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Spatial Patterns of Biomass and Carbon Sequestration as Affected by Vegetation and Topography in a Community Forest Selopuro Indonesia

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Abstract: This study aims to estimate biomass and carbon stocks stored based on variations in slope gradient and vegetation cover types in the Community Forest, Selopuro, Indonesia. The study was conducted on 24 sample plots arranged stratified based on a combination of four slope classes (0–8%, 8–15%, 15–30%, >30%) and two vegetation cover types (teak and mixed vegetation). The parameters observed included tree biomass, litter biomass, carbon content, and soil physical-chemical properties. Tree biomass estimation was calculated based on Diameter Breast Height (DBH) measurements and tree height using allometric equations. Data were analyzed using one-way analysis of variance (ANOVA), Tukey's extended test, and Pearson correlation analysis. The results showed that slope and vegetation cover types significantly affected litter biomass and the amount of carbon stored. Plots with mixed vegetation on slope classes 0–8% and 8–15% showed the highest biomass and carbon values. The main factors influencing carbon storage include soil organic C content, canopy length, and soil permeability. These findings emphasize the importance of conservation-based community forest management practices and agroforestry to increase carbon stocks sustainably and support climate change mitigation efforts.

Keywords: biomass, carbon stocks, community forests, slope, vegetation cover

Introduction

Climate change has become a tangible global challenge, marked by rising average temperatures, shifting precipitation patterns, and extreme weather events that threaten the sustainability of ecosystems and social systems (Sugiarto et al., 2024). These conditions affect various aspects, such as land productivity, water availability, and the sustainability of natural resources (Herdiansyah et al., 2024). Consequently, effective mitigation and adaptation strategies based on ecosystems and local data are urgently needed (Li et al., 2024). One prominent mitigation strategy is the ecosystem-based approach, wherein forests play a critical role in sequestering and storing carbon through photosynthesis and accumulating soil organic matter (Gunawan et al., 2024).

Community forests play an important part in ecosystem-based mitigation strategies. Besides their capacity to sequester carbon, they directly benefit local communities by serving as ecological buffers and providing both timber and non-timber forest products. Community-based forest management systems make forests more adaptable to local socio-ecological conditions while also enhancing climate resilience (Rijal & Sinutok, 2024). However, the potential for carbon sequestration in community forests is underexplored, particularly in terms of landscape biophysical parameters (Akter et al., 2022).

Research on carbon storage in community forests in Indonesia and Southeast Asia has primarily concentrated on lowland or monoculture systems, with many studies neglecting the combined influence of slope variation and vegetation structure. Studies in teak-based community forests in Yogyakarta reported relatively high carbon stocks but without considering topographic heterogeneity (Suharno et al., 2017), while research in Sumatra and Kalimantan focused shrubland and peatland rehabilitation yet failed to explicitly link slope conditions with carbon dynamics (Dharmawan et al., 2023; Dharmawan et al., 2024). Similarly, Southeast Asian studies on secondary forests emphasize species composition but rarely address slope-driven variability (Ngo et al., 2013). By integrating slope and vegetation type, this study fills a critical gap by demonstrating how mixed-species stands on gently sloping terrain enhance carbon sequestration more effectively than monocultures, offering new insights into landscape-level management of community forests.

In this context, it is crucial to understand how vegetation cover and topographic conditions independently influence the carbon storage potential in community forests. The objective of this study is to quantify biomass and carbon storage in the community forest, determine the impacts of slope and vegetation type on biomass and carbon storage, and assess the relationship between soil properties, biomass and carbon storage. This research is assessing the integrated effects of slope classes and vegetation types in community forest systems using GIS, statistical analysis, and allometric estimation methods. By focusing on the diverse topography of the Selopuro area, this research contributes to the limited literature on plot-level carbon storage in Indonesia. Additionally, it provides a conservation plan for community forest research.

Topographic characteristics, particularly slope, are among the most influential landscape factors affecting ecological processes (Zhou et al., 2023). However, the impact of slope on carbon storage cannot be understood in isolation—it must be viewed concerning the type and structure of vegetation covering the land (Dai et al., 2022). Slope influences the soil's ability to retain water, erosion rates, and substrate stability (Romadhon and Aziz, 2022), affecting vegetation growth and biomass accumulation (Mishra et al., 2021; Tan et al., 2025). Besides topography, vegetation structure and species composition play a vital role. Vegetation sequesters carbon and stabilizes soil, regulates microclimate, and provides organic inputs to the soil (Lenk et al., 2024). Mixed-species vegetation typically has a higher carbon storage capacity due to complex canopy structures and greater species diversity (Xiang et al., 2022).

Slope and vegetation type independently shape the spatial patterns of carbon distribution. Previous studies have shown that combining these two factors can result in spatial variations in soil and vegetation carbon content, depending on the local biophysical context (Zhang et al., 2025). However, most existing research remains at macro or regional scales and fails to explain detailed patterns at the plot level (Fang et al., 2022). Recent findings even highlight that areas with gentle slopes and diverse vegetation tend to have higher carbon storage capacity (Wu et al., 2024). Therefore, identifying the optimal combination of topography and vegetation is the key to developing adaptive and evidence-based community forest management strategies.

Materials and Methods

Research Location

This study was conducted in the Selopuro Community Forest area, Kelurahan Selopuro, Batuwarno Subdistrict, Wonogiri Regency, Central Java Province. Geographically, the area lies between 7°58′54.16″ to 8°0′42.38″ South Latitude and 110°58′21.49″ to 111°0′7.42″ East Longitude, with an average elevation of approximately 274 meters above sea level (m asl). The region is predominantly characterized by Inceptisol soils, with topography ranging from flat to steep slopes. The dominant vegetation consists of two types: monoculture teak stands (*Tectona grandis*) and mixed-species vegetation, including mahogany (*Swietenia macrophylla*), acacia (*Acacia spp.*), johar (*Cassia siamea*), and sonokeling (*Dalbergia latifolia*).

Research Method

This study employed an exploratory survey method combined with Geographic Information System (GIS) techniques and laboratory analysis. The total number of Land Map Units (LMUs) was eight, which were used to overlay thematic maps including soil type (Figure 1), slope (Figure 2), and rainfall (Figure 3) all at a scale of 1:30,000, processed using ArcGIS software version 10.4. The total research area encompasses 262.72 hectares, covering diverse ecological characteristics ranging from flat to steep slopes, Inceptisol soils, and two dominant vegetation cover types (monoculture teak and mixed-species stands).

