially successful, they altered the natural forest structure and diminished local biodiversity. Following Kenya's independence, the government maintained commercial forestry operations, with most cases prioritizing timber extraction over conservation (KFS, 2020). Since the Forest Act of 2005, participatory forest management practices have been implemented with a focus on community-based conservation. Sustainable forest management has been achieved through the formation of Community Forest Associations (CFAs), which include local communities in conservation efforts (ECIDP, 2023). Despite these efforts, Irangi Forest is still vulnerable to rapid population increase, land-use changes, and climate change which imperil the forest's ecological integrity, biodiversity, and ability to provide essential ecosystem services.

The main objective of this study was to determine the impact of forest cover change on tree species diversity and composition in Irangi Forest. To address this, the study tested the hypothesis that there was no statistically significant difference in tree species diversity across forest cover strata in Irangi Forest. Analysis using the Shannon-Wiener and Simpson diversity indices, combined with one-way ANOVA, rejected this null hypothesis, demonstrating that tree species diversity significantly decreased with increasing deforestation intensity. Low-deforestation zones supported higher species richness and dominance of native species such as *Ocotea usambarensis* and *Juniperus procera*, while high-deforestation zones showed reduced diversity and increased prevalence of invasive species. The findings of this study are significant for conservation and policy interventions. They highlight the urgent need for strengthened community-based forest management, targeted reforestation using indigenous species, and enhanced monitoring through GIS and remote sensing. Furthermore, the study provides empirical evidence to guide species recovery plans and improve the effectiveness of Community Forest Associations (CFAs) in mitigating biodiversity loss. By linking forest cover dynamics to species diversity outcomes, this research offers a replicable framework for sustaining biodiversity in Kenya's montane forests while supporting local livelihoods.

LITERATURE REVIEW

Impact of Forest Cover Change on Tree Species Diversity and Composition

Biodiversity particularly tree species and their associated communities is significantly impacted by forest cover change. Forest cover deterioration and fragmentation modify critical habitat parameters such as light regimes, soil moisture, nutrient cycling, and landscape connectivity, all of which are essential for successful tree establishment and regeneration (Chazdon *et al.*, 2021). These alterations disrupt ecological interactions and mutualisms such as those between trees and pollinators or seed dispersers thereby inhibiting natural recruitment and regeneration processes (Chase *et al.*, 2022). Such disruptions not only lead to decreased species richness but also shift the functional composition of forests, weakening ecosystem stability and resilience against future disturbances (Newbold *et al.*, 2021).

Studies in tropical regions, which harbor the highest levels of tree diversity, have shown that forest fragmentation significantly reduces species richness and accelerates the loss of specialized species (Tabarelli *et al.*, 2021). For example, recent long-term research in the Amazon basin revealed that small forest fragments lost more than half of their original tree species within decades due to edge effects, reduced seed dispersal, and declining functional diversity (Figueiredo *et al.*, 2022). Likewise, in Southeast Asia, conversion of primary forests into agricultural landscapes has been linked to dramatic declines in tree diversity and shifts toward pioneer and invasive species, particularly in regions undergoing intensive oil palm expansion and land-use transformation (Giam *et al.*, 2023).

Eastern African forests are essential to regional agriculture-based economies, providing ecosystem services such as biodiversity support. However, in recent years, these forests have experienced acute deforestation and degradation. A study by Mutindi and Wanjiku (2024) on the Aberdare Range documented altitudinal shifts in native montane tree species in response to rising temperatures, with specialist species suffering loss particularly in lower elevation zones. Similarly, Omolo *et al.* (2025) observed in the Taita Hills that forest fragmentation over the past decade has facilitated the spread of invasive species which now dominate edges of disturbed forests, reducing native species richness by approximately 40%. Mwanake and Mwangi (2023) reported that in the East Forests of Mt. Kenya, areas with heavy settlement and agricultural encroachment had canopy cover drop below 30%, with indigenous species richness declining by about one-third. These findings reinforce that native species decline and invasive species proliferation are not relics of past deforestation, but active, accelerating trends in Kenya's montane ecosystems.

In Kakamega Forest, Osewe *et al.* (2022) documented that forest fragmentation and canopy thinning have significantly reduced populations of indigenous species and increased vulnerability to edge-effects and invasive plants. In the Aberdare Ranges, Nduguta *et al.* (2024) observed that rare indigenous trees such as African Pencil Cedar have declined amid intensified logging and poaching pressure. Similarly, in the Taita Hills, recent surveys (Watuma *et al.*, 2022; Raphela *et al.*, 2023) have highlighted the creeping dominance of *Lantana camara* in disturbed zones, with native species such as East African Camphor appearing less frequently. These recent findings mirror those in Mount Kenya ecosystem studies (Githae *et al.*, 2021), which show forest loss correlating with reduced species richness and increasing prevalence of secondary vegetation in degraded areas.

