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Effect of Collaborative Forest Management on Carbon Stocks, Species Diversity and Stem Density in Mabira Central Forest Reserve, Uganda

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Abstract

Collaborative forest management (CFM) is a form of forest governance in which local communities are involved in the management and decision-making processes related to forest resources. It is believed that forests under such management are better in tree diversity and conservation status and thus hold more carbon stocks. The study assessed the impact of CFM on carbon stocks, tree species diversity & tree species density in Mabira Central Forest Reserve. Data were collected from plots that were systematically laid in the different purposively selected forest areas. The study findings show that there is no difference in stem density and carbon stocks between CFM and non-CFM areas. CFM areas had lower species richness compared to non-CFM areas. CFM areas, however, exhibited more species diversity than non-CFM areas. Climax colonization may favor a few dominant species over others, hence lowering species diversity despite the number of species being many in the understory, hence at the same time increasing species richness. Likewise, disturbance in CFM area may affect natural colonization and favor the emergency of many species either naturally or through assisted regeneration by reforestation, hence increasing diversity, whereas artificial selection of preferred species through harvesting may lower species richness, as observed. Recommendations for improving collaborative forest management (CFM) areas include implementing targeted interventions to enhance carbon sequestration, such as promoting reforestation and afforestation with high-carbon-storing species and strengthening monitoring and evaluation frameworks to assess carbon stock changes over time. Additionally, efforts should focus on enhancing bio-

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diversity conservation by implementing more stringent protection measures and reducing human disturbance while encouraging community participation in biodiversity monitoring and conservation education.

Keywords

Collaborative Forest Management (CFM), Carbon Stocks, Tree Species Diversity, Tree Stem-Densities, Mabira Central Forest Reserve

1. Introduction

Collaborative Forest Management (CFM) is a participatory approach to forest management that aims to establish a mutually agreed-upon and beneficial relationship between eligible local community groups and the forest authority (NFA, 2020). In other studies, it is termed as participatory forest management (PFM) and Kiprono et al. (2024) define participatory forest management as involvement of communities living around the forest in the management of the forests. Whatever the nomenclature, the concept remains the same. This research adopted CFM because it's the commonly used term in the area of study. CFM has been implemented in several countries, including Uganda, to promote sustainable forest management and improve the livelihoods of forest-adjacent communities (Turyahabwe et al., 2012). Over recent times, CFM has received considerable attention due to its potential to advance sustainable forest management, enhancing livelihoods, and countering climate change by bolstering carbon stocks within woodland areas (Thammanu et al., 2021; Gunawan et al., 2023).

In Uganda, Mabira Central Forest Reserve (CFR) has been the focus of CFM initiatives (Turyahabwe et al., 2012). The forest reserve is an important carbon sink and provides various ecosystem services to the surrounding communities, including timber, non-timber forest products, and water (Jjagwe et al., 2021; Gumoshabe et al., 2023).

Representing 33% of the global land area (FAO, 2022) and containing more carbon per unit area than any other land cover type (Hairiah et al., 2001), forests comprise the biggest percentage of biomass and play a big role in mitigating greenhouse gas emissions, especially carbon dioxide. The rate of deforestation, estimated at 0.4% - 0.7% per year (Barlow et al., 2016), constitutes immense environmental stress. Uganda's forest and woodland cover has dropped from 4.9 million hectares (20% of Uganda's land area) in 1990 to 3.6 million (14%) in 2005, representing a 1.9% deforestation rate (NFA, 2020).

To improve management in the forest reserve, several mechanisms have been devised including, Collaborative Forest Management (CFM) (Tumusiime et al., 2018). CFM, as a participatory approach to sustainable forest management, engages a diverse range of stakeholders including local communities, civil society organizations, the private sector, and government agencies and seeks to ensure effective planning, management and preservation of forest resources, with the ultimate goal of promoting sustainable practices (Jjagwe et al., 2021; Tumusiime et al., 2018).

CFM has been piloted in the Mabira Central Forest Reserve to improve forest management, given the pressure exerted by surrounding the population (Turyahabwe et al., 2012). However, while CFM has gained traction in Uganda, its effect on different forest components such as carbon stocks, tree species diversity and stem density are inadequately understood, an issue this study sought to address.