The heterogeneity of the research area was addressed using a stratified random sampling approach, in 8 LMU (Figure 4) and each LMUs treated as a stratum. Three plots were allocated in each LMU, producing a total of 24 observation plots. This number was not arbitrarily chosen but adjusted to balance spatial representation with practical feasibility. According to FAO (1990), a minimum of 2–3 plots per stratum is sufficient to ensure statistical reliability while avoiding over-sampling in relatively homogeneous units. The 8 LMUs distributed across 262.72 hectares, 24 plots are considered adequate to represent the spatial variability of the Selopuro Community Forest. This design ensures coverage of both vegetation types and the full slope classes while maintaining proportional representation of the study area.

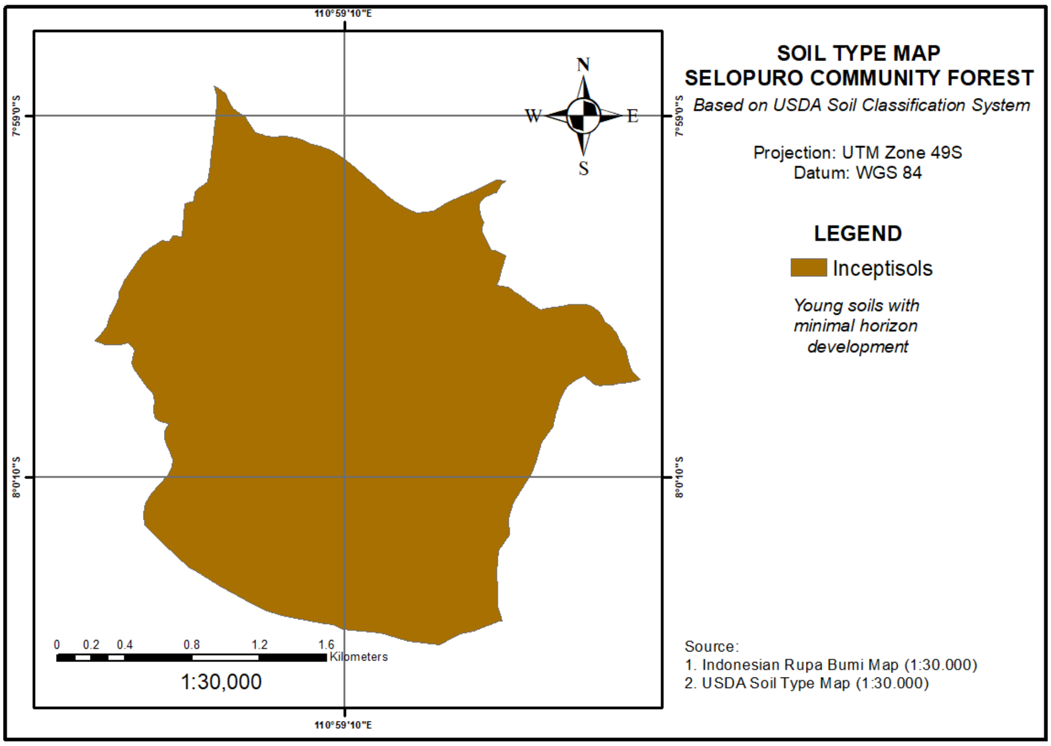

Figure 1. Map of soil type in the research area

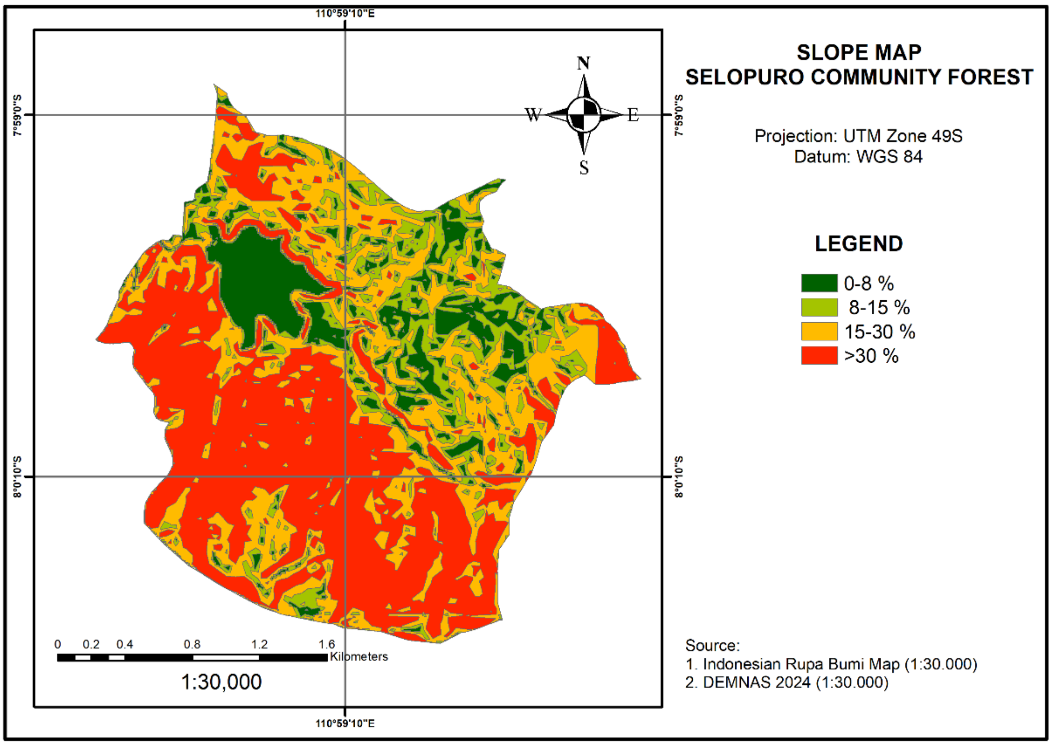

Figure 2. Map of slope gradients in research area

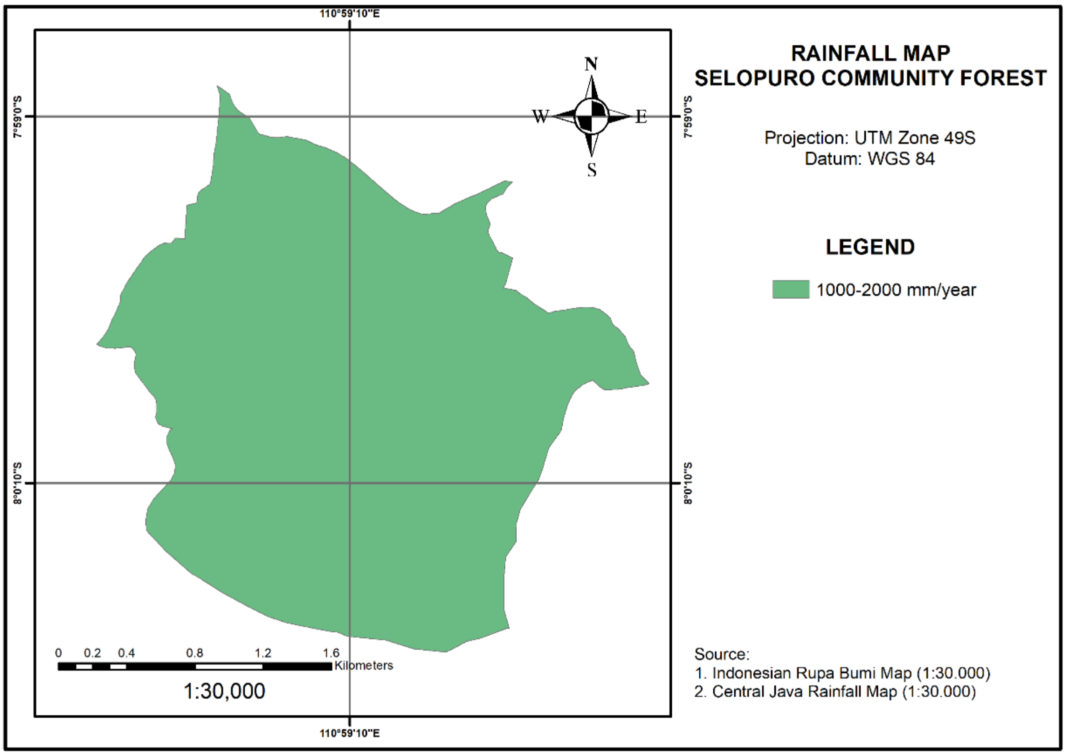

Figure 3. Map of rainfall intensity in the research area

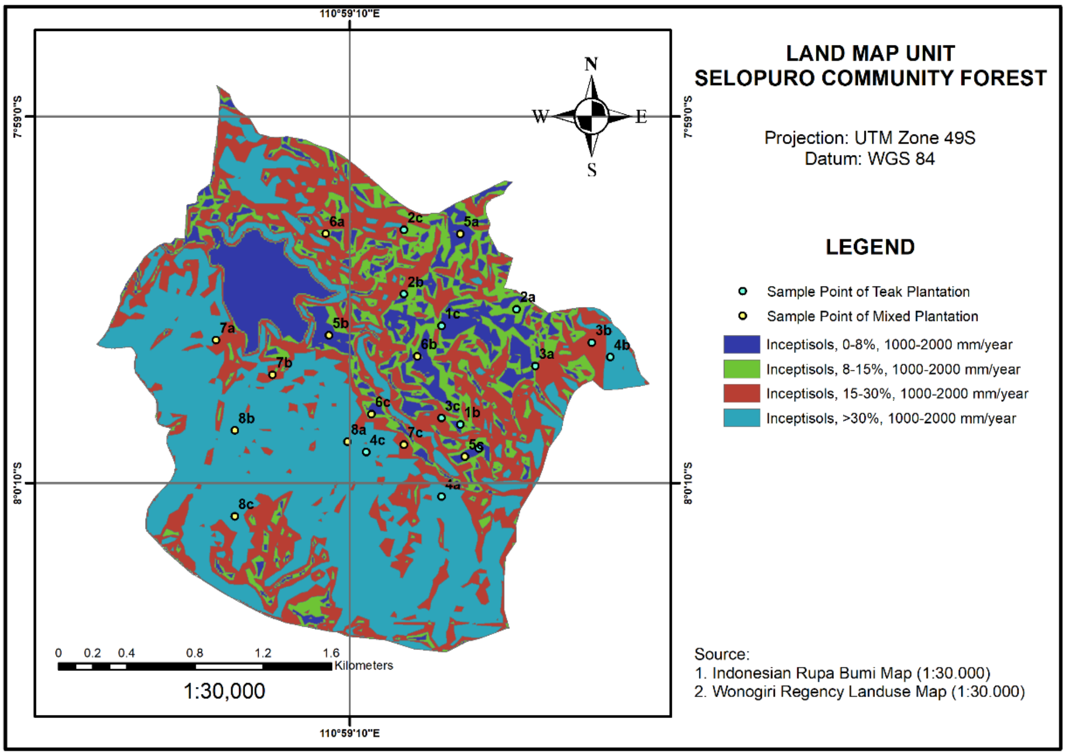

Figure 4. Sampling point of research area

Estimation of Biomass and Carbon Storage