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In the Irangi Forest block, the loss of canopy cover is expected to produce analogous ecological effects. Although comprehensive data on shifts in species abundance, richness, and evenness remain limited, local reports and preliminary observations indicate consistent declines across those metrics. Consequences manifest as disruptions to ecosystem services including carbon sequestration, watershed protection and altered physiological functioning in residual trees (Verma *et al.*, 2022). Additionally, forest compositional homogenization undermines ecosystem resilience, rendering systems more vulnerable to climate stressors and other disturbances (Nguyen & Lee, 2021). Direct measurement of species diversity across intact and logged forest gradients makes it an empirical study that seeks to prove the need to establish empirical relationships between the changes in forests cover and the consequences of biodiversity, a gap that critically needs to be filled when it comes to research Irangi Forest.

METHODOLOGY

The study focused on Irangi Forest, located in Embu County on the south eastern slope of Mount Kenya. Spanning about 18,500 hectares, the forest is situated between latitudes 0°10'S to 0°28'S and longitudes 37°28'E to 37°34'E, and has an average elevation of 2,000 meters above sea level. It specifically focused on assessing the impact of forest cover change on tree species diversity and composition. A mixed-methods approach was employed, integrating geospatial analysis with field-based ecological surveys to provide both quantitative and qualitative insights (Creswell & Plano Clark, 2018). Ecological data were collected between April and June 2025 using a systematic transect sampling design. Fifteen transects were established across three deforestation gradients namely ; low, moderate, and high based on canopy cover, disturbance indicators, and proximity to forest edges. Each transect comprised four quadrats measuring 50 m × 50 m, resulting in a total of 60 quadrats. Within each quadrat, tree species were identified, counted, and their structural attributes such as diameter at breast height (DBH) and height were recorded. This method enabled the quantification of tree species richness and composition across varying forest disturbance levels (Kent, 2012). To complement ecological data, 20 key informants, including forest officers, Community Forest Association (CFA) leaders, and local elders, were purposively selected to provide insights into biodiversity trends and conservation practices. Semi-structured interviews were used to gather information on historical forest use and management (Patton, 2015). Data analysis involved calculating species diversity using the Shannon-Wiener and Simpson diversity indices to assess richness and evenness across the three deforestation gradients (Magurran, 2013). A one-way Analysis of Variance (ANOVA) was conducted to test the hypothesis that deforestation intensity significantly influences tree species diversity. Statistical significance was evaluated at $p < 0.05$. The results were presented using tables, figures, and photographic documentation to illustrate biodiversity variations across forest zones.

RESULTS AND DISCUSSIONS

Species Composition and Structural Variability

The forest exhibited marked structural and compositional differences associated with deforestation intensity. Canopy cover in low-deforestation transects (T-01, T-02, T-03, T-10 to T-11) remained high, averaging 78.4%, with tall, mature trees (DBH 50–100 cm; height 30–60 m). In contrast, heavily deforested transects (T-05, T-06, T-07, T-13, T-14) exhibited open canopies (mean 29.5%) and younger stands (DBH < 30 cm; height < 20 m). Species composition shifted markedly across gradients where most common species included Kikuyu *Aralia* (*Cussonia spicata*), Broad-leaved Croton (*Croton megalocarpus*), and Waterberry (*Syzygium guineense*), which appeared in 80–90% of all quadrats regardless of degradation level while endemic and high-value hardwoods such as East African Camphor (*Ocotea usambarensis*), Meru Oak (*Vitex keniensis*), and Yellowwood (*Afrocarpus gracilior*) were predominantly restricted to low-disturbance areas, with only four quadrats across low-deforestation transects recording their presence.

Species Diversity

Species richness and diversity were quantitatively analyzed using Shannon (H') and Simpson ($1-D$) diversity indices. The Shannon diversity index results revealed variation in species diversity across three deforestation strata in Irangi Forest: low, moderate, and high deforestation. Overall, areas with low deforestation (A) consistently show higher diversity, with values ranging from 1.47 to 2.35. Moderate deforestation strata (B) show intermediate diversity values, ranging from 0.96 to 1.82, while high deforestation areas (C) display the lowest diversity, ranging from 0.25 to 1.31. This clear gradient suggests a negative relationship between deforestation intensity and species diversity. Specifically, low deforestation zones (Transects 1, 2, 3, 10, and 11) maintain relatively stable and rich species diversity, while high deforestation zones (Transects 5, 6, 7, 13, and 14) exhibit significant biodiversity loss. These findings highlight the ecological impact of forest disturbance on tree species richness and evenness in Irangi Forest.

