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Impacts of Disturbance and Elevation on Carbon Stock and Biomass of Plus Trees in Tropical Forests of Biliran Island, Philippines

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Abstract Forests play a critical role in carbon sequestration, but various environmental and anthropogenic factors influence their capacity to store carbon. This study assesses the Aboveground Biomass (AGB) and carbon stock of Individual Plus Trees (IPT) across different disturbance and elevation gradients in Villa Consuelo, Biliran Island, Philippines. A systematic field survey was conducted to measure tree diameter at breast height (DBH), total height, and biomass, with calculations based on the allometric equation. The influence of disturbance and elevation on AGB and carbon stock was analyzed using statistical regression models. The findings indicate that forests in less disturbed and higher elevation areas exhibit significantly greater AGB and carbon stock than those in severely disturbed and lower elevation areas. Severe disturbances, such as logging and land conversion, resulted in a substantial reduction in biomass accumulation and carbon sequestration capacity. Conversely, higher elevations support larger trees and greater biomass due to reduced human intervention and more favorable climatic conditions. Regression analysis confirmed a significant negative relationship between disturbance and AGB ($p < 0.001$), while the relationship between elevation and AGB was positive but not statistically significant ($p = 0.066$). These results emphasize the importance of conservation policies and sustainable forest management to protect undisturbed and high-altitude forests, which serve as vital carbon sinks. Efforts such as reforestation, strict regulation of land-use changes, and community-based forest management can enhance the resilience of forest ecosystems. This study contributes essential insights into carbon storage dynamics, supporting climate change mitigation strategies and biodiversity conservation in tropical forests.

Keywords Carbon Stock, AGB, Disturbance Gradient, Elevation, Tropical Forest

1. Introduction

The assessment of above-ground biomass (AGB) and carbon content in individual plus trees (IPT) is paramount for advancing our understanding of forest dynamics and their contribution to carbon sequestration. This current research is especially critical in diverse ecological contexts such as Villa Consuelo, Biliran Island, Philippines. AGB serves as a significant indicator of forest health and productivity, influencing not only ecological interactions but also carbon cycling within forest ecosystems [1]. Accurate quantification of AGB is essential for evaluating forests' roles as carbon sinks or sources, which largely depend on their management practices and disturbance history [2]. Similarly, examining the variability of AGB across different disturbance regimes and elevation gradients grants insights into the resilience and adaptability of forest ecosystems, especially in the face of rapidly changing environmental conditions [3].

Research highlights that AGB is influenced by several factors, including species composition, environmental gradients, and anthropogenic disturbances. Studies reveal a positive correlation between higher species diversity and increased AGB, attributed to complementary resource utilization among species [4, 5]. In addition, the structural complexity often associated with diverse tree species enhances biomass accumulation, further justifying the relevance of AGB in ecological studies. In the specific context of Villa Consuelo, understanding the interplay of elevation and disturbance gradients on AGB will enhance conservation strategies and sustainable forest management practices. These approaches are vital for preserving biodiversity and ensuring the continued provision of ecosystem services [6].

Moreover, the methodologies for estimating above-ground biomass (AGB) exhibit considerable variability, encompassing traditional allometric equations, ground-based inventory assessments, and advanced remote sensing techniques [7, 8]. While the integration of remote sensing data, particularly through technologies such as LiDAR and multispectral imagery, has indeed revolutionized biomass estimation, offering high-resolution spatial data that captures forest structure and composition with enhanced accuracy. However, it is essential to recognize that forest inventory remains the foundational approach for obtaining reliable ground-truth data, especially in carbon estimation [9, 10]. This is particularly crucial in the Philippines, where the rugged terrain often presents challenges for authoritative assessments performed solely through remote methods. While remote sensing notably augments biomass estimation capabilities, the implications of ground-level data collection should not be underestimated; the combined use of meticulous ground-based measurements alongside remote sensing can significantly improve the accuracy of AGB estimates in Villa Consuelo, ensuring that essential ecological assessments are both precise and reflective of real-world conditions.

While existing studies provide a solid foundation for understanding AGB and carbon dynamics, a notable research gap in this area remains; specifically, the synergistic effects of elevation and disturbance on AGB within specific tropical forest ecosystems such as Biliran Island have not been comprehensively studied. Investigating these relationships could enhance vital insights and inform better management strategies to bolster forest resilience in the face of environmental pressures. Given that forests in tropical regions like Biliran Island are vital for global carbon balance, it is imperative that future research addresses these gaps to support effective conservation and management practices that enhance both biodiversity and carbon sequestration capacity.