2. Materials and Methods

2.1. Study Area Location

The study was conducted in Mabira Central Forest Reserve situated between 024' - 035'N and 32'52' - 33'07'E (Weldemariam et al., 2017). Mabira CFR (**Figure 1**) covers an area of 29,974 hectares and is located in Buikwe and Mukono Districts. According to the management plan of 1994/95, the forest is subdivided into 65 compartments numbered from 170 to 235, and four management zones: buffer zone, recreation zone, production zone, and strict nature reserve (Mulugo et al., 2020). The forest was selected due to its critical ecological roles, vital biodiversity conservation functions, support for the livelihoods of local communities, and implementation of CFM programs.

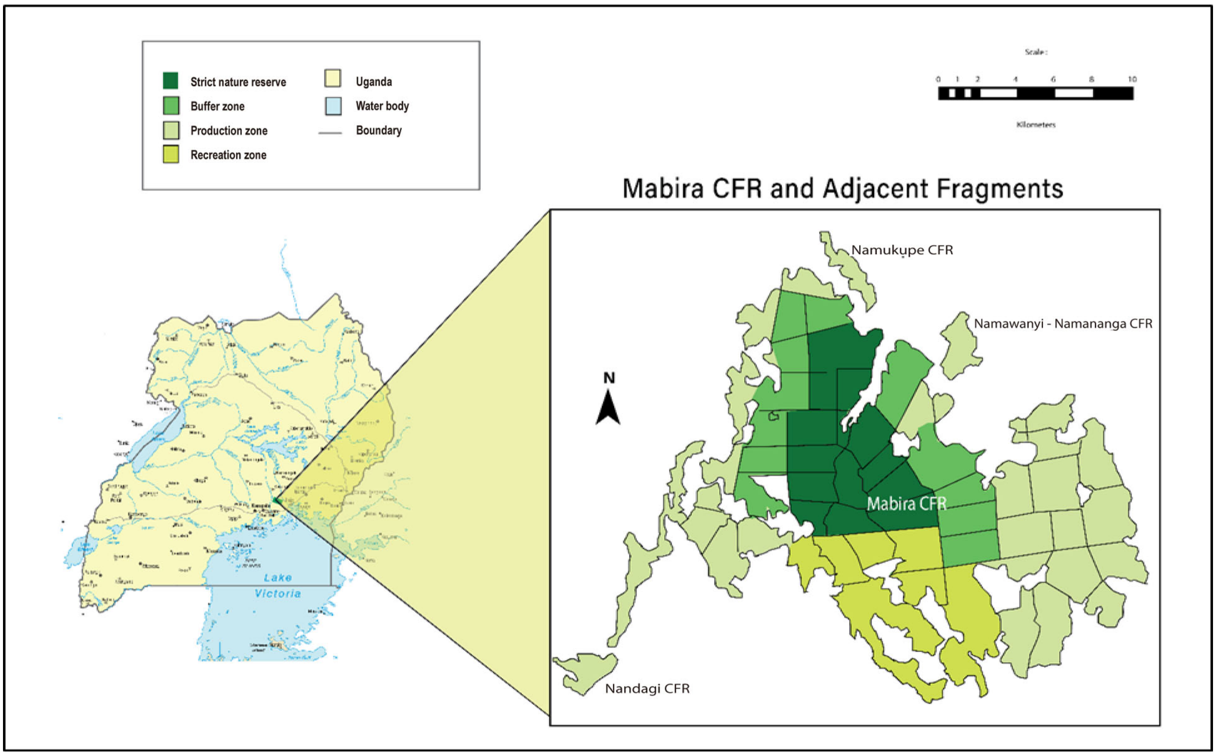

Figure 1. A Map of Mabira CFR. (NFA, 2020)

2.2. Study Design

The study adopted a quasi-experimental research design, and quantitative research approach. The study measured, quantified and compared amounts of carbon stocks and tree species diversity within forested areas under CFM with those in non-CFM areas. The study also measured tree stem densities in areas under different forest management strategies. The study involved both quantitative *in-situ* and herbarium *ex situ* tree species identification.

The inventories were taken in Mabira CFR using a systematic random sampling approach with a 0.5% sampling intensity and were applied within forty study plots. Forty square plots, each 400 m^2 in size, were used for trees (>10 cm DBH), while 50 m^2 plots were designated for saplings. DBH measurements were taken with a Diameter tape, and tree and sapling heights were measured using Abney's level. Rigorous quality assurance was upheld to ensure the collection and management of accurate data both in the field and post-collection.