The parameters observed in this study included tree biomass, litter biomass, and physical and chemical properties of the soil. Tree biomass was measured using a non-destructive method by recording the diameter at breast height (DBH) and total tree height at each observation point. The DBH and tree height values were then entered into a species-specific allometric equation, where teak trees used equation 1 (Purwanto et al., 2012).

$$\boldsymbol{Bt = 0.015\,(D^2.H)^{1,0842}} \quad \textbf{(1)}$$

Description:
Bt = Total Biomass
D = Diameter at Breast Height (cm)
H = Tree Height (m)

Mixed vegetation using the equation 2 (Chave et al., 2014). In this study, mixed vegetation referred to community forest stands composed of multipurpose tree species, including Mahogany (*Swietenia macrophylla*), Acacia (*Acacia* spp.), Johar (*Cassia siamea*), and Sonokeling (*Dalbergia latifolia*), often intercropped with scattered teak individuals. Stand age ranged between 10–20 years, with densities of approximately 400–900 trees per hectare, depending on site conditions. This standardized reporting of species, age, and density ensures comparability across plots.

$$\boldsymbol{AGB = 0.0673\,(\rho D^2 H)^{0,976}} \quad \textbf{(2)}$$

Description:
AGB = Above Ground Biomass (kg)
ρ = Wood Density (g/cm^3)
D = Diameter at Breast Height (cm)
H = Tree Height (m)

