Scientific Research Publishing

Open Journal of Forestry, 2025, 15(4), 281-291
https://www.scirp.org/journal/ojf
ISSN Online: 2163-0437
ISSN Print: 2163-0429

The Effects of Small-Scale Agricultural Expansion on Tree Species Composition and Diversity along Elevation Gradients in Tanzania's Dry Sub-Montane Tropical Forest Ecosystem

Sarafina N. Masanja[1]*, Deo D. Shirima[1,2], Pantaleo K. T. Munishi[1]

[1]Department of Ecosystems and Conservation, College of Forestry, Wildlife and Tourism, Sokoine University of Agriculture, Morogoro, Tanzania
[2]National Carbon Monitoring Centre, Morogoro, Tanzania
Email: *sarafina.masanja@sua.ac.tz

How to cite this paper: Masanja, S. N., Shirima, D. D., & Munishi, P. K. T. (2025). The Effects of Small-Scale Agricultural Expansion on Tree Species Composition and Diversity along Elevation Gradients in Tanzania's Dry Sub-Montane Tropical Forest Ecosystem. *Open Journal of Forestry, 15,* 281-291.
https://doi.org/10.4236/ojf.2025.154015

Received: June 28, 2025
Accepted: August 26, 2025
Published: August 29, 2025

Abstract

African forest ecosystems harbour significant biodiversity, yet face constant pressure from neighbouring communities, primarily due to selective harvesting and expansion of agricultural farming practices. Studies on how the forest structure changes because of small-scale farming within the landscape are limited. This study evaluated the effects of agricultural expansion on tree species composition and diversity along elevation gradients in a dry tropical forest mountain ecosystem. Vegetation data were collected from 60 sample plots established in disturbed areas affected by small-scale agriculture and another 60 plots from relatively undisturbed areas, across different elevations. We used agglomerative hierarchical clustering to identify tree species communities and an indicator species analysis to determine species significantly associated with each community. Species richness, evenness and Shannon-Wiener diversity indices were calculated using the "vegan" package in R software and compared between disturbed and undisturbed areas using Generalised Linear Models (GLMs). We recorded 1576 individual trees from 64 species and 27 families. Most of the identified tree species were shared among the three species communities. Agricultural practices were significantly linked to lower tree species richness and altered community composition compared to undisturbed areas, with varying effects along elevation gradients. Higher elevations exhibited low species diversity and composition, while mid-elevations showed more diversity in both disturbed and undisturbed zones. Disturbance from small-scale agricultural practices had a pronounced impact on species diversity at lower elevations. Our findings highlight the importance of considering topographic heterogeneity in conservation planning and sustainable land management strategies, emphasising strict regulations and effective measures to mitigate small-scale agricultural practices adjacent to and within protected forest ecosystems.

Keywords

Species Composition, Disturbances, Small-Scale Farming Practices

1. Introduction

Tropical forest ecosystems harbor globally important biodiversity, providing vital ecosystem services, including climate regulation and carbon storage (Chazdon et al., 2009), and supporting the livelihoods of millions of people worldwide (Assessment, 2005). However, these invaluable ecosystems are facing constant pressure from anthropogenic activities, with agricultural expansion being a major driver of deforestation and forest degradation (Foley et al., 2005; Laurance et al., 2014). In sub-Saharan Africa, population growth and the demand for food have intensified the conversion of forests into farmland, thereby compromising biodiversity integrity (Laurance et al., 2014).

Agricultural expansion is a major driver of land-use change worldwide, causing widespread deforestation, habitat degradation, and loss of biodiversity (Foley et al., 2005; Gibbs et al., 2010). This issue is especially severe in tropical forests, which host some of the highest levels of species diversity on Earth but are increasingly threatened by human activities (Laurance et al., 2014). In Africa, the expansion of agricultural land has accelerated over recent decades due to population growth, economic development, and food security needs, leading to significant conversion of forested areas into farmland. The effects of this expansion are particularly intense in forest ecosystems situated along elevation gradients, where biodiversity is often highly structured and vulnerable to environmental shifts (Rahbek, 2005).