3. Growth Parameters & Biodiversity Indices

The following growth parameters and biodiversity indices were used.

3.1. Carbon Stock

Carbon stocks from the Above Ground Biomass (AGB) were calculated using allometric equations (Chave et al., 2005).

$$\text{AGB} = \rho * \exp\left(-0.667 + 1.784 * \ln(D) + 0.207 (\ln(D))^2 - 0.0281 (\ln(D))^3\right) \quad [1]$$

where: ρ = wood specific gravity = oven-dry wood over green volume (g/cm^3). The mean ρ for tropical forests in Africa is estimated to be 0.5 g/cm^3. D = tree diameter at breast height (1.3 m).

3.2. Tree Diversity Estimation

The Shannon-Wiener index was calculated to estimate species diversity. Species dominance was calculated using the Simpson index. Species richness was determined using the Margalefs' richness index. Species Diversity was quantified using the Shannon-Wiener Diversity Index (H') according to the following equation.

$$SD = \sum_{i=1}^{S} Pi\, In\, Pi \quad [2]$$

where *SD* = Shannon-Wiener Diversity (H'), *S* = the number of species at that site, *Pi* = ni/N, that is, proportion of the individual trees of the ith species to the total, *ni* = total number of individuals in the ith species, *N* = total number of individuals of all species, *ln* = Natural logarithm to base *e*, Σ = is the sum of the calculations, and S is the number of species. The values of Shannon's diversity index, H', typically lie between 1.5 and 3.5, although in exceptional cases, they may exceed 4.5.

Tree Species Richness was determined by summing up the number of species identified within the CFM compartments and non-CFM area (Kacholi, 2019).

3.3. Tree Stem Density Estimation

CFM compartment sizes encompassed both the CFM area and the intact Mabira CFR area (Boton et al., 2021). Tree-stem density, calculated as the total stems per unit land area, was determined by direct counting within size classes and extrapolation using (Etigale et al., 2014) formula.

$$N = \frac{h}{a} \times C \quad [3]$$

where, h = one hectare, a = Area of plot measured in hectares, c = Number of trees in plot, N = estimated number of trees per hectare.

3.4. Data Analysis

Collected data were entered and processed in MS Excel, then exported and analyzed in R software. A one-sample K-S normality test was used to assess data distribution. Levene-tests were used to analyze variations in species diversity, stem density and carbon stocks between CFM and non-CFM area, all at a significance level (α) of 0.05.

4. Results

4.1. Carbon Stocks in the Study Areas

To understand the distribution of carbon stocks in the Mabira Central Forest Reserve, descriptive statistics were computed. The study findings reveal higher mean carbon stock in non-CFM areas compared to CFM areas (**Table 1**). These distinctive metrics highlight substantial variability in carbon stocks between the two management statuses, signifying potential differing influences on carbon sequestration and storage.

Table 1. Descriptive statistics showing carbon stocks in CFM and non-CFM areas.

CFM Status	Mean	N	Std. Deviation	Minimum	Maximum	Std. Error of Kurtosis	Kurtosis	Skewness	Std. Error of Skewness
CFM	6026703.05	371	34160679.95	2.2837	379571595.09	.253	76.57	8.219	.127
Non-CFM	7666878.15	284	37858303.56	3.5768	327996992.89	.288	35.17	5.778	.145
Total	6737862.20	655	35791937.82	2.2837	379571595.09	.191	54.52	6.987	.095

The study findings further reveal notable distinctions in carbon stock distributions. The box plot (**Figure 2**) shows a wider Interquartile Range (IQR) for non-CFM areas compared to CFM areas, indicating a more dispersed middle 50% of the Carbon Stocks data in the former. Both CFM and non-CFM areas showcase outliers, signifying extreme values in carbon stocks within the two areas. Moreover, the whiskers in the non-CFM areas appear longer than those in CFM areas, implying a greater variability and wider spread of carbon stock values in the non-CFM territories. Notably, the median position in both sets of areas is situated on the lower side of the IQR, suggesting a potential skewness towards lower carbon stock values in both CFM and Non-CFM areas. This analysis underscores the differences in variability and distribution patterns of carbon stocks between the two areas, with non-CFM areas displaying greater variability and a wider range of values compared to CFM areas.

