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Anthropogenic disturbance shapes plant community composition in the coastal forest of Pemba island, Zanzibar

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ABSTRACT

Tropical coastal forests provide essential ecological services and support high biodiversity, yet they are increasingly threatened by anthropogenic pressures linked to livelihood activities. This study examined the anthropogenic disturbance on plant diversity and community composition in the Ngezi-Vumawimbi Nature Forest Reserve (NVNFR), the largest remaining natural forest on Pemba Island, Zanzibar. Vegetation data were collected using systematic random sampling across two disturbance categories (high and low). Circular plots were established, and all woody species with a diameter at breast height ≥ 5 cm were identified and counted. Species richness, Shannon–Wiener diversity, and plant density were calculated and compared between disturbance levels, while community composition differences were assessed using Bray–Curtis dissimilarity, NMDS, and PERMANOVA. A socio-economic survey of households from five adjacent villages identified dominant livelihood activities and drivers of forest use. Species richness and diversity, were insignificantly between disturbance levels, indicating relative stability despite human pressure. However, community composition differed, with disturbed sites dominated by tolerant species such as *Elaeis guineensis* and lacking several forest-dependent species. Livelihoods varied among villages, with agriculture predominant and fishing localised. Economic necessity, cultural practices, and limited regulatory awareness drove resource use, highlighting the need for integrated ecological monitoring and community-based conservation.

Keywords: Anthropogenic activities-Species composition-Diversity-Coastal forests.

INTRODUCTION

Tropical forests are among the most biologically diverse and ecologically important ecosystems on Earth, playing a critical role in maintaining global environmental stability. They regulate climate, sequester carbon, stabilise soils, and support hydrological cycles, while also providing essential ecosystem services and livelihood for millions of people worldwide (Hansen *et al*. 2020, Gaglio *et al*. 2017, Sassen and Sheil 2013). Despite covering less than 7% of the Earth's land surface, tropical forests harbour more than 60% of terrestrial species, making them vital for biological conservation (Vogt *et al*. 2019). However, these ecosystems are increasingly threatened by anthropogenic activities such as agricultural expansion, logging, fuelwood extraction, and urban development, which drive deforestation, habitat fragmentation and ecological degradation (Andersson *et al*. 2021, Laurance *et al*. 2014). In sub-Saharan Africa, including Tanzania, these challenges are further intensified by rapid population growth and heavy reliance on forest resources for subsistence and economic activities (Mamo *et al*. 2007, Scanes 2018).

Tanzania hosts a wide range of forest ecosystems ranging from montane to coastal

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forests, each characterised by unique species assemblages and ecological functions. Coastal tropical forests are particularly important due to their high levels of endemism and their role as ecological buffers along the Indian Ocean coast (Gereau *et al*. 2016), yet they remain highly vulnerable to human encroachment and unsustainable resource use. The Ngezi-Vumawimbi Nature Forest Reserve (NVNFR), located on the northern tip of Pemba Island, Zanzibar, represents one of the remaining fragments of natural coastal forest in the country (Amidu 2009). Its vegetation forms a mosaic of coastal forest, mangrove patches, and lowland evergreen woodland (Chamshama and Vyamana 2010), supporting ecologically and economically important species such as the Pemba Flying Fox (*Pteropus voeltzkowi*) and the Pemba Cypress (*Cupressus lusitanica*), both threatened by habitat loss and human activities (Mwinyi 2020). In addition, the reserve provides essential ecosystem services and supports local livelihoods through non-timber forest products, medicinal plants, and climate regulation.

Anthropogenic disturbances can produce complex ecological effects that vary with intensity, frequency, and spatial extent. These disturbances often alter forest structure, disrupt the regeneration process, and shift species composition by favoring disturbance-tolerant species over sensitive taxa (Kacholi *et al*. 2015). While several studies in mainland Tanzania have examined the impact of human activities on forest ecosystems (Lolila *et al*. 2023, Mwakosya and Mligo 2014), such research remains limited for island systems like Pemba, where ecological dynamics are shaped by geographical isolation, restricted dispersal, and high endemism (Borregaard *et al*. 2017). This lack of empirical data constrains effective conservation planning in NVNFR. Therefore, this study aims to evaluate the impacts of human activities on plant species richness and diversity, examine changes in community composition across disturbance gradient, and identify major livelihood activities contributing to forest degradation and their spatial distribution among villages. The findings are intended to support evidence-based forest conservation and sustainable management interventions.