Tree biomass estimation is calculated per individual, then summed and converted to tons per hectare (ton ha^{-1}). Meanwhile, litter biomass is obtained from sampling using a 1 m × 1 m litter trap tool producing wet weight. The collected litter is dried in an oven at 80°C to constant weight, then weighed to produce dry weight. The dry weight value obtained is then converted into tons per hectare (ton ha^{-1}) by considering the area of the observation plot. Litter biomass per hectare is calculated using equation 3 (Hairiah & Rahayu, 2007):

$$\boldsymbol{DW\ Total} = \frac{\boldsymbol{DW\ of\ sub-sample\ (g)}}{\boldsymbol{FW\ of\ sub-sample\ (g)}}\ \boldsymbol{x\ Total\ FW\ of\ sample\ (g)} \quad \textbf{(3)}$$

Description:
DW = Dry Weight
FW = Fresh Weight

The estimate of carbon storage was obtained by multiplying the total biomass (combination of tree and litter biomass) by a carbon conversion factor of 0.47 (Thomas & Martin, 2012), using equation 4:

$$\boldsymbol{C\ Stock\ (ton\ ha^{-1}) = Biomass\ x\ 0.47} \quad \textbf{(4)}$$

Biomass is the total biomass (ton ha^{-1}), and 0.47 is a conversion factor, stating that 47% of dry biomass consists of carbon elements on average.

Data Analysis

The delineation of Land Map Unit (LMU) in the Selopuro community forest was carried out by integrating slope and vegetation data. Slope classes were determined according to the classification of the Ministry of Forestry of Indonesia, consisting of flat (0–8%), gently sloping (8–15%), moderately sloping (15–30%), and very steep (>30%). Vegetation cover was categorized into two main types: monoculture teak (*Tectona grandis*) stands and mixed-species vegetation, including Mahogany (*Swietenia macrophylla*), Acacia (*Acacia* spp.), Johar (*Cassia siamea*), and Sonokeling (*Dalbergia latifolia*).

The delineation process was divided into three stages: (1) slope data, were derived from a Digital Elevation Model (DEM) and reclassified based on slope percentage thresholds, (2) vegetation data, were obtained through direct field observations (ground-check), where tree species composition and dominance were recorded, and (3) slope and vegetation maps were overlaid using a Geographic Information System (GIS) to generate spatial units. Each LMU was identified as a distinct mix of slope gradient and vegetation type. The overlay produced eight LMUs, which served as the basis for sample plot allocation and subsequent biomass and carbon storage analysis. Spatial delineation and mapping of LMU were carried out using ArcMap 10.4 GIS software, ensuring reproducibility of the procedure.

The determinants of biomass and carbon storage data acquired from biomass measurements and soil parameter were then statistically analyzed using SPSS software version 25. The first stage of the research used an ANOVA to examine the effects of vegetation cover type (teak and mixed-species) and slope gradient (0–8%, 8–15%, 15–30%, >30%) on three response variables:

tree biomass, litter biomass, and carbon storage. This analysis aimed to determine whether there were significant differences in mean values between treatment groups at a 95% confidence level ($\alpha = 0.05$). If the ANOVA results indicated a significance value less than 0.05, a Tukey's Honest Significant Difference (HSD) post-hoc test was used to determine which treatment groups differed significantly. Tukey's HSD test provides a more accurate and efficient grouping when comparing means across treatment combinations.

In addition to the comparative analysis, Pearson's correlation analysis was conducted to evaluate the relationships between environmental and vegetation factors to biomass and carbon accumulation. The variables tested included soil physico-chemical properties (such as pH, porosity, permeability, texture, and soil organic carbon) and vegetation characteristics (such as canopy length and tree height). Pearson's correlation was chosen for its ability to measure the strength and direction of linear relationships between two numerical variables. The correlation results were used to identify the key factors significantly contributing to carbon storage potential in community forest systems shaped by topographic and vegetative characteristics.

Results and Discussion

Carbon Storage and Biomass

Tree biomass, litter biomass, and carbon storage show clear variation across Land Map Unit (LMU) in the Selopuro community forest (Table 1). Unlike many state-managed forests, Selopuro Forest is managed through community-based practices (Suharno et al., 2017), where smallholders determine vegetation composition and land use strategies. The highest tree biomass was recorded in LMU 1 (teak, slope 0–8%) with 9.14 ton ha^{-1}, while the lowest occurred in LMU 3 (teak, slope 15–30%) with 2.92 ton ha^{-1}. For the litter component, LMU 5 (mixed vegetation, slope 0–8%) showed the highest biomass at 2.33 ton ha^{-1}, whereas LMU 4 (teak, slope >30%) had the lowest at 0.65 ton ha^{-1}. Carbon storage generally followed the same trend, with the highest value in LMU 5 (8.55 ton ha^{-1}) and the lowest in LMU 4 (3.56 ton ha^{-1}). Overall, mixed vegetation consistently maintained higher biomass and carbon storage compared to homogeneous teak stands, reflecting the influence of species diversity and complementary ecological functions. These results suggest that farmer-driven diversification strategies not only provide multiple livelihood benefits but also enhance ecosystem services, particularly carbon sequestration, even under challenging topographic conditions such as steep slopes.

Table 1. Biomass and carbon storage based on slope and vegetation cover

LMU	Vegetation	Slope (%)	Tree Biomass		Litter Biomass		Carbon Storage	
			ton.ha^{-1}	%	ton ha^{-1}	%	ton ha^{-1}	%
1	Teak	0–8	9.14	19.92%	1.31	13.02%	7.43	15.39%
2	Teak	8–15	3.88	8.46%	1.23	12.22%	5.28	10.93%
3	Teak	15–30	2.92	6.36%	0.68	6.76%	3.72	7.70%
4	Teak	>30	2.92	6.36%	0.65	6.46%	3.56	7.37%
5	Mixed vegetation	0–8	7.95	17.32%	2.33	23.16%	8.55	17.71%
6	Mixed vegetation	8–15	5.35	11.66%	2.18	21.67%	6.99	14.47%
7	Mixed vegetation	15–30	5.88	12.82%	0.90	8.95%	5.35	11.08%
8	Mixed vegetation	>30	7.85	17.11%	0.78	7.76%	7.41	15.34%