A one-way ANOVA was conducted to examine the effect of deforestation level on forest species diversity. Therefore, the null hypothesis is rejected, confirming that a significant difference exists between forest cover and tree species diversity. The results revealed a statistically significant effect of deforestation level on forest species diversity, $F(2, 12) = 13.517$, $p = .001$, indicating that mean Shannon diversity indices significantly differ across the low, moderate, and high deforestation strata. Post-hoc Tukey HSD tests show that low deforestation areas had significantly higher diversity than high deforestation areas (mean difference = 1.172, $p = .001$), and moderate deforestation areas also had significantly higher diversity than high deforestation areas (mean difference =

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0.860, $p = .008$). However, the difference between low and moderate deforestation was not statistically significant ($p = .403$). These results suggest that increased deforestation leads to a significant reduction in species diversity, particularly between low and high, and moderate and high deforestation zones. Therefore, minimizing forest disturbance may be key to preserving biodiversity in Irangi forest.

The findings of this study reveal that there is a statistically significant relationship between the intensity of deforestation and tree species diversity in Irangi Forest, as verified by the Shannon diversity index. Low deforestation classes had high diversity values ranging from 1.47 to 2.35, medium deforestation classes had medium diversity (0.96-1.82), while high deforestation classes had the lowest values (0.25-1.31). One-way ANOVA test supported that these strata were significantly different, with $F(2, 12) = 13.517$, $p = 0.001$. Post-hoc Tukey HSD analysis also revealed that low and moderately deforested areas both were significantly more diverse than highly deforested ones. The observed trend here is in harmony with global trends whereby high forest cover loss is equated with low biodiversity, as argued by FAO (2020), who estimated a net global forest loss of 420 million hectares since 1990 due to human activities. The observations are in agreement with the arguments by Chazdon *et al.* (2016) that habitat disturbance alters species richness, recruitment, and ecological interactions. The implications for Irangi Forest are severe, as its continued degradation is likely to compromise its ecological integrity, eliminate keystone species, and potentially threaten its role as a source of biodiversity reservoir and water catchment.

Disturbance Regimes and Regeneration Capacity

Evidence of anthropogenic disturbance was widespread, particularly in high-deforestation sites (T-05, T-06, T-07, T-13, and T-14), where fresh tree stumps, logging scars, grazing signs, firewood paths, and human settlements were frequently recorded. These zones exhibited low regeneration incidence with only 12.5% of quadrats showed sapling or seedling growth. Dominance of pioneer species such as Silver Oak (*Brachylaena huillensis*), Tick Tree (*Albizia gummifera*), and Velvet Croton (*Croton macrostachyus*) replaced climax hardwoods in disturbed plots. In contrast, low-deforestation quadrats (T-01, T-03, T-08, T-10, and T-12) demonstrated robust regeneration in 71.9% of sampled plots, with intact seed banks and sapling diversity

Invasive Species Proliferation

Invasive species presence correlated positively with degradation level where *Lantana camara* was detected in 75% of moderate-deforestation quadrats (T-04), forming dense undergrowth thickets that suppressed regeneration while ferns and other ruderal species were dominant in 100% of high-deforestation and post-logging zones (T-05, T-06, T-07, T-13, and T-14), reflecting disturbance-facilitated colonization

Edge Effects and Conservation Hotspots

Forest-edge transects (T-09, T-10) displayed intermediate structural features but significant pressure indicators such as tree stumps, road construction, and illegal logging. Interestingly, these zones retained high species richness, including rare trees such as African Sandalwood (*Osyris lanceolata*) and Pepper-bark Tree (*Warburgia ugandensis*), suggesting urgent need for targeted protection with table 1 showing a summary of ecological patterns by deforestation intensity.