METHODOLOGY

Description of study area

The study was conducted in the Ngezi-Vumawimbi Nature Forest Reserve (NVNFR) located in Micheweni District, North Pemba Region, Zanzibar, Tanzania, with coordinates 39˚40’ to 39˚44’E and 4˚58‘to 4˚54’S. NVNFR is the largest remaining block of natural forest on Pemba Island, covering approximately 20 km^2 (Beentje 1993). The reserve borders the Indian Ocean and its surroundings by ten rural villages (Fig. 1) with a combined population of about 12,600 people (URT 2022).

The area experiences a tropical coastal climate characterised by bimodal rainfall, with long rains occurring between March and May and short rains between October and December. Annual rainfall ranges from 1400 - 2000 mm, and temperatures vary between 24 ^{0}C and 30 ^{0}C. The vegetation is a mosaic of coastal evergreen forest, riverine forest, thicket and mixed lowland forest. Dominant tree species include *Dialium holtzii*, *Antiaris toxicaria*, *Pachystela brevipes*, *Upaca guineensis*, and *Quassia undulata* (Beentje 1993). The reserve is also home to several endemic species, such as *Chrysalidocarpus pembanus* and Pteropus *voeltzkowi*. Despite being a protected area, NVNFR faces escalating anthropogenic pressure due to its proximity to the surrounding population. Major threats include firewood collection, charcoal, illegal logging, agricultural encroachments and unregulated harvesting of non-timber forest products. These pressures provide the basis for studying the

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relationship between human disturbance and forest plant diversity.

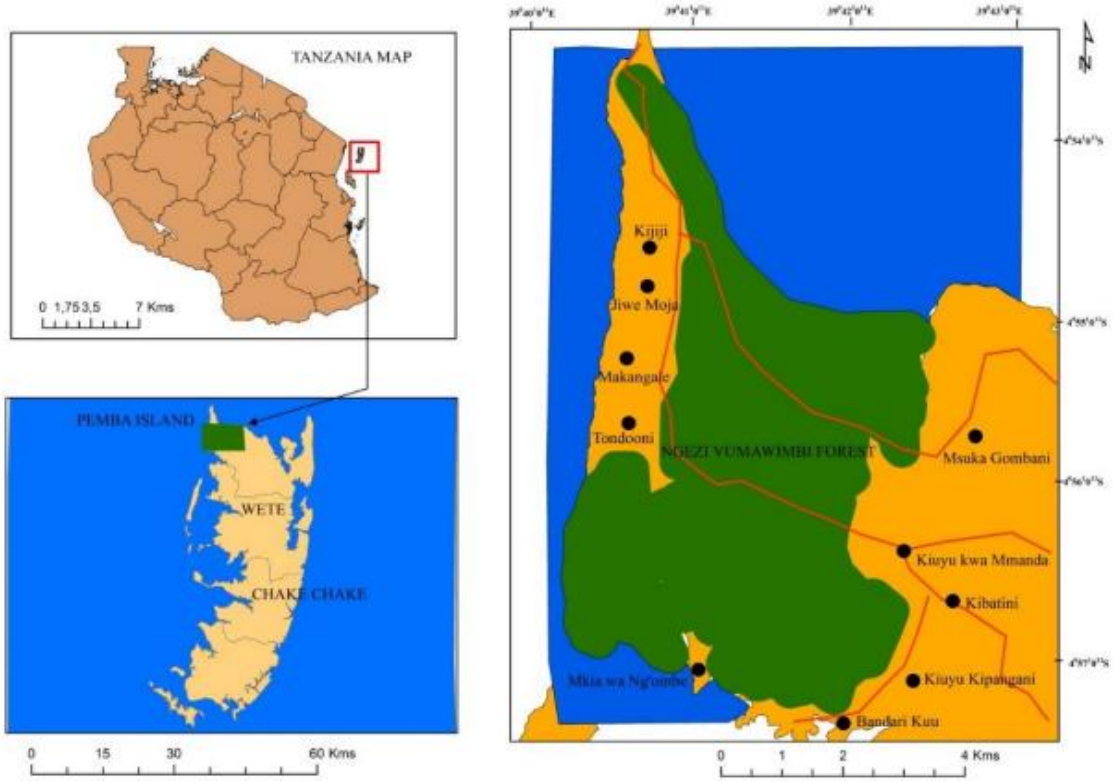

Figure 1: Map of Tanzania showing the study area and surrounding villages in Ngezi-Vumawimbi Nature Forest Reserve