Elevation gradients serve as a vital ecological axis, affecting species distribution, community composition and ecosystem functioning. Changes in temperature, precipitation, and soil properties along these gradients create unique habitats, often resulting in significant species turnover (Lomolino, 2001). However, human activities, especially agricultural expansion, increasingly disrupt these ecological processes by causing habitat loss and altering environmental conditions that support diverse species assemblages (Pfeifer et al., 2017). Despite the crucial role of elevation gradients in biodiversity conservation, there is still limited understanding of how small-scale farming practices and expansion influence tree species richness and community composition across different elevations.

Tropical dry sub-montane forests are a valuable natural resource, home to diverse tree species and supporting various ecological functions (Kacholi, 2019). Protected areas in sub-Saharan Africa are experiencing immense pressure from encroachment due to small-scale agricultural expansions by communities living adjacent to the reserves (Sentonzi & Katega, 2007). Agricultural encroachment reduces forest cover and disrupts habitats of numerous species, leading to a decline in biodiversity. Understanding the extent and impact of these disturbances is essential for developing strategies to mitigate their effects and promote sustainable land-use practices. Therefore, this study assessed the impact of agricultural expansion on tree species composition and diversity along different elevation gradients in Pangawe West Forest Reserve. Specifically, the study examined 1) how tree species composition and diversity vary across elevation gradients and 2) how agricultural expansion alters species composition and diversity compared to undisturbed areas along these gradients. Understanding how topography and human activities influence changes in biodiversity is vital for informing conservation planning and sustainable land management strategies, highlighting the need for strict regulations and effective measures to counteract agricultural encroachment in forest areas.

2. Materials and Methods

2.1. Study Site Description

The Pangawe West Forest Reserve is located in the Morogoro Region, Tanzania (06˚49' S and 37˚46' E), **Figure 1**. The reserve has an area of 405 hectares and is situated at an elevation range between 300 and 1400 meters above sea level. The reserve is bordered by two villages, which are Mkambarani and Kiroka. It is accessed via the Morogoro-Kisaki road, which is 60 km from Morogoro Municipality. The area has two main rain patterns known as short rains (November-December) and long rains (March-May). Average rainfall varies from 600 mm in lowland areas to 3000 mm in mountainous areas. Temperature normally ranges from 20˚C to 30˚C during cooler and warmer seasons.

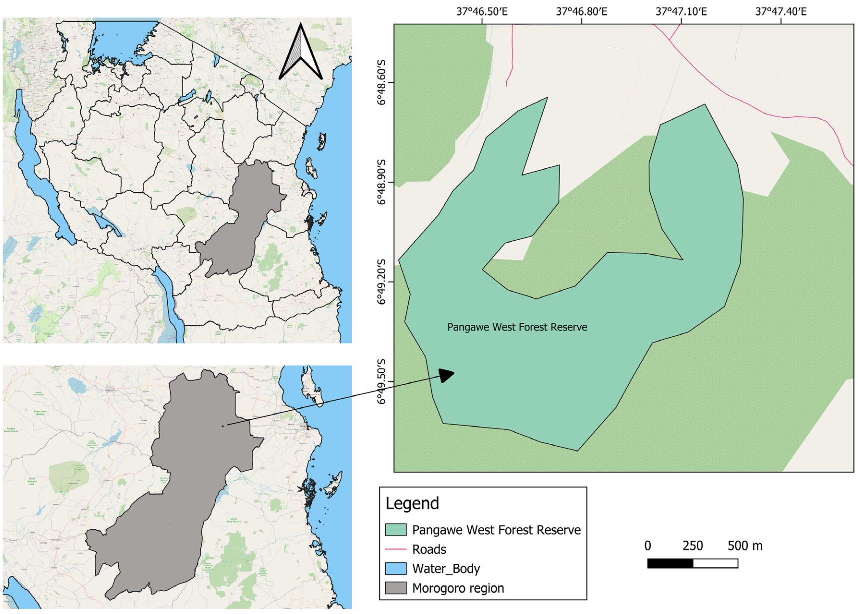

Figure 1. A map showing the location of the study area.