In summary, assessing AGB and carbon content in IPT across varying disturbance and elevation gradients in Villa Consuelo is not merely important for local forest dynamics but also contributes significantly to wider ecological and climate-change research. Integrating diverse methodologies while considering critical environmental influences in this research can provide invaluable insights into forests' roles in carbon sequestration and biodiversity conservation. Such knowledge is essential for developing effective management strategies that enhance forest resilience and sustainability amid ongoing environmental changes.

2. Materials and Methods

2.1. Study Area

The Province of Biliran is situated at 11° 28' 0" north latitude and 124° 28' 0" east longitude (Figure 1). The study specifically focuses on Brgy. Villa Consuelo, Municipality of Naval, where the Individual Plus Tree (IPT) is located. The forest is part of the Community Based-Forest Management Agreement (CBFM) managed by the Peoples Organization (PO).

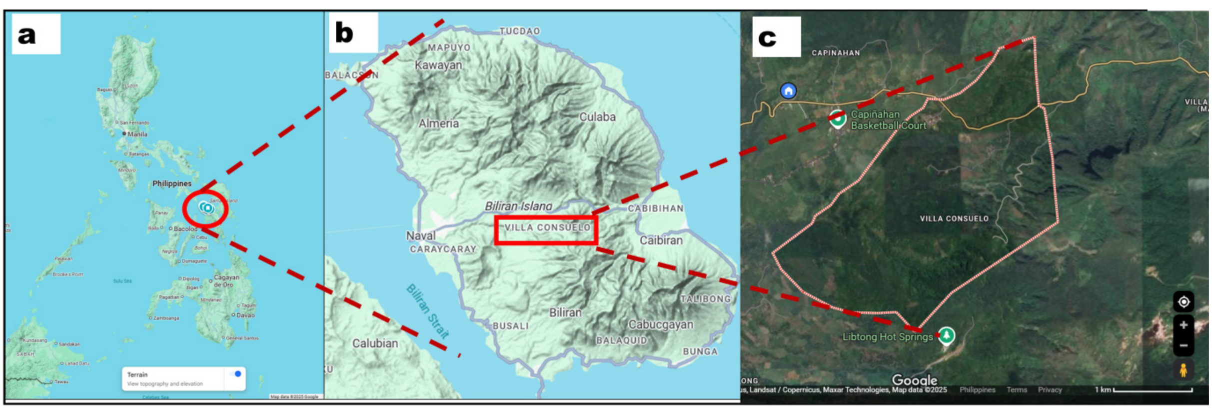

Figure 1. Study site location maps. (a) Map of the Philippines, showing the Biliran Island, (b) Map of Biliran Island showing the study site in Villa Consuelo, (c) Sattellite map showing the location of Villa Consuelo where permanent plots were established, with elevation contours

Biliran experiences a Type II climate, characterized by the absence of a distinct dry season and alternating warm and cool conditions. Rainfall is most pronounced in December, reaching approximately 500 mm, while the lowest recorded rainfall occurs in April, with an average of 1500 mm [11, 12].

2.2. Sampling Design and Data Collection

Data collection was carried out in forested areas across varying levels of disturbance, classified as less disturbed and severely disturbed at different elevations (499, 615, and 710 meters above sea level-masl). The less disturbed areas were located farther from the road, with no visible signs of human activity such as logging or tree cutting. In contrast, the severely disturbed areas were in close proximity to the road and showed clear evidence of disturbance, including tree cutting and logging. Sampling plots were established systematically across the study area, ensuring coverage of all significant forest types and gradients. Within each plot, all trees with a diameter at breast height (DBH) ≥ 6 cm were identified, measured, and tagged. Tree species were identified using field guides and, when necessary, local taxonomists were consulted to verify species names.

Tree height measurements were taken using a range finder. The DBH of each tree was measured at 1.3 meters above ground level using a diameter tape. Additionally, environmental data, such as elevation, slope, and canopy cover, growth patterns were recorded for each plot.