Research design

A systematic random sampling design was implemented to assess plant species composition and to quantify the influence of anthropogenic disturbance within the reserve. The forest was preliminarily surveyed to identify two distinct disturbance categories based on visible human activities and consultation with forest rangers. High disturbance areas were characterised by multiple visible indicators of human interference, such as tree cuttings, grazing, charcoal-burning sites, or cleared patches. Low disturbance areas were characterised by areas having minimal or no visible evidence of human activities and relatively intact canopy structure.

A total of 20 circular sample plots (Hossain *et al*. 2020, Palace *et al*. 2015), each with a radius of 15 m (plot area = 706.86 m^2), were established across the two disturbance levels, with 10 plots allocated to each level. Only 20 plots were sampled due to limited logistical and financial resources; however, sampling sufficiency was evaluated using a species accumulation curve and the Chao 1 richness estimator to determine whether the sampling effort adequately captured species richness (Thompson and Thompson 2007). Plots were positioned systematically along a transect spaced 200 m apart to reduce spatial autocorrelation. Plot centres were georeferenced using a handheld GPS unit (Yang *et al*. 2019).

Vegetation sampling

All woody plants (trees and shrubs) with a diameter at breast height (DBH) ≥ 5 cm were identified and counted within each plot. DBH measurements were taken at 1.3 m above the ground using a diameter tape. For multi-stemmed individuals, each stem meeting the DBH threshold was recorded separately. Species identification was conducted using vernacular names and

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botanical field guides for the East African coastal flora (Dharani 2011). Unidentified specimens were collected, pressed and taken to the Forestry Herbarium in Zanzibar for taxonomic verification. For each species, we record the number of individuals, DBH values, Regeneration status (seedling, sapling, juvenile or mature), and proximity to disturbance features (such as stumps, fire scars, paths). Data were collected from March to April 2025.

Anthropogenic disturbance assessment

Two types of assessment were used, i.e. field-based assessment and questionnaire survey. In field-based assessment within each plot, the intensity of anthropogenic disturbance was evaluated by recording the presence and condition of the indicators, which were: fresh or old tree stumps (logging), charcoal kilns or charcoal residue, grazing signs (dung, trampling, browsing marks), footpaths and human trails, burnt vegetation or ash, farm extension or encroachments and litter and other waste materials.

Questionnaires were used to supplement ecological data, whereby a socioeconomic survey was conducted among residents. A total of 150 structured questionnaires were administered, with 30 respondents from each of the five villages adjacent to the reserve. Respondents were selected through purposive sampling, emphasizing individuals who frequently use forest resources. Collected information from questionnaires includes: common anthropogenic activities within the reserve, drivers of forest dependence, awareness of forest conservation policies, and perceived changes in forest condition and biodiversity.

Data analysis

Species richness was calculated as the total number of species recorded per plot and the estimated richness using the Chao-1 species richness estimator, while plant density was expressed as the total number of individuals per plot and standardised per plot area. Species diversity was quantified using the Shannon-Wiener diversity index (H'), calculated as:

$$H' = -\sum_{i=1}^{s} p_i \, ln \, p_i$$

Where p_i is the proportional abundance of individuals belonging to species $_{i.}$

Before statistical analysis, data were assessed for normality and homogeneity of variance using the Shapiro-Wilk and Levene's test, respectively. Differences in species richness, plant density and Shannon diversity between high and low disturbance sites were evaluated using Welch's two-sample t-test to account for unequal variances.

To analyse the differences in plant community composition between disturbance levels, species abundance data were used to construct Bray-Curtis dissimilarity matrices. Community composition patterns were visualised using non-metric multidimensional scaling (NMDS) ordination. Permutational multivariate analysis of variance (PERMANOVA) was applied to test for significant differences in species assemblage between high and low disturbance sites. In addition, polled community-level diversity between categories was compared using Hutchison's t-test.