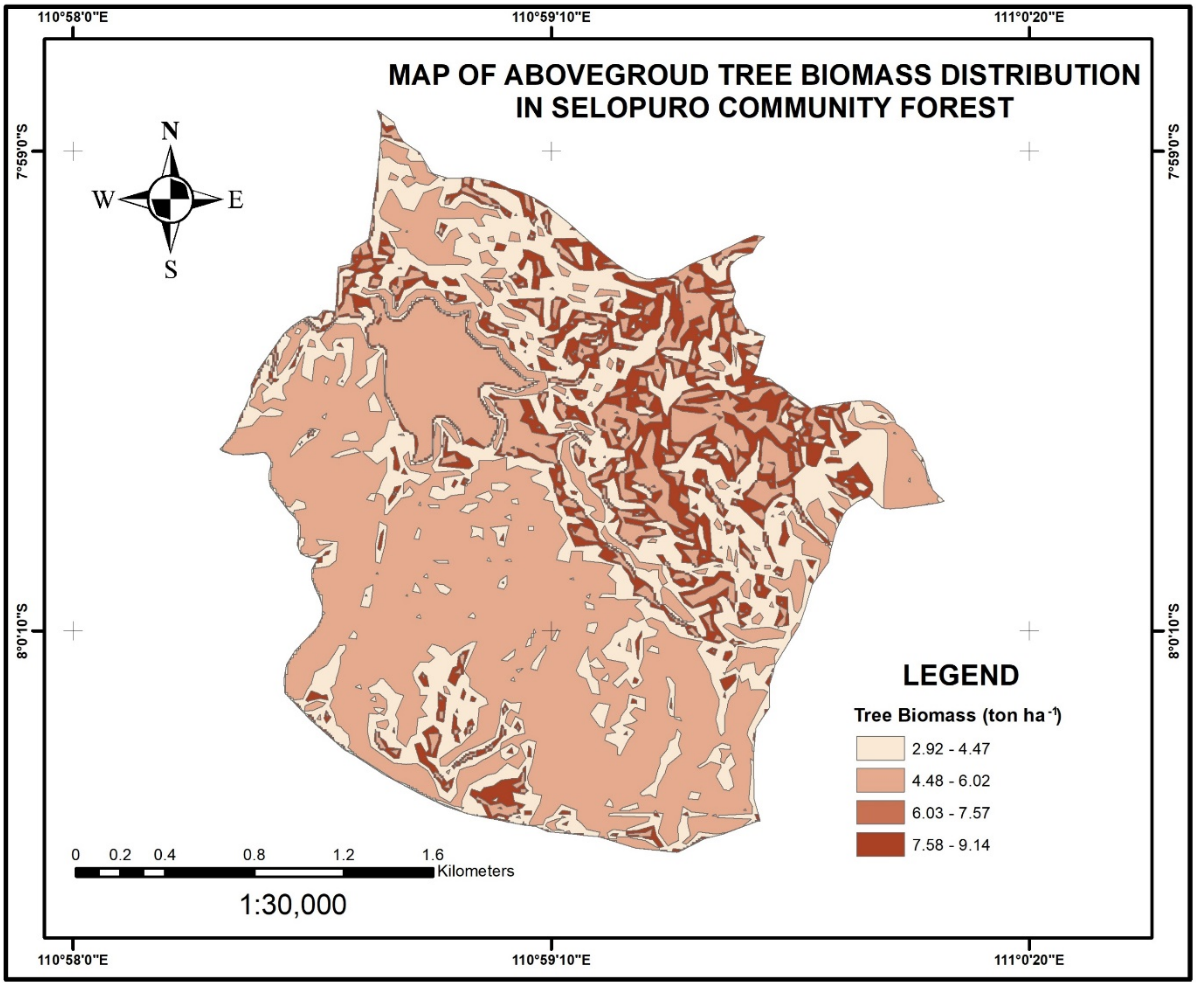

Figure 5. Distribution of tree biomass in research area

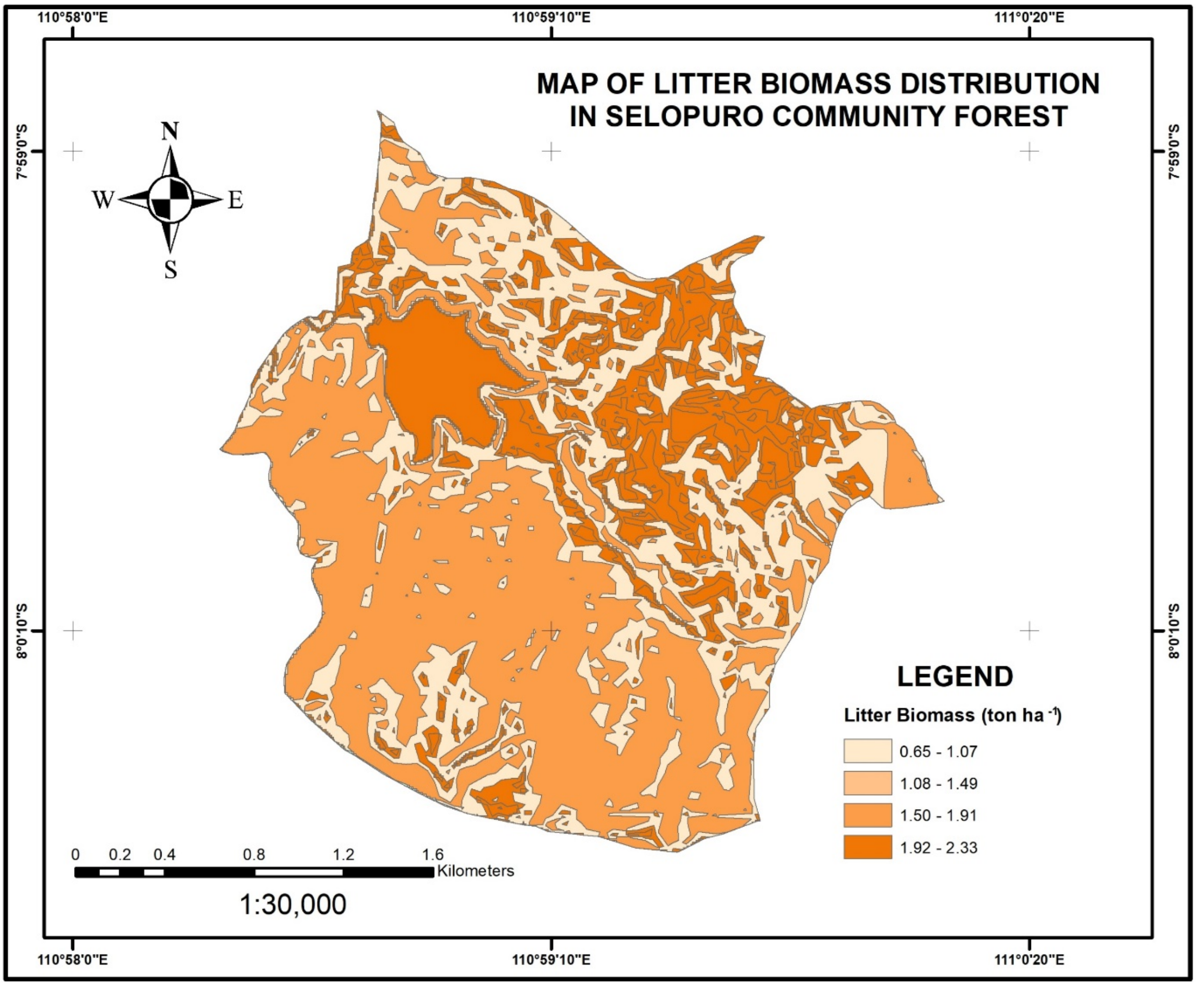

Figure 6. Distribution of litter biomass

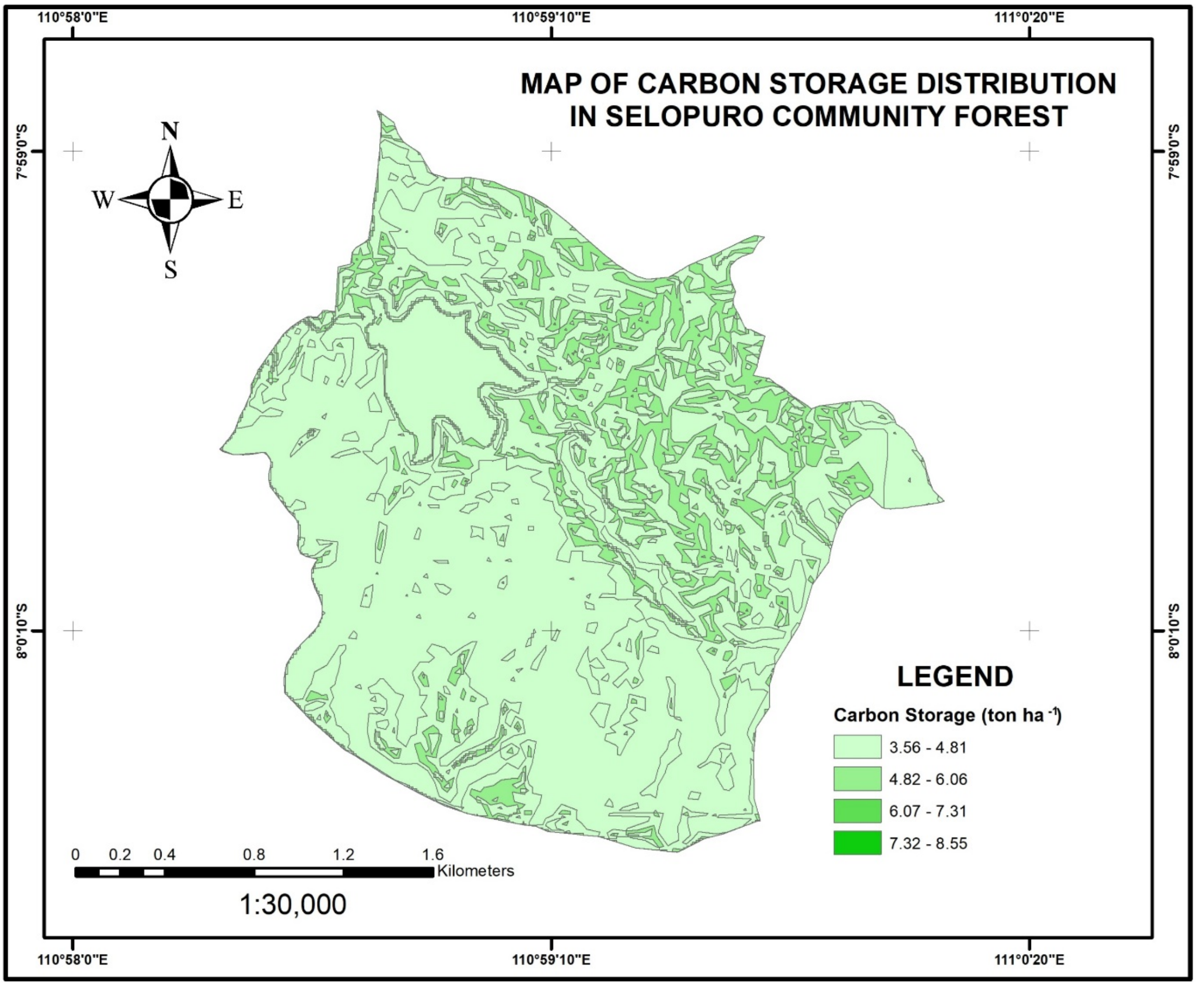

Figure 7. Distribution of Carbon storage

Figures 5, Figure 6, and Figure 7 illustrates the spatial distribution of tree biomass, litter biomass, and carbon storage in the Selopuro community forest, which reveals significant ecological gradients. Higher tree biomass in 0–25% slope areas implies dense vegetation and environmental diversity, which promotes both forest production and long-term carbon sequestration. Litter biomass distribution demonstrates the importance of canopy density and vegetation cover in regulating organic matter intake to the forest floor, with higher accumulation supporting nutrient cycling and soil fertility. These patterns lead to regional variations in carbon storage, with high-biomass zones also serving as stronger carbon sinks. The findings highlight how forest structural complexity, including differences in topography, influence biomass distribution and ecosystem function (Diochon & Kellman, 2022).

According to Table 1, mixed vegetation contributes the largest proportion of biomass and carbon storage in community forests. It accounts for 58.9% of tree biomass, 61.54% of litter biomass, and 58.61% of total carbon storage. In comparison, teak plantations contribute a smaller share, with 41.1% of tree biomass, 38.46% of litter biomass, and 41.39% of total carbon storage. These findings indicate that mixed vegetation systems have greater potential for carbon accumulation than monoculture teak stands. The higher values in mixed vegetation may be attributed to greater species diversity, which enhances structural complexity, organic matter input, and soil nutrient cycling. Consequently, promoting mixed vegetation could be an effective strategy for improving biomass productivity and increasing carbon storage capacity in community forests.