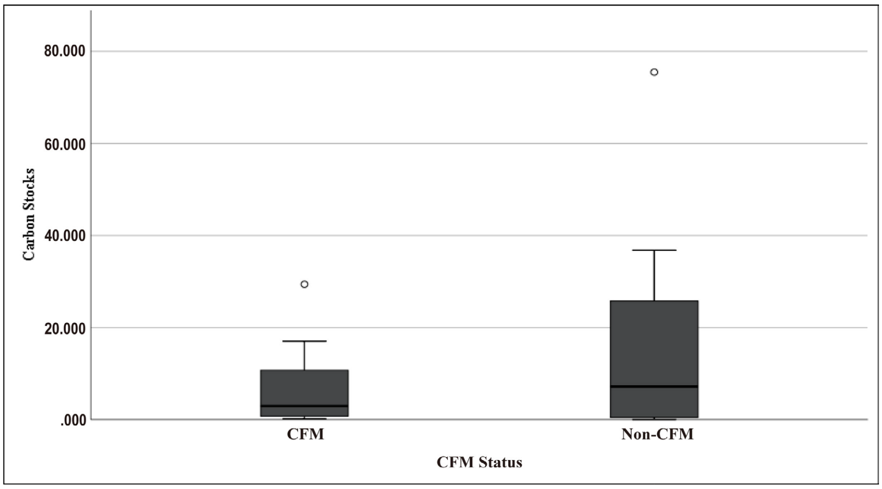

Figure 2. Variation in carbon stocks between the CFM and non-CFM areas.

4.2. Variation in Carbon Stocks According to CFM Status

The Levene test was used to assess the equality of variances in carbon stocks between CFM and non-CFM areas within the Mabira Central Forest Reserve. The results indicate that the variances in carbon stocks display consistency across the different statistical approaches (**Table 2**). Specifically, the Levene tests based on mean values demonstrated a marginal difference in variances between CFM and non-CFM areas ($p = 0.051$), suggesting a potential but not statistically significant variance disparity. Similarly, tests utilizing median, adjusted degrees of freedom with median, and trimmed mean values all indicated no significant differences in variances ($p > 0.05$). These findings consistently imply a lack of substantial evidence supporting unequal variances in carbon stocks between CFM and non-CFM areas. Therefore, the data suggest relative similarity in the variability of carbon stocks across CFM and non-CFM areas.

Table 2. Test of homogeneity of variances of carbon stocks.

		Levene Statistic	df1	df2	Sig.
Carbon Stock	Based on Mean	4.253	1	22	.051
	Based on Median	1.157	1	22	.294
	Based on Median and with adjusted df	1.157	1	11.029	.305
	Based on trimmed mean	1.893	1	22	.183

4.3. Floral Composition in the Study Area

4.3.1. Species Richness

The study findings indicate a lower observed species richness in CFM compared to non-CFM areas (**Figure 3**). The non-CFM area shows rapid species discovery from plots 1 to 3, followed by a slower increase in species count from plots 3 to 6, and a subsequent rapid rise from plots 6 to 12. In contrast, the CFM area demonstrates a quick discovery of species from plots 1 to 4, a slower increase from plots 4 to 5, and a stable, significant increase in species count from plots 5 to 12. Both curves exhibit continuous ascent, suggesting ongoing species discovery, with convergence at plot 12, implying similar observed species richness in both areas at this sampling effort. This comparison underscores distinct patterns of species discovery and richness between CFM and non-CFM areas.

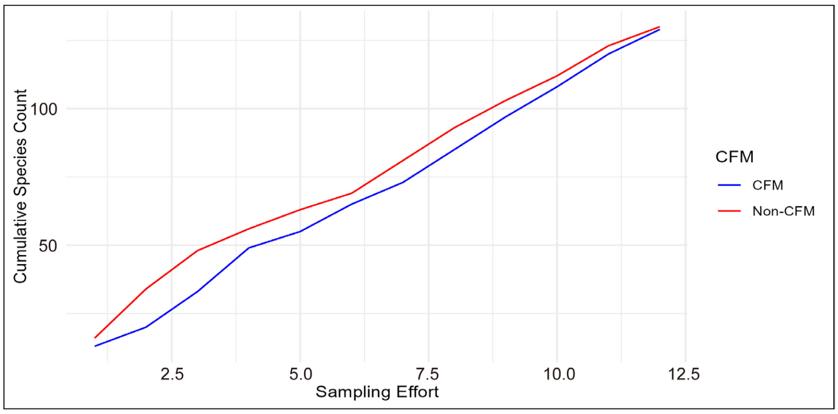

Figure 3. Rarefaction curve showing the species richness in CFM and non-CFM areas.