For Social-ecological data obtained from household questionnaires, data were coded and analysed using descriptive statistics, including frequencies and percentages, to summarise livelihood activities and drivers of forest resource use. Differences in livelihood activities among villages were assessed using Pearson's chi-square tests. Standardised residuals from chi-square analyses were examined to identify activities that contributed most strongly to observed differences among villages. To explore similarities among villages based on livelihood composition, multivariate clustering was performed and visualised using a heatmap. All statistical tests were conducted at a significance level of $\alpha = 0.05$

and were conducted using R statistical software (R Core 2022)

RESULTS

Plant Species Richness and Diversity

Species accumulation curves approached an asymptote (Fig.2), and the Chao 1 richness estimator indicated that observed species richness (58 species) was close to the estimated richness (62 species), suggesting that most of the expected species pool was captured by the sampling effort. Species richness, Shannon diversity, and plant density were not significant between disturbance levels (Fig. 3). The high-disturbance site had an average species richness of 20.6 ± 2.37, while the low-disturbed site had 19.6 ± 3.53. (t = 0.74, df 15.72, $p = 0.468$). Shannon diversity was also similar across disturbance levels, with high-disturbance sites averaging 2.70 ± 0.18 and low-disturbance sites averaging 2.78 ± 0.22 (t-test, t = -0.88, df = 17.42, $p = 0.393$). On the other hand, the mean plant density also did not differ significantly between high-disturbed and low-disturbed sites (905 ± 202 individuals and 780 ± 198 individuals, respectively) (t-test, t=1.41, df 17.99, $p = 0.176$). Even though species richness, Shannon diversity, and plant density did not differ significantly between disturbance levels, disturbance had a strong effect on species composition, indicating that anthropogenic activities alter community structure through species turnover rather than changes in overall diversity.

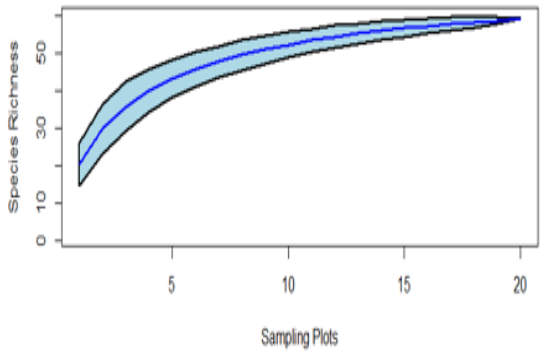
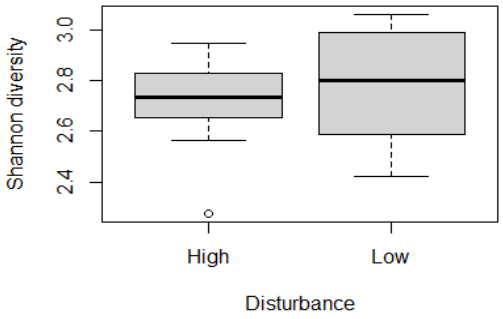


Figure 2: Species accumulation curve showing observed species richness across sampling effort at NVNFR

(A)



(B)

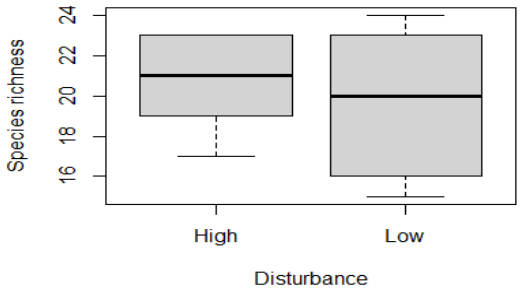


Figure 3. Mean species richness (A), Shannon diversity index (B), in high- and low-disturbance sites. Error bars represent ±1 standard deviation. Plot-level differences between disturbance levels were not significant (Welch's t-tests, $p > 0.05$)

Community composition changes across disturbance levels

Despite no significant differences in species richness, diversity, or abundance, community composition differed significantly across the disturbance levels. PERMANOVA analysis based on Bray–Curtis dissimilarities revealed a significant effect of disturbance on species composition ($R^2 = 0.455$, $F = 15.05$, $p = 0.001$),

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indicating that nearly half of the variation in species composition was explained by disturbance. Pooled community-level diversity (Hutchinson's t = 5.83, df = 1185.8, $p < 0.001$) further confirmed that overall species composition differed between disturbance levels (Fig. 4).