Building on these spatial observations, analysis across Land Map Units (LMUs) reveals significant differences in total carbon storage (tree biomass plus litter carbon). LMU 5 stored 8.55 ton ha^{-1}, while LMU 4 stored only 3.56 ton ha^{-1}–4.99 ton ha^{-1} gap across contrasting slope-vegetation conditions. In teak-dominated plots, the difference between LMU 1 (7.43 ton ha^{-1}) and LMU 4 (3.56 ton ha^{-1}) was 3.87 ton ha^{-1}, whereas in mixed-species plots the variation was only 1.14 ton ha^{-1} (LMU 5 vs. LMU 7). These results align with findings from Bukoski et al. (2022), who documented significant variation in carbon accumulation tied to vegetation density and terrain complexity. The greater stability observed in mixed-species stands also concurs with Warner et al. (2023), who found more consistent carbon storage in mixed plantations compared to monocultures.

Despite this within-site variation, overall biomass and carbon storage in Selopuro remain low relative to other community and secondary forests in the region. For example, community teak stands in Jatimulyo Village have aboveground biomass of 27 ton ha^{-1}, equivalent to roughly 13.5 ton ha^{-1} (Suharno et al., 2017), nearly an order of magnitude higher than the lowest Selopuro LMU. Similarly, secondary forests in Seram, Maluku store around 70 ton ha^{-1}, while primary forests can reach up to 175 ton ha^{-1} (Stas, 2014). The data showed research area, Selopuro, have experienced the degradation, due to past land-use pressures and vegetation conversion that have diminished ecosystem productivity and carbon sequestration potential. Biomass production activities on land inconsistent with slope requirements have resulted in a decline of crop productivity and soil degradation through erosion. Erosion is a natural process, but human activities have accelerated it, so that the volume of soil lost exceeds the rate of natural soil formation. Archaeological evidence indicates that accelerated soil erosion emerged as a serious environmental issue as early as 8,000 years ago. Today, drylands around the world are experiencing rapid soil degradation and shifts in vegetation composition in response to climate change and anthropogenic disturbances (Frasetya et al., 2019). These findings underscore the urgency of implementing restoration strategies for climate mitigation, including reforestation, enrichment planting, and promoting mixed-species stands, in order to rebuild forest structure and enhance long-term carbon storage capacity.

Distribution and Influence of Environmental Factors on Biomass and Carbon

Biomass and carbon storage in Selopuro community forest are distributed across vegetation types and slope. Tree biomass, litter biomass, and carbon storage tend to be higher in mixed vegetation compared to teak stands, while flat (0–8%) to gently (8–15%) sloping areas generally retain greater amounts than steep slopes (>30%). As presented in Table 3, depicts that both vegetation cover and slope significantly influence on litter biomass and carbon storage. These findings indicate that vegetation composition types and topographic variation shape the distribution of biomass and carbon across the landscape and determine the ecological capacity of community forests.

Slope has a substantial effect on tree biomass (p value $0.022 < 0.05$) (Table 2), whereas vegetation type does not (p value > 0.05), indicating that topography is more crucial for tree growth. Litter biomass is extremely responsive in vegetation ($p = 0.032$), and slope ($p = 0.000$). Carbon storage is also influenced by vegetation ($p = 0.016$) and slope ($p = 0.034$), which indicating the long-term effects of tree biomass and litter input. These findings suggest that flatter areas with mixed vegetation support more biomass and carbon storage, but steep slopes are more prone to erosion and decreased productivity. Similar trends have been observed in other tropical forests, where slope and vegetation structure strongly regulate carbon sequestration.

Table 3 shows the average tree biomass across various slope. Flat slopes (0–8%) had the maximum tree biomass, supporting about 95% more biomass than very steep slopes (>30%). This sharp decline emphasizes the ecological importance of topography, as gentle slopes provide deeper soils and greater water retention, which supports root growth, whereas steeper terrains suffer from run-off and nutrient loss, limiting biomass accumulation (Nguyen et al., 2023; Huang et al., 2022). In contrast, Zhang et al. (2024) indicated that slope serves as a substantial regulator on aboveground biomass, in other community forest systems.

Table 2. Effect of vegetation types and slope on biomass and carbon storage

Environmental factor	Tree Biomass (p-value)	Litter Biomass (p-value)	Carbon Storage (p-value)
Vegetation	0.070	0.032*	0.016*
Slope	0.022*	0.000**	0.034*

*Remark: *) = significant at α < 0.05, error bars represent 95% confidence intervals; **) = Highly significant at α < 0.01, error bars represent 99% confidence intervals.*

Table 3. Distribution value of tree biomass under various slope

Environmental factor	Types	Tree biomass
Slope	0–8	8.54a
	8–15	5.38ab
	15–30	4.61b
	>30	4.39b

Remark: Mean values with different letters indicate significant differences at the 5% level.

Table 4. Distribution of litter biomass and carbon storage under various vegetation types and slope

Environmental factor	Types	Litter biomass	Carbon storage
Vegetation	Teak	0.96b	4.99b
	Mixed vegetation	1.55a	7.07a
Slope	0–8	1.82a	7.99a
	8–15	1.70a	6.13ab
	15–30	0.79b	5.48ab
	>30	0.71b	4.53b

Remark: Mean values with different letters indicate significant differences at the 5% level.

Litter biomass affected by vegetation cover types and slope (Table 4). Mixed vegetation resulted in 61% higher litter accumulation (1.55 ton ha^{-1}) compared to teak monocultures (0.96 ton ha^{-1}). The stabilizing effect of diversity in vegetation species is further amplified by slope, which flat slopes (0-8%) producing about 150% more litter than steep slopes (15-30%), indicating how canopy richness and lower erosion vulnerability to improve surface organic matter retention. This evidence supports to Ma et al. (2023) and Rahman et al. (2024) claims that diverse canopy structures maintain favorable microclimates for litter persistence, whereas continuous multi-species litter input promotes nutrient cycling.

Carbon storage showed a similar pattern, with mixed stands sequester approximately 42% more carbon (7.07 ton ha^{-1}) compared to teak monocultures (4.99 ton ha^{-1}) (Table 4). Based on carbon storage under various of slopes, slopes with 8–15% retained 35% more carbon than very steep slopes (>30%), implying that balanced drainage and soil stability at mid-slopes (<30% gradients) offer ideal carbon accumulation conditions. These findings confirm that both vegetation heterogeneity and slope variation influence carbon dynamics (Chen et al., 2022, Wang et al., 2024). In practical terms, research demonstrates that integrating mixed-species management with slope conservation strategies can maximize carbon sequestration while supporting ecosystem resilience and sustainable land use.