4.3.2. Species Diversity

The study findings reveal a lower mean species diversity index (H) in CFM areas (1.41 ± 0.584) compared to non-CFM areas (1.86 ± 0.275) (**Table 3**). This discrepancy implies a potential association between forest management strategies and species diversity within the reserve. Moreover, the wider range of species diversity values in CFM areas, as indicated by the larger standard deviation, implies greater variability in species composition within these managed zones.

Table 3. Descriptive statistics of the species diversity in CFM and non-CFM areas.

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
CFM	22	1.41114	.584833	.124687	1.15184	1.67044	.444	2.505
Non-CFM	15	1.85528	.275527	.071141	1.70270	2.00786	1.429	2.364
Total	37	1.59120	.527173	.086667	1.41543	1.76697	.444	2.505

The study findings further reveal that contrary to typical trend, CFM areas have more varied Species Diversity than non-CFM areas (**Figure 4**). The middle 50% of Species Diversity data in CFM areas exhibit a broader central portion, denoted by a wider Interquartile Range (IQR), compared to the Non-CFM areas. Additionally, CFM areas are characterized by longer whiskers compared to the non-CFM areas, suggesting a greater variability and wider spread of Species Diversity values in CFM areas. Notably, the median in the non-CFM areas is higher than that in the CFM areas, indicating that the middle value of Species Diversity data is positioned at a higher level in non-CFM regions. This comparison highlights the contrasting patterns of Species Diversity between CFM and Non-CFM areas, with CFM areas demonstrating a broader central range and greater variability, while non-CFM areas showcase a higher median value, potentially indicating a more concentrated or elevated species richness in those regions.

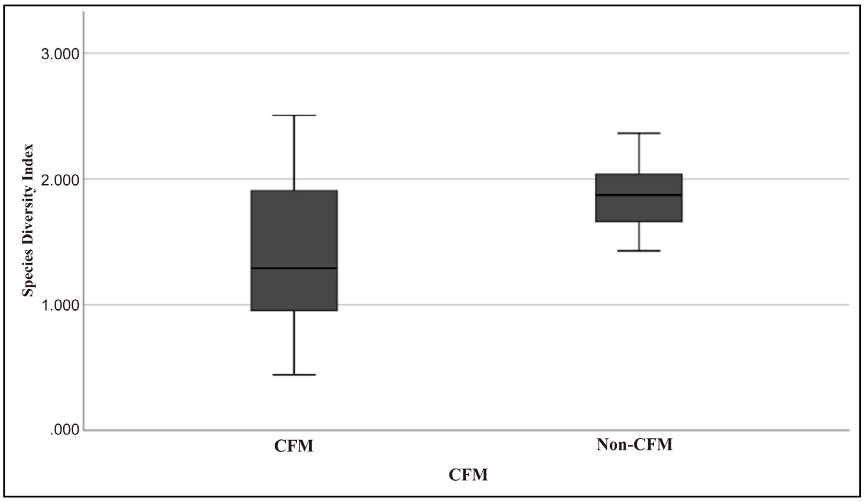

Figure 4. Variation in species diversity between the CFM and non-CFM areas.

4.3.3. Variation in Species Diversity

Table 4 assesses the homogeneity of variances for the Species Diversity Index between different groups within the study area, and the Levene test was performed. The findings reveal statistically significant differences in variances across groups, as indicated by the low p-values ($p < 0.01$) for all tested methods (mean, median, adjusted median, trimmed mean). The results suggest that the variances of species diversity indices significantly vary between the examined groups, potentially influencing the reliability of certain statistical analyses and emphasizing the need for cautious interpretation when comparing species diversity across CFM and non-CFM areas.

Table 4. Levene test of homogeneity of variances.