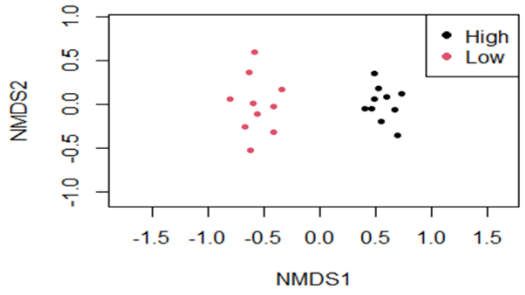

Figure 4: NMDS plot showing community composition differences

The ten most abundant species included *Elaeis guineensis*, *C. pembanus*, and *Erythrophloeum suavelens*. Several species, including *Elaeis guineensis* and *C. pembanus*, were far more abundant in high-disturbance sites, suggesting their tolerance to or association with the disturbed conditions, whereas species such as *Cremaspora triflora* and *Afzelia quanzensis* were absent from these sites, hence showing their sensitivity to anthropogenic pressure (Fig. 5).

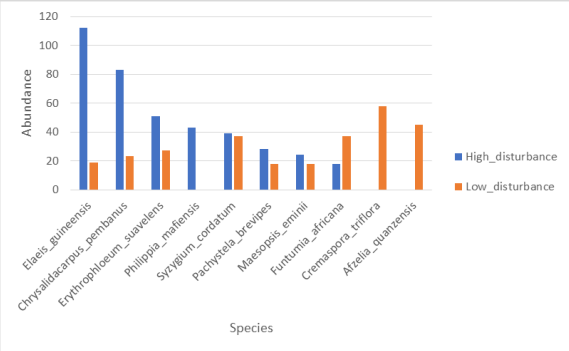

Figure 5: Abundance of the ten most common species in high- and low-disturbance sites of NVNFR. Species are ordered by total abundance across all sites.

Spatial distribution of livelihood activities

Livelihood activities varied substantially among the five surveyed villages. Agriculture emerged as the dominant activity in Kiuyu Kwa Mmanda (70%), Bandari Kuu (70%), and Kiuyu Kipangani (60%), whereas Makangale showed a contrasting pattern, with 60% of respondents reporting fishing as their primary source of livelihood. Mkia Ng'ombe demonstrated a more diversified livelihood profile, with agriculture (50%), fishing (10%), logging (10%), and tourism (5%) contributing to household economic activities (Fig. 6). The Pearson chi-square test indicated a highly significant association between village and livelihood activity ($X^2 = 259.13$, $p < 0.001$), confirming that livelihood strategies were unevenly distributed across villages.

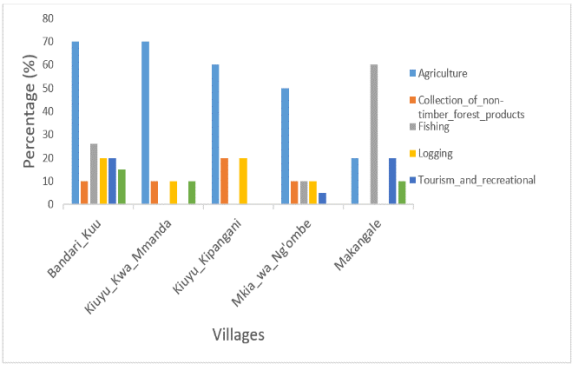

Figure 6: Percentage distribution of livelihood activities across villages surrounding NVNFR

These visible disparities indicate that livelihood structure is not uniform across villages, which is fully consistent with the highly significant Chi-square test result.

Composition of livelihood activities and forest resource dependence

The heatmap (Fig.7) illustrates clear spatial variation in livelihood activities across the five villages. The heatmap reinforced these patterns of activities in all five villages: agriculture appeared as a dominant high-intensity activity in most villages (indicated by warm colours), while fishing showed a

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concentrated peak only in Makangale. Lower-intensity activities such as tourism, urban development, and logging exhibited subtle inter-village differences, with Bandari Kuu showing relatively higher engagement in tourism and urban development compared with the others.