Table 1: Summary of Ecological Patterns by Deforestation Intensity

Metric	Low Deforestation	Moderate Deforestation	High Deforestation
Canopy Cover (mean %)	78.4	55.3	29.5
Endemic Species / Quadrat (avg.)	3.2	1.6	0.7
Regeneration Observed (%)	71.9	36.4	12.5
Invasive Species (%)	6.3	75.0	85.0
Shannon Index (H')	2.87	2.14	1.62
Simpson Index (1-D)	0.91	0.75	0.53

Table 4 : Descriptive Statistics of the Most Endangered Tree Species

Tree species	N	Range	Mean	Std. Deviation	Variance
African pencil	20	3.00	1.9118	.69357	.481
East African Camphor	20	2.00	1.9044	.69792	.487
Yellow wood	20	2.00	1.8971	.70216	.493
Red stink wood	20	2.00	1.8382	.71202	.507
Meru Oak	20	2.00	1.6691	.68912	.475
African Geenheart	20	2.00	1.1691	.44813	.201
Croton	20	2.00	1.4559	.63090	.398

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Newtonia Tree	20	2.00	1.5000	.68853	.474
Valid N	20				

Descriptive statistics in table 4 show that all eight tree species have a response from 20 respondents, hence ensuring consistency in the dataset. African Pencil has the highest range (3.00), which implies that it has the highest variation of responses, while the other seven species range at 2.00. From the average scores, African Pencil Cedar (1.9118), East African Camphor (1.9044), and Yellow wood (1.8971) is identified as the most endangered species in the Irangi Forest. On the contrary, African Geenheart (1.1691) has the lowest average score, suggesting it is seen as the least endangered among the species listed. The standard deviation and variance values also confirm these results with African Geenheart showing least variation (standard deviation of 0.44813 and variance of 0.201), which shows high agreement levels among respondents. The other group such as Red Stink Wood, Meru Oak, and Newtonia tree also possess mean scores ranging from moderate to high with relatively uniform variability, indicating a concordance in their vulnerable status. Overall, the evidence suggests that African pencil Cedar, East African Camphor, and Yellow wood trees are perceived to be the most vulnerable species, while Croton tree is considered relatively less vulnerable.

Ecological Impacts and Biodiversity Loss

Participants reported considerable ecological degradation associated with forest fragmentation. All pointed towards the loss of significant indigenous trees such as African pencil Cedar, East African Camphor, and Yellow wood species all of which were prone to fragmentation and over-extraction indicating a trend of biodiversity loss linked to forest disturbances. At the same time, wildlife habitats have been altered, with creatures such as elephants and bongos relocating from exhausted locations. Forest degradation has also significantly impaired the catchment function of the Tana River Basin to the level of diminished water volume, poorer infiltration, erosion, and siltation. These outcomes align with Newbold *et al.*'s (2015) findings that forest degradation reduces species richness and disrupts ecosystem services such as regulation of water. The same problems were experienced by Lung & Schaab (2010) in Kakamega Forest, where fragmentation caused 30% reduction of endemic species and hydrological instability. Hansen *et al.* (2023) also note that forest fragmentation, through reducing genetic diversity and ecological resilience, unleashes cascading ecological impacts. Therefore, the conservation of Irangi Forest is not just about keeping trees but keeping essential services such as water supply, corridors of biodiversity, and climate regulation for the nearby area.

COCLUSIONS

The ecological assessments indicated that deforestation intensity significantly affected biodiversity. High-deforestation areas exhibited lower canopy cover where native canopy-dependent species such as *Ocotea usambarensis* and *Juniperus procera* declined significantly, reduced diameter at breast height (DBH), and fewer indigenous species. Disturbed landscapes exhibited lower Shannon diversity indices ($H' = 1.2 \pm 0.3$) compared to core forest zones ($H' = 2.8 \pm 0.4$). Invasive pioneer species such as *Lantana camara* dominated degraded and scrub areas, reducing structural complexity while less disturbed areas preserved higher biodiversity, with dominance of native species. Based on the findings, deforestation directly contributes to a decline in tree species diversity, altering forest structure and functionality. Although efforts such as CFAs and reforestation have been initiated, they remain insufficient without stronger institutional support and local involvement.

RECOMMENDATIONS

To mitigate further biodiversity loss, a multifaceted approach is necessary. These combined efforts can bridge conservation with livelihood improvement and align with national and global sustainability targets.

- i. Community-Based Forest Management (CBFM) should be enhanced through capacity building of CFAs, secure funding mechanisms, and legal support.
- ii. Collaboration between CFAs and Kenya Forest Service must be strengthened to enforce anti-logging measures.
- iii. Alternative livelihood initiatives such as apiculture, agroforestry, and ecotourism should be promoted, alongside access to renewable energy sources.
- iv. Reforestation programs must prioritize indigenous species, supported by local nurseries and public awareness campaigns.
- v. Integration of GIS and drone surveillance should be adopted for real-time monitoring, supported by robust policy enforcement and the inclusion of indigenous knowledge in planning.
- vi. Public education on forest value should be expanded through schools and media

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