		Levene Statistic	df1	df2	Sig.
Species Diversity Index	Based on Mean	10.697	1	35	.002
	Based on Median	8.159	1	35	.007
	Based on Median and with adjusted df	8.159	1	26.323	.008
	Based on trimmed mean	10.557	1	35	.003

4.4. Stem Density Variation

4.4.1. Stem Density Distribution in the Study Area

The descriptive statistics from the study findings reveal that the average stem density in CFM areas was higher (309 stems per hectare) compared to non-CFM areas (239 stems per hectare) (**Table 5**). The variability within CFM areas, denoted by a standard deviation of 103 stems, appears slightly lower than that within non-

CFM areas. The confidence intervals for the mean densities illustrate a range within which the true population mean is likely to fall, emphasizing the need for further analysis to discern any significant differences between the CFM and non-CFM statuses in terms of stem density distribution and forest health.

Table 5. Descriptive statistics showing stem density in CFM and non-CFM areas.

Stem Density Per Hectare								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
CFM	12	309.17	102.908	29.707	243.78	374.55	170	460
Non-CFM	12	239.17	114.293	32.994	166.55	311.78	80	470
Total	24	274.17	112.208	22.904	226.79	321.55	80	470

In terms of variation in Stem Density, both CFM and non-CFM areas exhibit nearly the same Interquartile Range (IQR), with the non-CFM areas displaying a narrower IQR (Figure 5). This suggests that while the middle 50% of Stem Density values are similar between both types of areas, the non-CFM areas have a more concentrated range of data within this middle portion. Moreover, the whiskers in the non-CFM areas are longer than those in the CFM areas, indicating a greater variability and wider spread of Stem Density values in non-CFM areas. Notably, the CFM areas exhibit a higher median compared to non-CFM areas, suggesting that the middle value of Stem Density data is positioned at a higher level in CFM regions. This comparison underscores the differences in variability and central tendency of Stem Density between CFM and non-CFM areas, with non-CFM areas displaying a narrower range but greater variability, while CFM areas demonstrate a higher median value, potentially indicating a more concentrated or elevated Stem Density.

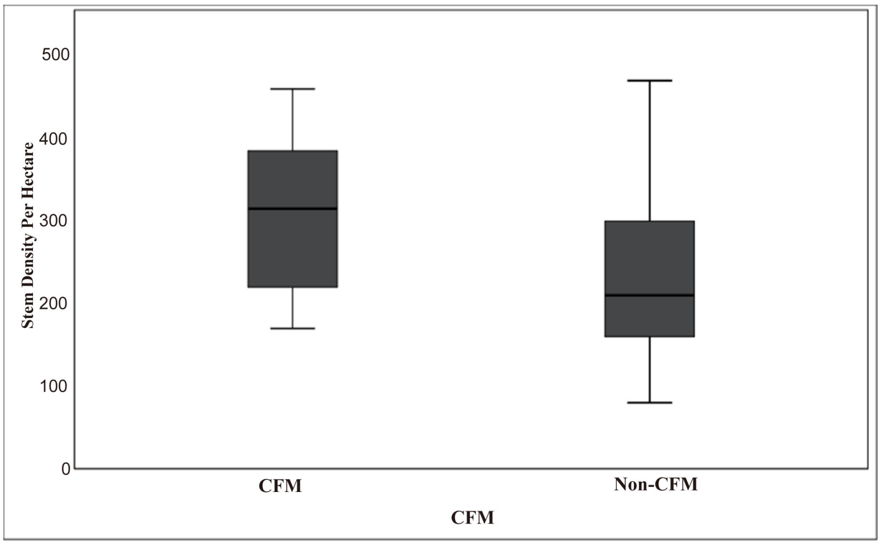

Figure 5. Box plot showing the variation in the stem density in CFM and non-CFM areas.

4.4.2. Variation in Stem Density in CFM and Non-CFM Areas

Table 6 presents various statistics to assess the homogeneity of variances for stem density, a Levene test was performed. The findings indicate equal variances for stem density per hectare between CFM and non-CFM areas. This suggests a relative similarity in the variability of stem density values in CFM and non-CFM areas, irrespective of the measure used to assess variance homogeneity.

Table 6. Levene test of homogeneity of variances in stem density.