2.2. Data Collection

This study employed a systematic sampling design whereby a total of 120 sample plots were established across different elevation categories to evaluate elevation-dependent ecological patterns along the disturbance gradient. Sixty plots were established in areas affected by agricultural expansion (disturbed areas), while the remaining 60 plots were situated in relatively undisturbed parts of the forest reserve. The plots were distributed across different elevation gradients defined in three categories as lower elevations (500 - 900 m), mid-elevations (900 - 1000 m), and higher elevations (>1000 m) as shown in **Table 1**. Each plot measured 30 m × 20 m and was arranged along transect lines spaced 100 m apart, and plot locations were recorded using a hand-held GPS. Within each plot, all trees with a Diameter at Breast Height (DBH) ≥ 5 cm were identified to the species level with the assistance of local botanists.

Table 1. Distribution of plots across different elevation gradients in the study area.

Elevation gradient	Forest status	Number of plots
Lower elevation (500 - 900 m)	Disturbed areas	30
	Undisturbed areas	30
Mid-elevation (900 - 1000 m)	Disturbed areas	18
	Undisturbed areas	18
Higher elevation (>1000 m)	Disturbed areas	12
	Undisturbed areas	12
Total		120

2.3. Data Analysis

Data were analysed using R software, version 4.3.1. All recorded species were identified and counted to determine species composition and their abundance values respectively. Species dominance was assessed by calculating the Species Importance Value Index (SIVI). SIVI was computed as the sum of relative density, relative dominance, and relative frequency of the species per plot (Beals, 1984). Agglomerative hierarchical clustering analysis was performed to identify distinct tree species communities within the reserve. Indicator species analysis was then performed using the package "labdsv" to determine the species that were significantly associated with each identified community. Each community was named after the two most dominant species based on high synoptic cover abundance values. Non-metric multidimensional scaling (NMDS) analysis was conducted to show distinct differences in community composition between disturbed and undisturbed areas. Tree species richness, evenness, and Shannon-Wiener diversity indices were calculated for each plot using the "vegan" package. Generalized Linear Models (GLMs) were used to compare these diversity indices across disturbed and undisturbed areas along different elevation gradients. All graphs were generated using the package "ggplot2" in R software.

3. Results

3.1. Tree Species Composition

A total of 1576 individual trees belonging to 64 species and 27 families were recorded across all the sampled plots. The most prevalent families were Fabaceae, Sterculiaceae, Malvaceae, Anacardiaceae, and Meliaceae. The five most dominant species in terms of Species Importance Value Index (SIVI) were *Sterculia appendiculata*, *Cassia abbreviata*, *Dombeya rotundifolia*, *Acrocarpus fraxinifolius* and *Sclerocarya birrea* (**Table 2**). Through agglomerative hierarchical clustering analysis, three distinct tree species communities were identified, each primarily characterised by shared species and some indicator species unique to each community: Community one (C1): *Moringa oleifera* and *Sterculia appendiculata*; Community two (C2): *Grewia similis* and *Acrocarpus fraxinifolius*; Community three (C3): *Anthocleista usambarensis* and *Surugada zanzibarensis* (**Figure 2**).

Table 2. Species importance value index (SIVI) for dominant species in disturbed and undisturbed areas.