2.3. Data Analysis

The collected data were analyzed to estimate aboveground biomass (AGB) and carbon stock for each tree using the allometric equation developed by Chave et al. [13]:

$$AGB=0.0673\times(\rho\times D2\times H)^{0.976}$$

where:

- ρ = wood density (g/cm³)
- D = diameter at breast height (DBH) in centimeters
- H= total tree height in meters

The carbon stock for each tree was calculated by multiplying the estimated AGB by a carbon conversion factor of 0.47. Total carbon stock per plot was obtained by summing the carbon stock of all individual trees. These values were then extrapolated to a per-hectare basis. To evaluate the influence of disturbance and elevation on carbon stock, we applied a simple linear regression model using the formula:

$$\text{Carbon Stock}=\beta0+\beta1(\text{Disturbance})+\beta2(\text{Elevation})+\varepsilon$$

Model diagnostics, including residual analysis, Q-Q plots, and Cook's distance, were conducted to validate regression assumptions and detect potential outliers. All statistical analyses were performed in R software (version 4.2.0). Visualizations were generated to illustrate the relationships between variables, helping to identify the primary drivers of carbon stock variability in the study area.

3. Results

3.1. DBH among Disturbance Levels and Elevation Gradients

The analysis of tree characteristics across different disturbance levels revealed a clear contrast in tree size and biomass accumulation (Tables 1 and 2). In less disturbed forests, trees exhibited significantly higher average diameter at breast height (DBH) (27.43 cm) compared to severely disturbed forests (15.12 cm). Furthermore, trees in less disturbed areas showed a wider range of DBH values (6.0 cm to 92.91 cm) and had a higher median DBH (21.96 cm), indicating the presence of mature trees capable of greater carbon sequestration. In contrast, severely disturbed forests were dominated by smaller trees with a median DBH of 9.92 cm, highlighting the adverse impact of human activities such as logging and land conversion on forest structure and biomass accumulation. The mean elevation of less disturbed plots (699.42 m) was also higher than that of severely disturbed plots (550.10 m), suggesting a possible correlation between disturbance levels and elevation, where higher-altitude forests tend to experience lower human interference.

Table 1. Summary of tree characteristics by disturbance level in Villa Consuelo, Biliran Island, Philippines. The table presents the number of plots and trees surveyed, minimum, maximum, mean, and quartile values of diameter at breast height (DBH in cm), as well as the mean elevation for each disturbance category

Disturbance	nb_plot	nb_trees	DBHMIN	DBHMAX	DBHMEAN	DBH25Q	DBHMEDIAN	DBH75Q	ElevationMEAN
Less disturbed	10	653	6.00	92.91	27.43	11.00	21.96	42.63	699.42
severely disturbed	20	1028	5.40	111.73	15.12	7.32	9.92	18.50	550.10

Table 2. Summary of tree characteristics by elevation category in Villa Consuelo, Biliran Island, Philippines. The table provides details on the number of plots and trees surveyed, DBH (cm) range, mean, and quartiles across lower, middle, and upper elevation forests

Elevation	nb_plot	nb_trees	DBHMIN	DBHMAX	DBHMEAN	DBH25Q	DBHMEDIAN	DBH75Q	ElevationMEAN
Lower	10	417	5.80	111.73	13.12	7.30	9.50	15.30	501.83
Middle	10	611	5.40	91.04	16.48	7.50	10.20	20.10	583.05
Upper	10	653	6.00	92.91	27.43	11.00	21.96	42.63	699.42

Similarly, elevation was found to significantly influence tree size distribution and biomass accumulation. Forests at higher elevations (Upper category, mean elevation = 699.42 m) exhibited the largest mean DBH (27.43 cm), followed by middle elevation forests (16.48 cm) and lower elevation forests (13.12 cm). This pattern suggests that trees at higher elevations tend to be larger, possibly due to reduced anthropogenic disturbances and favorable climatic conditions that support slower but more sustained growth. The upper elevation forests also displayed a greater variation in DBH values (6.0 cm to 92.91 cm), indicating a more diverse age structure. In contrast, lower elevation forests had a smaller range of DBH values (5.8 cm to 111.73 cm) and a lower median DBH (9.50 cm), reflecting the prevalence of younger or secondary-growth trees in these areas. Hence, elevation plays a significant role in determining the structure and ecological characteristics of forest ecosystems, particularly in relation to biodiversity and conservation strategies. Higher altitudes can be especially beneficial for the conservation of endangered or threatened species, serving as refuges amid threats from climate change and habitat alteration.