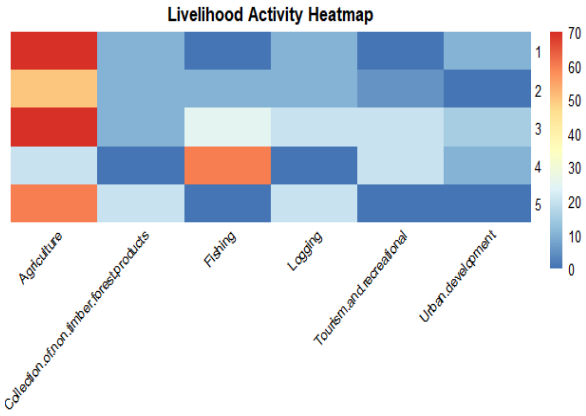

Figure 7: Heatmap of livelihood activities of five villages surrounding NVNFR

Results also show that there was a clear pattern in village similarity based on livelihood activity composition. Kiuyu Kwa Mmanda, Bandari Kuu, and Kiuyu Kipangani formed a coherent cluster characterised by dominant agricultural activity and moderate contributions from secondary livelihoods. Mkia Ng'ombe occupied an intermediate position, reflecting its diversified livelihood structure. Makangale stood apart as a distinct cluster due to its exceptionally high reliance on fishing. These clustering patterns were supported by standardised residuals from the chi-square test (Table 1), which showed strongly positive residuals for fishing in Makangale (+11.64) and notable positive residuals for tourism (+2.41) and urban development (+1.89) in Bandari Kuu. Together, these findings demonstrate that livelihood selections are shaped by distinct socio-ecological contexts and are not uniformly distributed across the study area.

Table 1: Standardised residuals from chi-square analysis of the livelihood activities performed by surrounding villagers of NVNFR

Name of village	Agriculture	Collection on non-timber forest products	Fishing	Logging	Tourism	Urban Development
Kiuyu kwa mmanda	4.72	0.38	-5.02	-0.29	-3.28	1.68
Mkia wa Ng'ombe	2.04	0.96	-1.42	0.31	-0.82	-2.6
Bandari kuu	-1.47	-1.44	-0.59	0.82	2.41	1.89
Makangale	-7.14	-3.69	11.64	-4.08	4.32	1.34
Kiuyu Kipangani	2.51	4.24	-5.02	3.27	-3.28	-2.87

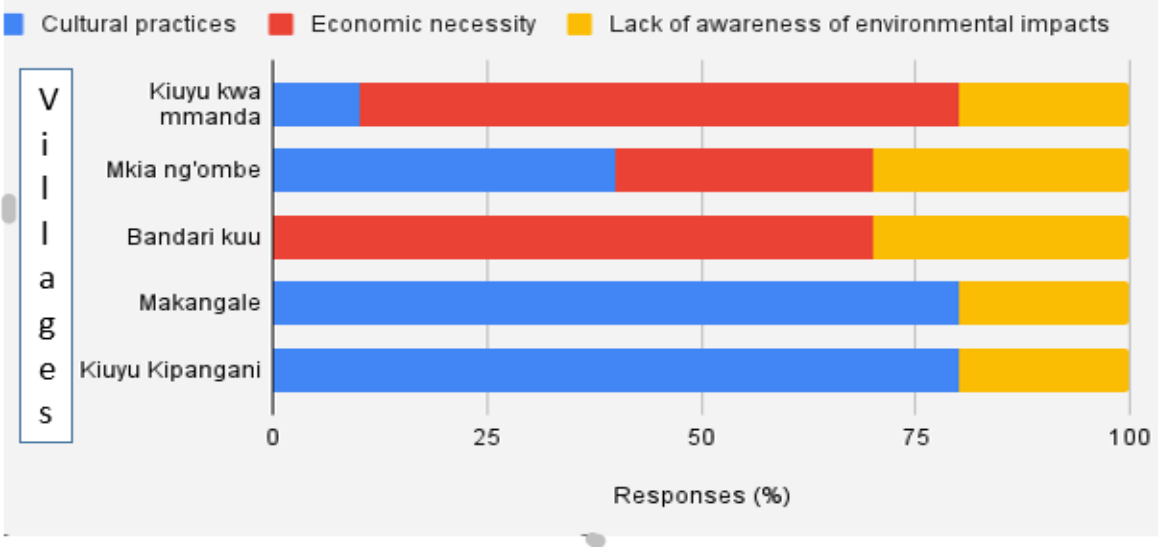

Figure 8: Reason for village engagement in different activities within NVNFR

Economic necessity and cultural practices were the main reasons for villager's engagement in forest destruction activities, but also lack of awareness was the other reason observed in all villages (Fig. 8).