Species name	SIVI in disturbed areas	SIVI in undisturbed areas
Sterculia appendiculata	12.3	28.7
Cassia abbreviata	18.9	5.2
Acrocarpus fraxinifolius	15.4	8.1
Dombeya rotundifolia	9.8	14.6
Sclerocarya birrea	6.5	19.3

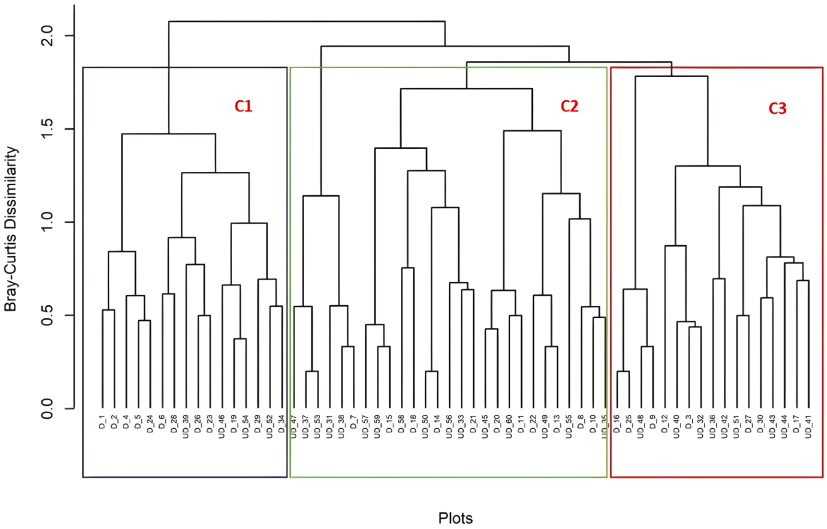

Figure 2. Dendrogram of hierarchical clustering showing three community types in different sites (plots 1 - 60) across Pangawe West Forest Reserve. The communities are named after two dominant species: Community one (C1): *Moringa oleifera-Sterculia appendiculata*, Community two (C2): *Grewia similis-Acrocarpus fraxinifolius*, and Community three (C3): *Anthocleista usambarensis-Suregada zanzibarensis.*

3.2. Effects of Small-Scale Agricultural Expansion on Tree Species Composition

Nonmetric multidimensional scaling (NMDS) analysis revealed clear differences in community composition between disturbed and undisturbed areas (ANOSIM R = 0.69, $p < 0.01$). In undisturbed regions, tree species communities across various elevations formed separate clusters, indicating distinct species assemblages along the elevation gradient (**Figure 3**). However, in disturbed areas, there was greater overlap between species groups across elevations, suggesting homogenisation of tree communities due to agricultural expansion. Species that were more abundant in undisturbed areas, such as *Sterculia appendiculata* and *Sclerocarya birrea*, were significantly reduced in disturbed areas, where more disturbance-tolerant species, like *Acacia mearnsii* and *Cassia abbreviata*, dominated. This compositional shift reflects the replacement of native forest species with generalist species that thrive in disturbed environments.

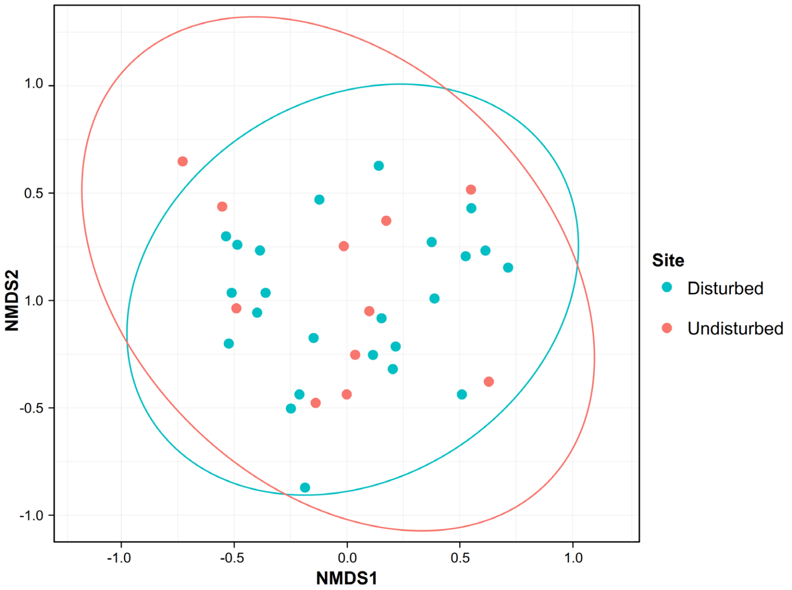

Figure 3. Nonmetric multidimensional scaling (NMDS) showing the distinction of community composition between disturbed and undisturbed areas.