3.2. Aboveground Biomass and Carbon Stock Comparing Disturbance

The analysis of Aboveground Biomass (AGB) and Carbon Stock across disturbance levels revealed substantial differences in forest carbon storage potential (Tables 3 and 4). Less disturbed forests exhibited a significantly higher mean AGB (286.51 kg) compared to severely disturbed forests (136.65 kg), indicating that human disturbances such as logging and land-use changes substantially reduce biomass accumulation. The median AGB was also much higher in less disturbed forests (126.79 kg) compared to severely disturbed forests (28.30 kg), reinforcing the idea that intact forests sustain larger trees with greater carbon storage capacity. Similarly, carbon stock followed a similar trend, where less disturbed forests had a higher mean carbon stock (134.66 kg C) compared to severely disturbed forests (64.23 kg C). The median carbon stock in less disturbed forests (59.59 kg C) was more than four times that of severely disturbed forests (13.30 kg C), emphasizing the role of undisturbed forests in maintaining high carbon sequestration levels. These findings highlight the strong negative impact of disturbance on forest biomass and carbon storage, highlighting the need to conserve and/or protect and restore less disturbed forests to secure and enhance their role as carbon sinks and mitigate climate change.

3.3. Aboveground Biomass and Carbon Stock across Elevation Gradients

The analysis of Aboveground Biomass (AGB) and Carbon Stock across different elevation gradients revealed a strong correlation between elevation and biomass accumulation (Tables 5 and 6). Upper elevation forests exhibited the highest mean AGB (286.51 kg), followed by middle elevation forests (155.21 kg) and lower elevation forests (109.46 kg), suggesting that trees at higher altitudes accumulate more biomass, potentially due to reduced human disturbance and more favorable climatic conditions. A similar trend was observed in carbon stock, where upper elevation forests had the highest mean carbon stock (134.66 kg C), compared to middle (72.95 kg C) and lower elevation forests (51.45 kg C). The median values further emphasize this pattern, with upper elevation forests maintaining the highest median AGB (126.79 kg) and median carbon stock (59.59 kg C), indicating a greater presence of mature trees with higher carbon sequestration capacity. The interquartile range (IQR) for both AGB and carbon stock was also wider at higher elevations, suggesting a more diverse age structure and biomass distribution. These findings highlight the importance of conserving and protecting high-altitude forests, which act as significant carbon sinks and play a crucial role in climate change mitigation and biodiversity preservation.

3.4. DBH-Height Relationship

The relationship between Diameter at Breast Height (DBH) and Tree Height varied across disturbance levels and elevation gradients (Figures 2 and 3). Trees in less disturbed forests generally had greater heights at similar DBH values compared to those in severely disturbed forests, indicating that disturbance negatively affects vertical and radial growth potential. Similarly, trees in upper elevation forests tended to be taller than those in lower and middle elevations, suggesting that reduced human disturbance and favorable environmental conditions at higher altitudes support better vertical and radial tree growth. These results highlight the importance of minimizing disturbances and conserving and/or protecting high-altitude forests to maintain forest structure, enhance biomass accumulation, and improve carbon sequestration potential.

Table 3. Summary of Aboveground Biomass (AGB) across disturbance levels in Villa Consuelo, Biliran Island, Philippines. The table presents the number of plots and trees surveyed, minimum, maximum, mean, and quartile values of AGB (kg), along with the mean elevation for each disturbance category

Disturbance	nb_plot	nb_trees	AGB_kgMIN	AGB_kgMAX	AGB_kgMEAN	AGB_kg25Q	AGB_kgMEDIAN	AGB_kg75Q	ElevationMEAN
Less disturbed	10	653	4.97	2966.80	286.51	28.51	126.79	409.82	699.42
severely disturbed	20	1028	3.51	7520.37	136.65	11.92	28.30	110.45	550.10

Table 4. Summary of Carbon Stock across disturbance levels in Villa Consuelo, Biliran Island, Philippines. The table provides details on the number of plots and trees surveyed, minimum, maximum, mean, and quartile values of carbon stock (kg C), as well as the mean elevation for each disturbance category

Disturbance	nb_plot	nb_trees	Carbon.Stock_kgC_MIN	Carbon.Stock_kgC_MAX	Carbon.Stock_kgC_MEAN	Carbon.Stock_kgC_25Q	Carbon.Stock_kgC_MEDIAN	Carbon.Stock_kgC_75Q	ElevationMEAN
Less disturbed	10	653	2.34	1394.40	134.66	13.40	59.59	192.62	699.42
severely disturbed	20	1028	1.65	3534.57	64.23	5.60	13.30	51.91	550.10