DISCUSSION

Human activities effect on species richness and diversity

This study evaluated how anthropogenic disturbances influence plant community composition and diversity in the NVNFR. The species accumulation curve approached an asymptote, with observed species richness closely matching Chao 1-estimated richness, indicating that the sampling effort captured most of the floristic diversity present in the study area. Overall species richness, Shannon diversity, and plant density did not differ significantly between disturbance levels, suggesting that the forest retains a relatively stable species pool despite human pressure. This pattern indicates that disturbance in NVNFR does not lead to species loss at the alpha diversity level, but may instead influence how species are distributed across the community. Similar neutral responses in diversity metrics have been reported in tropical woodland systems where disturbance-tolerant species compensate for the loss of sensitive species, thereby maintaining alpha diversity even as species identities change (Mligo 2011).

In addition, scale-dependent response to disturbance may explain these patterns, whereas diversity responses vary depending on spatial scales and habitat heterogeneity (Dumbrell *et al.* 2008). Such scale-dependent responses to disturbance may help explain the absence of significant differences in species richness and diversity between disturbance levels in NVNFR, despite pronounced shifts in plant community composition.

However, other similar studies in Tanzania have reported a contrasting outcome, where anthropogenic activities reduce diversity and alter forest structure (Msilu *et al*. 2025, Pascal *et al*. 2025), highlighting that diversity metrics alone may not fully capture ecological change.

Plant community composition shifts under anthropogenic disturbance

Consistent with broader ecological theory and observed findings, plant community composition in NVNFR was strongly influenced by disturbance, as shown by PERMANOVA and NMDS analyses. This

indicates that anthropogenic activities act primarily as an ecological filter, reshaping species identities rather than overall diversity.

Disturbance-tolerant species such as *E. gueneensis* and *C. pembanus* dominated highly disturbed plots, while disturbance-sensitive species such as *C. trifloral* and *A. quanzensis* were largely absent. This composition shifts align with ecological theory, where disturbance favours generalists and pioneer species while disadvantaging specialists and late-successional taxa (Kassahun *et al*. 2024, Ramírez-Marcial *et al*. 2001). Similar long-term compositional shifts have been documented in logged African forests, where disturbed and undisturbed stands maintain distinct assemblages even decades after disturbance (Kissa *et al*. 2024).

Livelihood activities as drivers of forest degradation

The observed compositional differences are closely linked to variation in livelihood activities across surrounding villages. Agriculture dependence dominated most villages, while fishing was predominant in Makangale, indicating strong heterogeneity in human-environmental interactions. This spatial variation in livelihood strategies is reflected in the disturbance gradients influencing NVNFR vegetation.

Agricultural expansion, fuelwood collection, and small-scale logging are major drivers of forest modification in sub-Saharan Africa, often promoting disturbance-tolerant species while reducing forest specialist taxa. In VNVFR, the dominance of *E. guineensis* and the absence of sensitive species in highly disturbed sites reflect this process of human-mediated species filtering. These patterns are consistent with studies showing that livelihood dependence on forest resources strongly shapes forest condition and regeneration dynamics (Laurance *et al*. 2014, Msilu *et al*. 2025).

Socioeconomic analysis further reveals that economic necessity and cultural practices are the primary drivers of forest resource use across villages, while limited conservation awareness also contributes. Similar findings have been widely reported in other African forest communities, where dependence on natural resources persists due to poverty, weak enforcement, and limited livelihood alternatives (Kideghesho *et al*. 2007, Munaw 2023). These factors help explain why compositional shifts occur even in the absence of significant changes in species richness and diversity.

CONCLUSION

Overall, the results highlight that NVNFR functions as a coupled social-ecological system in which human livelihood strategies directly shape disturbance patterns that selectively filter plant species. While alpha diversity remains relatively stable, disturbance drives significant compositional turnover, highlighting the importance of integrating species identity and community structure into conservation planning. Strengthening community-based forest management, improving livelihood diversification and enhancing conservation awareness are therefore essential for maintaining long-term ecosystem integrity (Agrawal and Gibson 1999, Folke *et al.* 2010).

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