Indicator species analysis also identified several species that were strongly associated with either disturbed or undisturbed areas. In undisturbed areas, species such as *Sterculia appendiculata* and *Sclerocarya birrea* were consistently identified as indicators of forest integrity, being significantly more abundant in undisturbed areas across all elevations ($p < 0.05$). These species are typically slow-growing and depend on stable forest conditions, making them highly vulnerable to habitat disturbance. Conversely, *Acacia mearnsii*, *Cassia abbreviata* and *Acrocarpus fraxinifolius* were more prevalent in disturbed areas, particularly at lower elevations. These species are well adapted to open, disturbed habitats, and their proliferation in such areas suggests they may outcompete native species in the long term, further diminishing forest biodiversity.

3.3. Effects of Small-Scale Agricultural Expansion on Species Diversity along Elevation

Species richness and diversity also varied significantly between disturbed and undisturbed areas across elevation gradients, as shown in Figure 4 and Figure 5. The Shannon-Wiener diversity index tends to decrease slightly with increasing elevation in both disturbed and undisturbed areas. However, undisturbed areas consistently maintain higher diversity across the gradient, with mid-elevations (900 - 1000 m) showing the species diversity (1.29), followed by lower elevations (500 - 900 m) (1.22), while higher elevations (>1000 m) have the lowest species diversity (0.87) (Table 3).

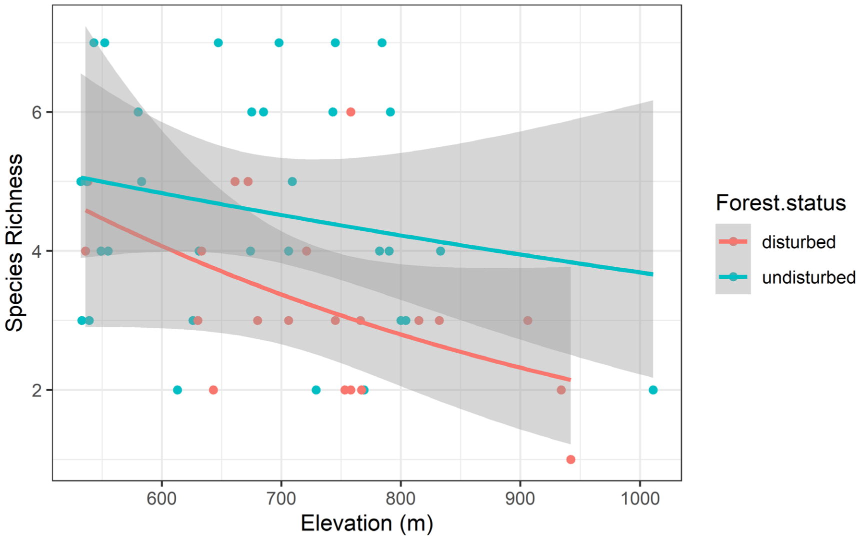

Figure 4. A graph showing patterns of species richness along elevation gradients in disturbed and undisturbed areas.