Table 5. Summary of Aboveground Biomass (AGB) across elevation gradients in Villa Consuelo, Biliran Island, Philippines. The table presents the number of plots and trees surveyed, minimum, maximum, mean, and quartile values of AGB (kg), along with the mean elevation for each elevation category

Elevation	nb_plot	nb_trees	Carbon.Stock_kgC_MIN	Carbon.Stock_kgC_MAX	Carbon.Stock_kgC_MEAN	Carbon.Stock_kgC_25Q	Carbon.Stock_kgC_MEDIAN	Carbon.Stock_kgC_75Q	ElevationMEAN
Lower	10	417	1.65	3534.57	51.45	5.15	12.11	32.51	501.83
Middle	10	611	2.05	1789.33	72.95	5.82	13.72	70.33	583.05
Upper	10	653	2.34	1394.40	134.66	13.40	59.59	192.62	699.42

Table 6. Summary of Carbon Stock across elevation gradients in Villa Consuelo, Biliran Island, Philippines. The table provides details on the number of plots and trees surveyed, minimum, maximum, mean, and quartile values of carbon stock (kg C), as well as the mean elevation for each category

Elevation	nb_plot	nb_trees	AGB_kgMIN	AGB_kgMAX	AGB_kgMEAN	AGB_kg25Q	AGB_kgMEDIAN	AGB_kg75Q	ElevationMEAN
Lower	10	417	3.51	7520.37	109.46	10.97	25.77	69.16	501.83
Middle	10	611	4.36	3807.09	155.21	12.39	29.19	149.64	583.05
Upper	10	653	4.97	2966.80	286.51	28.51	126.79	409.82	699.42

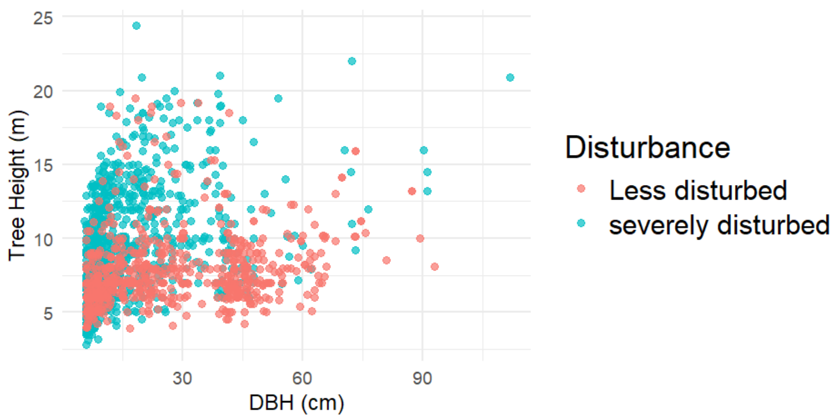

Figure 2. Scatter plots showing the relationship between Diameter at Breast Height (DBH) and Tree Height across disturbance levels in the study site. Different colors represent disturbance levels-showing variations in tree height and DBH distribution

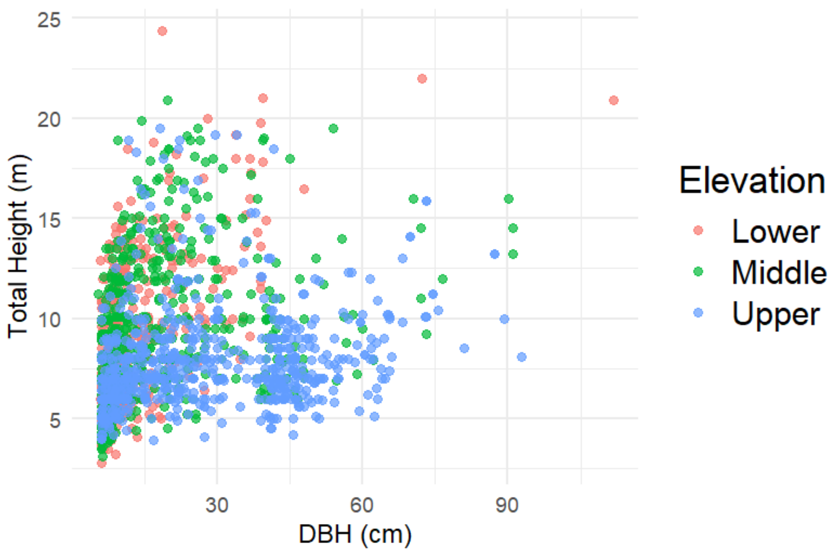

Figure 3. Scatter plots showing the relationship between Diameter at Breast Height (DBH) and Tree Height across elevation gradients in the study site. Different colors represent elevation categories, showing variations in tree height and DBH distribution