		Levene Statistic	df1	df2	Sig.
Stem Density Per Hectare	Based on Mean	.005	1	22	.946
	Based on Median	.004	1	22	.948
	Based on Median and with adjusted df	.004	1	17.806	.948
	Based on trimmed mean	.001	1	22	.970

5. Discussion

5.1. Effect of CFM on Carbon Stocks

Study findings did not provide substantial evidence supporting clear-cut differences in carbon stocks between CFM and non-CFM areas. The findings from the analysis of carbon stocks in the Mabira CFR, comparing CFM and non-CFM areas, have nuances with most existing literature to a considerable extent but also align with some literature warranting further exploration and consideration. This finding diverges slightly from some literature that suggests CFM areas tend to consistently maintain higher carbon stocks. It resonates with the broader understanding that the impact of CFM on carbon stocks can vary significantly based on contextual factors, as highlighted by Melikov et al. (2023). The insignificance in carbon stocks in both areas could be attributed to similar impacts from illegalities from the surrounding communities based on the fact that both areas are proximate to key highly populated communities and enclaves that have a greater demand for forest products. In addition, these studied areas were close to each other, perhaps mirroring the same spatial difference. The similarity in the overall variability of carbon stocks, as indicated by the Levene test results, suggests that both management regimes face similar environmental conditions and ecological processes that influence carbon storage (Braga et al., 2024). This includes factors like soil fertility, climate conditions, and natural disturbances, which can affect carbon sequestration regardless of management practices (Ekoungoulou et al., 2018)The diverse effects of forest management practices on carbon stocks are highlighted in the literature, emphasizing the significance of factors beyond the management status alone. For instance, studies have indicated that CFM doesn't always guarantee higher carbon stocks compared to other management practices like Protection Forest management (PFM), as seen in Nepal (Lamsal et al., 2023). Additionally, local conditions, species selection and previous land use significantly influence the impact of CFM on carbon stocks, echoing the complexities observed in the Mabira CFR analysis.

Moreover, forest management practices like intensive timber harvesting, fertilization, or species dominance can either augment or diminish carbon stocks, suggesting that the nuanced outcomes seen in the Mabira CFR might be influenced by a multitude of such factors. The importance of active management in potentially increasing carbon sequestration rates, as highlighted by Patton et al. (2022), aligns with the variability observed in the Mabira analysis but also raises questions about potential trade-offs in forest structural complexity.

Overall, whereas the findings from the Mabira CFR don't support the notion that CFM can positively influence carbon stocks, the observed variability between CFM and non-CFM areas underscore the complex interplay of management practices, local conditions, and other factors that collectively shape carbon stock dynamics. This comprehensive understanding emphasizes the need for holistic approaches considering multifaceted factors beyond management status alone to effectively manage and enhance carbon stocks in forested areas.

5.2. Effect of CFM on Tree Species Diversity

Study findings revealed that non-CFM areas exhibit higher species richness and diversity compared to CFM areas. The rarefaction curve indicates more rapid species discovery in non-CFM plots, suggesting less human disturbance. In terms of species diversity, non-CFM areas have a higher mean diversity index (1.86) than CFM areas (1.41), with non-CFM areas showing less variability in species composition. The Levene test confirms significant differences in variances across groups, underscoring the influence of management strategies on diversity outcomes. Additionally, species evenness is slightly lower in CFM areas (0.688) compared to non-CFM areas (0.726), with greater variability observed in CFM areas, as evidenced by broader interquartile ranges and longer whiskers. This suggests that human activities in CFM areas contribute to greater variability in species distribution and abundance, whereas non-CFM areas benefit from more stable and higher species diversity due to reduced disturbance.

The disparity in species diversity between CFM and non-CFM areas is largely attributed to the varying levels of human disturbance and resource utilization (Turyahabwe et al., 2012). CFM areas, which involve active human engagement through sustainable harvesting and utilization of forest resources, experience habitat disruption that can reduce species richness and diversity (Boton et al., 2021). In contrast, non-CFM areas, with less direct human interference, maintain more stable and diverse ecosystems (Sassen & Sheil, 2013). Furthermore, distinct management practices play a crucial role; CFM areas often balance conservation with economic benefits for local communities, leading to selective logging and other practices that negatively impact species diversity (Ellis et al., 2019). On the other hand, non-CFM areas, governed by stricter conservation policies, prioritize ecosystem preservation, resulting in higher species richness and diversity (Fleishman et al., 2006). Additionally, non-CFM areas are at more advanced stages of ecological succession, providing more mature forests that support a greater number of species due to increased habitat complexity and resource availability (Chazdon, 2017). This advanced ecological succession is evidenced by the quicker species discovery in non-CFM plots, suggesting well-established habitats that support diverse flora (Brazier et al., 2020).