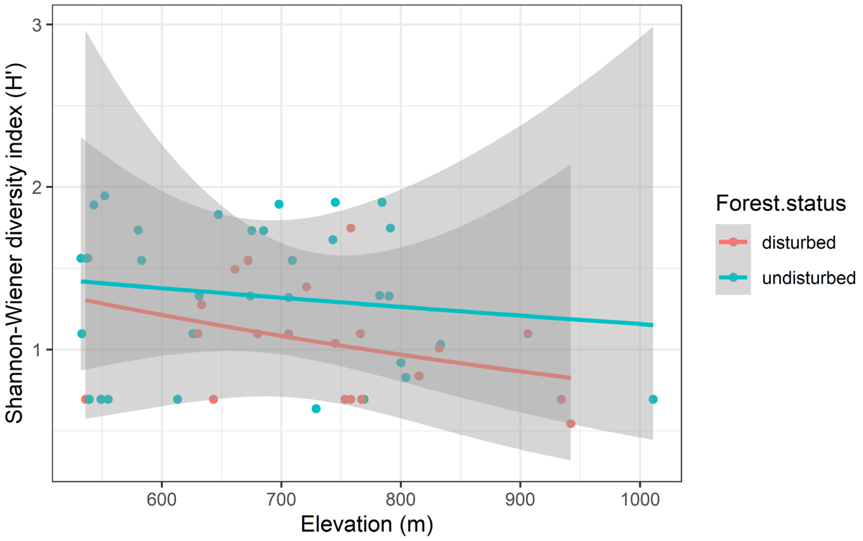

Figure 5. A graph showing patterns of species diversity along elevation gradients between disturbed and undisturbed areas.

Table 3. Diversity indices between disturbed and undisturbed areas along different elevation gradients.

Forest status	Elevation gradient	Average species richness	Average species evenness	Average Shannon-Wiener diversity index
Disturbed areas	Mid-elevation (900 - 1000 m)	3.2	0.59	1.04
	Lower elevations (500 - 900 m)	3.3	0.60	0.75
	Higher elevations (>1000 m)	2.0	0.57	0.60
Undisturbed areas	Mid-elevation (900 - 1000 m)	4.4	0.51	1.29
	Lower elevations (500 - 900 m)	4.5	0.55	1.22
	Higher elevations (>1000 m)	3.0	0.54	0.87

Conversely, disturbed areas displayed a marked reduction in species richness, particularly at lower elevations, where richness declined by approximately 26.7% compared to undisturbed areas ($p < 0.01$). The loss of species was less pronounced at mid-elevations, where disturbed areas exhibited a 27.3% reduction in richness, and at higher elevations, which showed a 33.3% reduction in richness (Table 3).

4. Discussion

There were relatively fewer species in the disturbed areas compared to the undisturbed areas across the elevation gradient. Small-scale agricultural expansion significantly reduced species richness across all elevation gradients. However, this effect varied with elevation, with lower- and mid-elevations showing fewer tree species in disturbed areas than in undisturbed areas. The lower-elevation areas are more accessible to smallholder farmers, leading to intensified farming practices and, consequently, the lowest number of tree species. This can be attributed to increased pressure from activities such as land clearing for crops, selective wood harvesting, and grazing, all of which exert intense pressure on forest ecosystems (Gibson et al., 2011). The conversion of forested land into agricultural fields directly leads to habitat loss, but it also indirectly affects forest structure by reducing canopy cover, altering microclimatic conditions, and increasing soil degradation.

The change in species composition in disturbed areas further supports the idea that small-scale agricultural practices and expansion impact ecological communities. Indicator species analysis showed that species adapted to more open, disturbed habitats, such as *Acrocarpus fraxinifolius* and *Cassia abbreviata,* were more abundant in disturbed areas. In contrast, species typical of intact forest environments, like *Sclerocarya birrea* and *Sterculia appendiculata*, were significantly low in disturbed areas. This shift in species composition could reflect the loss of specialized species and the proliferation of more generalist species, which are better suited to withstand disturbances (Lira et al., 2012). These patterns align with the theory of biotic homogenisation, where diverse species groups are replaced by fewer, more resilient species due to human activities (Olden & Rooney, 2006).

Interestingly, species richness followed a hump-shaped distribution along the elevation gradient, with mid-elevations harbouring the highest diversity in both disturbed and undisturbed areas. This pattern suggests that mid-elevation zones in the forest reserve provide optimal environmental conditions, such as moderate temperatures and precipitation, which may promote higher species richness (Rahbek, 2005). In contrast, higher elevations, characterized by harsh environmental conditions, including lower temperatures and increased wind, exhibited lower species diversity, which may explain the lower resilience of these zones to disturbance (Guo et al., 2013).