3.5. Elevation, Disturbance, Biomass and Carbon Stock

The impact of disturbance on forest biomass and carbon content is critical in understanding the ecological dynamics of forest ecosystems. The findings from the study indicate that forests located in less disturbed areas exhibit significantly higher aboveground biomass (AGB) and carbon stocks (Figures 4 and 5; Tables 7 and 8). This observation aligns with previous research that highlights the detrimental effects of disturbances, such as logging and land conversion, on forest health and carbon storage capacity [14, 15]. The correlation between disturbance and AGB was statistically significant ($p < 0.001$), reinforcing the necessity for effective conservation and protective policies aimed at minimizing disturbances to maintain the carbon storage potential of forests [16].The importance of protecting less disturbed forests is further underscored by their role in mitigating climate change through enhanced carbon sequestration [17].

The structural differences observed between trees in disturbed and undisturbed forests provide additional insights into the implications of forest management practices. In less disturbed areas, trees demonstrated a wider range of diameter at breast height (DBH) and height values, indicative of growth conditions that favor trees at different levels of maturation and biomass accumulation [18]. Conversely, the clustering of trees in lower DBH and height ranges in severely disturbed areas suggests growth conditions that favor trees at similar levels of maturation and biomass accumulation due to increased resource competition, soil degradation, and canopy loss. These findings are consistent with literature indicating that undisturbed forests promote stable tree population dynamics, allowing for greater biomass accumulation over time [19]. Therefore, the long-term benefits of conserving and/or protecting undisturbed forests are evident, as they contribute to both carbon storage and biodiversity conservation.

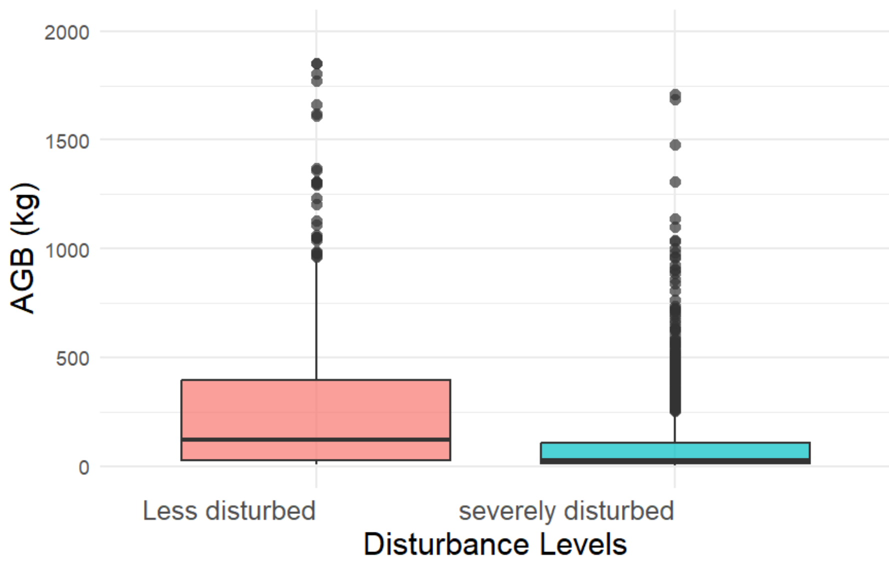

Figure 4. Boxplots of Aboveground Biomass (AGB) across the elevational gradient the study site