Determinants of Biomass and Carbon Storage

Soil organic carbon (SOC) in Table 5 shows the strongest positive correlation (r = 0.812, p-value < 0.01) with total carbon storage. This finding confirms that soil quality is an important factor of ecosystem function (Wang et al., 2024). SOC improves aggregate stability, water retention, and microbial activity, all of which are necessary for organic matter decomposition and mineralization (Lal, 2021). Organic inputs such as compost, biochar, and plant residue recycling can help to keep soil organic carbon levels stable (Herawati et al., 2024). These approaches have also been proven to increase soil carbon levels in agroforestry systems (Nonglait et al., 2024).

Diameter at breast height (DBH) had the strongest association with tree biomass (r = 0.727, p-value < 0.01) and carbon storage (r = 0.523, p-value < 0.01). Larger DBH increases stem volume and enhances long-term carbon accumulation (Plaga et al., 2024). Canopy length has a considerable impact on carbon storage (r = 0.546, p-value < 0.01), highlighting the improtance of broad crowns in cacthing light and supporting photosynthesis (Zhou et al., 2025). In contrast, soil pH and tree height exhibited weak or non-significant associations, implying that not all site or tree attributes contribute equally to biomass and carbon dynamics.

Table 5. Relationship between soil properties to biomass and carbon storage

Soil properties	Tree Biomass (r)	Litter Biomass (r)	Carbon Storage (r)
Porosity	-0.050	0.410*	-0.020
Organic-C	0.390	0.537**	0.812**
Soil pH	-0.262	-0.074	-0.276
Permeability	0.102	0.451*	0.204
Tree Height	0.395	0.042	0.296
Tree Canopy Length	0.562**	0.076	0.546**
Diameter Breast Height (DBH)	0.727**	0.331	0.523**

**Remark: *) significant at α 0.05, error bars represent 95% confidence intervals; **) highly significant at α 0.01, error bars represent 99% confidence intervals.*

The morphometric attributes of trees, particularly their diameter at breast height (DBH) and crown length, have a significant impact on biomass and carbon storage. Larger DBH increases stem volume and long-term carbon accumulation, whereas broader crowns collect more light and enhance photosynthetic efficiency, resulting in increased productivity (Plaga et al., 2024, Daba et al., 2022). Mixed-species stands frequently combine these characteristics, allowing them to maintain carbon storage, particularly under varying slope gradients. Teak-dominated stands, on the other hand, typically have smaller DBH and narrower crowns, reducing carbon storage potential and ecological resilience.

Soil properties shape carbon dynamics in community forests. High porosity enhances aeration and moisture conditions, whereas high permeability allows for water infiltration, minimizes runoff, and stabilizes organic matter, all of which support microbial activity and litter decomposition (Kurniawati et al., 2024). Soils with high organic carbon (SOC) provide the strongest support for biomass and carbon accumulation because they enhance nutrient availability and long-term carbon stabilization (Wang et al., 2024). These processes are further regulated by the structure of the vegetation. Tall trees with dense canopies frequently restrict understory growth and litter input, reducing carbon source diversification (Lili et al., 2024). Mixed-species stands with multi-strata canopies, on the other hand, improve carbon capture efficiency and act as a microclimatic buffer (Simmavong et al., 2025). Steep slopes, on the other hand, accelerate runoff and erosion, reducing carbon retention, whereas moderate slopes promote carbon accumulation (Hu et al., 2025). These findings demonstrate how vegetation mix, tree structure, soil quality, and slope interact to determine biomass distribution and carbon storage. Managers can strengthen community forest resilience by encouraging mixed-species growth, increasing soil organic matter, and controlling slope degradation. Such measures directly increase carbon sequestration and aid in forests adaptation to climate change (Xu et al., 2024, Ma et al., 2023).

Conservation Strategies

The Selopuro Community Forest's poor status necessitates management measures that combine ecological restoration and socioeconomic benefits. This study demonstrates that mixed-species stands outperform teak monocultures in carbon storage, particularly on flat to gently slope gradient (0-15%). Mixed-species planting should be prioritized for restoration on these slopes in order to enhance biomass productivity and stabilize carbon storage. Soil conservation is crucial for maintaining high litter buildup in flat slopes (0-8%). Micro-terracing, ground cover crops, and limited tillage are all practices that can help to prevent erosion, preserve organic matter, and improve soil structure (Huang et al., 2025).

Strengthening soil organic carbon using compost, mulch, or crop residues is a low-cost, locally available technique for increasing fertility and carbon sequestration (Bai et al., 2023). Because DBH and crown structure have a significant impact on long-term carbon storage, species selection should prioritize fast-growing timber and multipurpose species that meet the ecological and economic needs of local farmers (Yu et al., 2023). Regular monitoring of biomass and carbon levels is required to assess management efficacy and alter techniques over time.

From a socioeconomic perspective, conservation strategies should align with incentive mechanisms such as REDD+ and carbon payment schemes, which can provide direct financial benefits to smallholders while promoting climate policy goals (Angelsen et al., 2022). Integrating community-based forest management with carbon market opportunities also strengthens local institutions, builds technical capacity among farmers, and enhances resilience of household livelihoods. In this way, community forests can function as both carbon reservoirs and engines of rural development.

Conclusion

This study demonstrates that slope class and vegetation cover have a considerable influence on biomass distribution and carbon storage in the Selopuro Community Forest. Mixed-species vegetation stores more carbon and litter than teak monocultures, particularly on flat to gently sloping terrain (0–15%). Soil organic carbon (SOC) diameter at breast heigh (DBH), and crown length are all important environmental determinants that influence biomassaccumulation and overall carbon storage directly. These findings highlight the need of community forest management strategies that integrate site-specific ecological variables and vegetation structure in order to increase carbon sequestration potential.

Integrating mixed-species replanting and slope-based land management into community forest policy could optimize carbon sequestration while also benefiting rural livelihoods. Farmers in the community can enhance soils with organic amendments, diversify species composition, and maintain trees with larger DBH and broader crowns to maximize carbon benefits. At the policy level, including these practices within REDD+ schemes and local land-use planning can achieve climate mitigation goals offering socioeconomic benefits. This work establishes a scientific foundation for adaptive, climate-responsive, and community-centered forest management in Indonesia and Southeast Asia by connecting biological factors to practical measures.

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