Mid-elevations, while more resilient to agricultural disturbances, still experienced significant species loss and compositional changes. Although these areas generally have more favourable growing conditions, the conversion of forest land into agricultural fields disrupts ecological processes such as nutrient cycling and water regulation, thereby reducing the capacity of these forests to support diverse species assemblages. This suggests that even resilient ecosystems can be degraded by anthropogenic activities, particularly when disturbances are sustained over time (Jakovac et al., 2015).

Findings indicated that different elevation zones respond distinctly to small-scale agricultural expansion, and conservation efforts should be customised to address these differences. For example, lower elevations, which are more prone to human encroachment, may benefit from stricter enforcement of land use regulations and the promotion of agroforestry systems that combine tree species with agricultural landscapes, thereby alleviating pressure on forested areas (Schroth et al., 2013). Meanwhile, mid-elevation zones, which are biodiversity hotspots, require targeted conservation measures to prevent further species loss. This may involve establishing buffer zones around critical habitats and adopting sustainable land use practices that minimise forest fragmentation.

Furthermore, the findings emphasise the vital role of forests in conserving diverse tree species, especially in regions experiencing rapid agricultural expansion. Conservation policies should concentrate on protecting undisturbed forest areas while promoting landscape-scale strategies that integrate agricultural lands into biodiversity conservation efforts (Laurance et al., 2014). A landscape mosaic approach, which includes protected areas, buffer zones, and sustainably managed agricultural lands, can help maintain ecosystem services while supporting local livelihoods (Gardner et al., 2009).

The observed shifts in tree species composition and diversity along elevation gradients have broader implications for climate change resilience, as forests are essential for carbon sequestration. The loss of tree species, particularly slow-growing ones that store substantial amounts of carbon, can reduce the forest's capacity to combat climate change (Sullivan et al., 2017). Therefore, protecting diverse forest communities across different elevations is vital for conserving biodiversity and sustaining the forest's role in the global carbon cycle.

5. Conclusion

The study has shown a significant negative impact of agricultural expansion on tree species richness and community composition across elevation gradients in Pangawe West Forest Reserve. It highlights the importance of elevation in shaping biodiversity patterns and the resilience of forest ecosystems to human disturbances. Immediate measures are needed to reduce the effects of agricultural encroachment on forest biodiversity. These include strengthening forest protection by enforcing strict regulations against encroachment in the forest, prioritizing community-based forest management practices by creating buffer zones adjacent to protected areas, and promoting agroforestry practices, such as the use of multipurpose, nitrogen-fixing trees that are compatible with agricultural crops like maize, in order to reduce pressure on primary forest while sustaining livelihoods.

Data Availability Statement

Data sets analysed in this study are available upon reasonable request from the corresponding author.

Acknowledgements

We cordially thank the forest guards and the surrounding villagers for their assistance during data collection at Pangawe West Forest Reserve.

Conflicts of Interest

The authors declare no conflicts of interest.

References

Assessment, M. E. (2005). *Ecosystems and Human Well-Being: Biodiversity Synthesis* (p. 86). World Resources Institute.

Beals, E. W. (1984). Bray-Curtis Ordination: An Effective Strategy for Analysis of Multivariate Ecological Data. In *Advances in Ecological Research* (Vol. 14, pp. 1-55). Elsevier. https://doi.org/10.1016/s0065-2504(08)60168-3

Chazdon, R. L., Peres, C. A., Dent, D., Sheil, D., Lugo, A. E., Lamb, D. et al. (2009). The Potential for Species Conservation in Tropical Secondary Forests. *Conservation Biology, 23,* 1406-1417. https://doi.org/10.1111/j.1523-1739.2009.01338.x

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R. et al. (2005). Global Consequences of Land Use. *Science, 309,* 570-574. https://doi.org/10.1126/science.1111772

Gardner, T. A., Barlow, J., Chazdon, R., Ewers, R. M., Harvey, C. A., Peres, C. A. et al. (2009). Prospects for Tropical Forest Biodiversity in a Human-Modified World. *Ecology Letters, 12,* 561-582. https://doi.org/10.1111/j.1461-0248.2009.01294.x