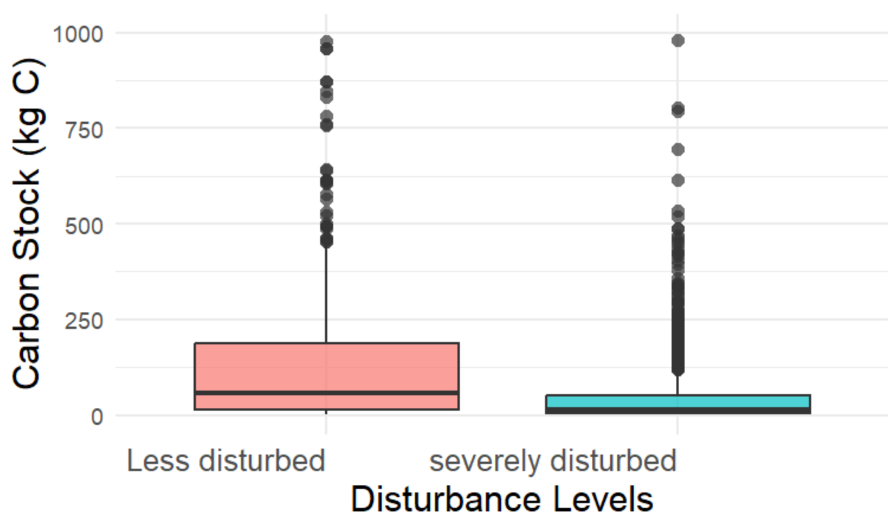

Figure 5. Boxplots of carbon stock across disturbance levels in the study site

Table 7. Linear Model of Aboveground Biomass (AGB) by Disturbance and Elevation

Predictors	Estimates	CI	p-value	Observations	R^2	Adjusted R^2
(Intercept)	286.51	256.49 – 316.54	<0.001	1681	0.036	0.034
Disturbance [Severely Disturbed]	-177.05	225.15 – -128.95	<0.001			
Elevation [Middle]	45.74	-3.00 – 94.48	0.066			

Table 8. Linear Model of Carbon Stock Kg by Disturbance and Elevation

Predictors	Estimates	CI	p-value	Observations	R^2	Adjusted R^2
(Intercept)	134.66	120.55 – 148.77	<0.001	1681	0.036	0.034
Disturbance [Severely Disturbed]	-83.21	-105.82 – -60.61	<0.001			
Elevation [Middle]	21.5	-1.41 – 44.41	0.066			

Elevation is another critical factor influencing forest biomass and carbon storage, as evidenced by the study's results indicating that higher elevation forests possess greater AGB and carbon stocks compared to their lower elevation counterparts (Figures 6 and 7). This trend can be attributed to lower levels of human disturbance and more favorable environmental conditions, such as cooler temperatures and increased moisture, which facilitate more rapid and regular tree biomass accumulation and carbon assimilation [20]. Although the linear regression model indicated a positive relationship between elevation and AGB ($p = 0.066$), the lack of statistical significance suggests that other factors, including soil fertility and species composition and competition, also play a crucial role in determining carbon storage potential in tropical forests which would require further inquiry [21, 22]. This multifaceted relationship highlights the complexity of forest ecosystems and the need for a comprehensive understanding and deployment of management strategies that consider various environmental factors.

From a management perspective, the study emphasizes the necessity for targeted forest management strategies that prioritize the conservation and/or protection of high-elevation and less disturbed forests, which are vital carbon reservoirs. Implementing strict enforcement of environmental laws, such as the Philippine Forestry Code, alongside community-based reforestation programs and mixed-tree species and agroforestry initiatives, can significantly mitigate the impacts of deforestation and degradation [22, 23]. Additionally, fostering local community participation through incentive-based conservation programs would enhance the sustainability of forest conservation efforts. Continued research on carbon sequestration, incorporating seasonal variations and species-specific growth patterns, is essential for refining biomass and carbon stock estimates, thereby providing a robust scientific foundation for conservation and/or protective policies [23]. By integrating these strategies, the sustainable management of Villa Consuelo's forests can be strengthened, ensuring their vital role in biodiversity conservation and climate change mitigation.