Monarrez-Gonzalez et al. (2020) indicate that intensive management interventions can decrease tree diversity. This aligns with the study's findings, which show lower observed species richness in CFM areas than in non-CFM areas. Both sources highlight the potential impact of management interventions on reducing floral diversity. The spatial comparison in the study showcases distinct patterns between CFM and Non-CFM areas. Despite convergence at the 12th plot in terms of observed species richness, the spatial analysis reveals a consistently lower observed species richness in CFM areas compared to Non-CFM areas, emphasizing spatial disparities in floral composition influenced by management practices.

Despite differences in management practices, both CFM and non-CFM areas exhibit similarities in species richness and diversity due to shared ecological characteristics, such as climate, soil type, and topography, which influence species composition (Thammanu et al., 2020). These common ecological features can result in similar baseline species richness and diversity over time, as shown by the convergence of species richness curves in plot 12. Additionally, increased community engagement and conservation awareness in CFM areas can lead to protective measures that enhance biodiversity (Fielding et al., 2023). Community members, recognizing the long-term benefits of biodiversity, may engage in activities like planting native species and protecting key habitats, which mitigate some negative impacts of resource utilization and promote species richness (Salmi et al., 2023). Furthermore, both CFM and non-CFM areas benefit from natural regeneration processes, where natural disturbances create opportunities for new species to establish, maintaining a dynamic equilibrium in species diversity (Shono et al., 2007). This natural resilience allows ecosystems to recover from disturbances, leading to similar levels of species richness over time.

Wood et al. (2019) and Ramos et al. (2019) support the idea that CFM positively impacts biodiversity conservation. The study findings align with this perspective by showcasing CFM's role in mitigating forest loss and maintaining biodiversity, albeit at lower species diversity indices in the spatial analysis. Despite lower observed species richness in CFM areas, the study indicates a convergence in diversity at the 12th plot, suggesting CFM's role in mitigating forest loss and maintaining certain aspects of biodiversity. This highlights CFM's spatial impact on overall floral composition, reinforcing its positive contribution to biodiversity conservation within specific spatially managed zones.

5.3. Effect of CFM on Stem Density

Study findings reveal similar variability in stem density values across both forest management types. The similarities in stem density between CFM and non-CFM areas can be attributed to several factors. In CFM areas, active human engagement through sustainable harvesting and resource utilization often leads to average stem densities; these practices encourage planting and maintaining more trees to support both community needs and conservation goals (Boton et al., 2021). Conversely, non-CFM areas, with less direct human interference, may experience average stem density as well due to natural thinning processes and less interventionist management practices (Giuggiola et al., 2012). Additionally, CFM areas typically balance forest utilization with protection, resulting in a managed increase in stem density. Community-led initiatives often include reforestation and afforestation efforts, enhancing stem density (Bowler et al., 2010). Similarly, non-CFM areas, which prioritize conservation, might not have the same level of active natural regeneration mirroring the same conditions as CFM squarely stem density. More so, both CFM and non-CFM areas share similar ecological characteristics such as climate, soil type, and topography, contributing to baseline similarities in stem density.

6. Conclusion

It acknowledges that collaborative forest management (CFM) affects forest dynamics (carbon stock, species diversity, and species stem density) differently according to prevailing conditions that are both naturogenic and anthropogenic. The study was justified by the need to empirically assess the ecological effects of CFM, a strategy intended to balance forest conservation with community benefits. Understanding these impacts is crucial for informing forest management policies and practices that can effectively sustain forest ecosystems while supporting local communities. The nuances in results, especially from the norm, highlight the need to conduct comparative studies on CFM practices in different regions/forests to understand contextual factors influencing their effectiveness. Investigations of both short-term and long-term ecological impacts of CFM on forest health and resilience, as well as exploration of the socio-economic benefits of CFM to local communities and how these relate to ecological outcomes, are key areas for further research.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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