Gibbs, H. K., Ruesch, A. S., Achard, F., Clayton, M. K., Holmgren, P., Ramankutty, N. et al. (2010). Tropical Forests Were the Primary Sources of New Agricultural Land in the 1980s and 1990s. *Proceedings of the National Academy of Sciences, 107,* 16732-16737. https://doi.org/10.1073/pnas.0910275107

Gibson, L., Lee, T. M., Koh, L. P., Brook, B. W., Gardner, T. A., Barlow, J. et al. (2011). Primary Forests Are Irreplaceable for Sustaining Tropical Biodiversity. *Nature, 478,* 378-381. https://doi.org/10.1038/nature10425

Guo, Q., Kelt, D. A., Sun, Z., Liu, H., Hu, L., Ren, H. et al. (2013). Global Variation in Elevational Diversity Patterns. *Scientific Reports, 3,* Article No. 3007. https://doi.org/10.1038/srep03007

Jakovac, C. C., Peña-Claros, M., Kuyper, T. W., & Bongers, F. (2015). Loss of Secondary-Forest Resilience by Land-Use Intensification in the Amazon. *Journal of Ecology, 103,* 67-77. https://doi.org/10.1111/1365-2745.12298

Kacholi, D. S. (2019). Assessment of Tree Species Richness, Diversity, Population Structure and Natural Regeneration in Nongeni Forest Reserve in Morogoro Region, Tanzania. *Tanzania Journal of Science, 45,* 330-345.

Laurance, W. F., Sayer, J., & Cassman, K. G. (2014). Agricultural Expansion and Its Impacts on Tropical Nature. *Trends in Ecology & Evolution, 29,* 107-116. https://doi.org/10.1016/j.tree.2013.12.001

Lira, P. K., Ewers, R. M., Banks-Leite, C., Pardini, R., & Metzger, J. P. (2012). Evaluating the Legacy of Landscape History: Extinction Debt and Species Credit in Bird and Small Mammal Assemblages in the Brazilian Atlantic Forest. *Journal of Applied Ecology, 49,* 1325-1333. https://doi.org/10.1111/j.1365-2664.2012.02214.x

Lomolino, M. V. (2001). Elevation Gradients of Species-Density: Historical and Prospective Views. *Global Ecology and Biogeography, 10,* 3-13. https://doi.org/10.1046/j.1466-822x.2001.00229.x

Olden, J. D., & Rooney, T. P. (2006). On Defining and Quantifying Biotic Homogenization. *Global Ecology and Biogeography, 15,* 113-120. https://doi.org/10.1111/j.1466-822x.2006.00214.x

Pfeifer, M., Lefebvre, V., Peres, C. A., Banks-Leite, C., Wearn, O. R., Marsh, C. J. et al. (2017). Creation of Forest Edges Has a Global Impact on Forest Vertebrates. *Nature, 551,* 187-191. https://doi.org/10.1038/nature24457

Rahbek, C. (2005). The Role of Spatial Scale and the Perception of Large-Scale Species-richness Patterns. *Ecology Letters, 8,* 224-239. https://doi.org/10.1111/j.1461-0248.2004.00701.x

Schroth, G., da Fonseca, G. A., Harvey, C. A., Gascon, C., Vasconcelos, H. L., & Izac, A.-M. N. (2013). *Agroforestry and Biodiversity Conservation in Tropical Landscapes.* Island Press.

Sentonzi, H., & Katega, I. B. (2007). *Rural Livelihoods and Forest Reserves Encroachment in Tanzania: A Case of Biharamulo Forest Reserve in Biharamulo District, Kagera Region.*

Sullivan, M. J. P., Talbot, J., Lewis, S. L., Phillips, O. L., Qie, L., Begne, S. K. et al. (2017). Diversity and Carbon Storage across the Tropical Forest Biome. *Scientific Reports, 7,* Article No. 39102. https://doi.org/10.1038/srep39102