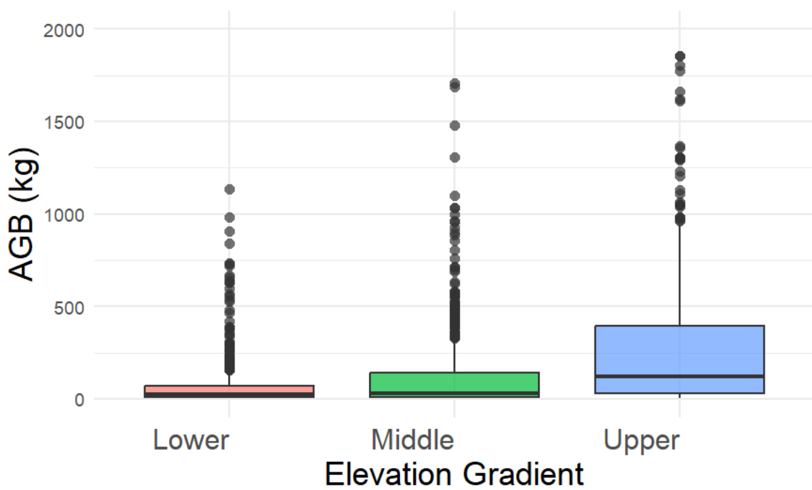

Figure 6. Boxplots of Aboveground Biomass (AGB) across the elevational gradient the study site

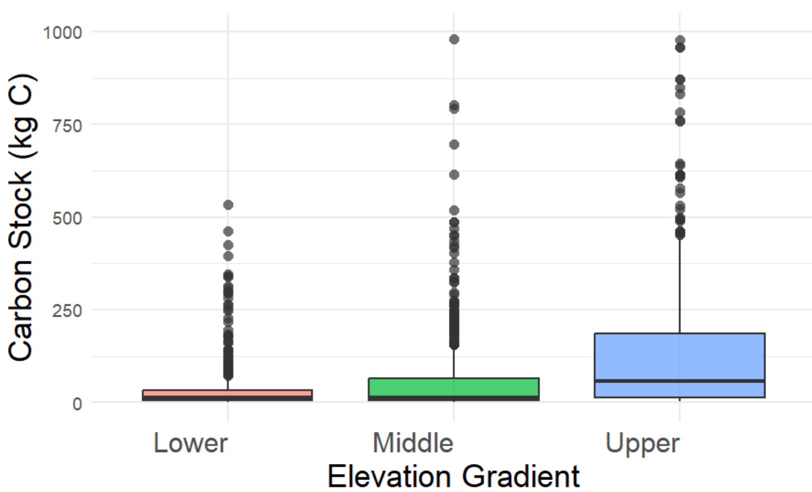

Figure 7. Boxplots of carbon stock across elevation gradients in the study site

3.6. Management Implications

The study's findings highlight the critical need for targeted forest management strategies that prioritize the conservation and/or protection of high-elevation and less disturbed forests, as they serve as key carbon reservoirs. Protecting these forests through strict enforcement of environmental laws, such as the Philippine Forestry Code (PD 705), can help mitigate the impacts of deforestation and degradation. Additionally, implementing community-based reforestation programs and incentivizing local participation through mixed-tree agroforestry initiatives would encourage long-term conservation and/or protective efforts. Sustainable agroforestry systems should be promoted to balance economic benefits with ecological preservation, ensuring that communities can thrive without compromising forest integrity. Furthermore, continued research on carbon sequestration, considering seasonal variations, soil properties, and species-specific growth patterns, will refine biomass and carbon stock estimates, providing a stronger scientific basis for forest management. By integrating these strategies, the sustainable management of Villa Consuelo's forests can be strengthened, securing their role in biodiversity conservation and/or protection, climate change mitigation, and sustainable development for local communities.

4. Conclusions

The study highlights that higher elevation and less disturbed forests have greater DBH, Aboveground Biomass (AGB), and carbon stock, making them crucial carbon reservoirs. In contrast, severely disturbed and lower elevation forests exhibit significantly lower values due to human activities such as deforestation and agricultural expansion. Elevation plays a key role in forest structure, with higher elevations supporting larger trees and greater biomass accumulation due to lower disturbance levels and more favorable growing conditions. The relationship between DBH and tree height was also strongly influenced by disturbance and elevation, with trees in less disturbed areas exhibiting greater and more regular growth potential. These findings emphasize the importance of forest conservation and/or protection, sustainable management, and reforestation efforts to maintain carbon sequestration capacity and ecosystem stability in Villa Consuelo, Biliran, Philippines.

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Credit Authorship Contribution Statement

Ruffy Rodrigo: Conceptualization, Data Collection, Writing – original draft, Resources, Methodology.

Randy Villarin: Conceptualization, Writing – original draft, Resources, Financial Administration.

Jay Mark Rosallosa: Conceptualization, Writing – review & editing.

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