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Forest Structure and Threatened Tree Species along Elevation and Disturbance Gradients in a Tropical River Watershed

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ABSTRACT

Understanding the relationship between forest structure, elevation, and species conservation status is vital for developing effective biodiversity and carbon management strategies. The current study examined 27 forest plots within the selected River Watershed in the Philippines to assess how disturbance and elevation influence tree diameter, height, basal area, aboveground biomass, and the occurrence of threatened species. Structural attributes varied widely across plots, with mean tree diameter ranging from 13.9 to 29.2 cm, and biomass spanning from approximately 3,100 kg to over 30,600 kg per plot. Undisturbed plots consistently exhibited higher basal area and biomass, reflecting greater structural integrity and ecological resilience. Conservation status data revealed that plots hosted up to six IUCN-listed threatened species and as many as 15 DAO 2017-11 classified species, with elevated and undisturbed plots supporting the greatest numbers. Regression models confirmed that elevation significantly influenced the richness of IUCN-listed species, while disturbance strongly predicted reductions in both biomass and basal area. Plots above 700 meters above sea level emerged as conservation hotspots, emphasizing the value of upland forests as refugia for threatened taxa.Visual analyses reinforced these findings: undisturbed plots had double the biomass and nearly twice the basal area compared to disturbed counterparts. These results align with regional and global literature, highlighting the urgency of protecting intact forest landscapes. By linking forest structure with conservation indicators, the study provides empirical evidence to inform sustainable forest management and biodiversity conservation in tropical ecosystems under increasing human pressure.

Keywords: *tropical river watershed, forest structure, biomass, conservation, disturbance, elevation.*

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1. Introduction

Forest ecosystems in tropical nations, such as the Philippines, are pivotal for providing essential ecological services, including biodiversity conservation, climate regulation, and carbon sequestration. However, these invaluable ecosystems face significant threats from land conversion, logging, and various human disturbances that jeopardize their integrity [1, 2]. Understanding the interplay between forest structure and conservation status is vital for developing effective forest management and protection strategies. Forest structure, which is characterized by metrics such as tree diameter, height, and basal area, serves as a useful proxy for assessing ecological integrity and habitat quality [3]. Further, complex forest structures typically support greater biomass and provide critical niches for diverse species, including those threatened with extinction [4]. However, there remains a paucity of studies directly linking forest structure with the presence of threatened species across varying disturbance gradients, particularly within the Philippine context [5].

The Amambahag River Watershed, located in Biliran Island, exemplifies a crucial ecological corridor that sustains biodiversity and underpins local livelihoods [6]. Unfortunately, parts of this landscape are undergoing increasing disturbances, which threaten its conservation potential.

This present study seeks to investigate how disturbance and elevation modulate forest structure, biomass, and the richness of conservation-listed species. By integrating field-based forest inventories with species-level conservation assessments, the research aimed to offer empirical evidence regarding the structural and biodiversity value of undisturbed forests [7]. Such research is crucial for assessing forest condition in relation to conservation importance at a local scale and will support informed decision-making focused on forest protection and sustainable management practices [8].

Hence, this research will address the interactions between elevation, disturbance, and forest metrics, not only enhancing our understanding of tropical forest ecosystems but is essential for calibrating conservation efforts within ecologically sensitive areas like the Amambahag River Watershed. Through this investigation, the findings will contribute to the broader body of knowledge that informs forest conservation strategies, which are imperative for safeguarding the rich biodiversity and ecosystem services that these forests provide [9].

2. Materials and Methods

3.1 Study Area

The study was situated in the Amambahag River Watershed on Biliran Island, located in the Eastern Visayas region of the Philippines (Figure 1).

This watershed encompasses a diverse range of montane and submontane forest ecosystems recognized for their rich biodiversity and ecological significance, particularly regarding flora and fauna typical of tropical mountainous regions [10]. Elevations within the watershed vary from approximately 500 to 900 meters above sea level (masl), resulting in a range of microclimates. The forest areas surveyed included both disturbed sites, characterized by logging or human access, and undisturbed patches, which provide critical habitats for various species. Such a mixed environment facilitates the evaluation of how anthropogenic pressures and elevation influence forest structure and conservation value, as human disturbances can significantly alter both biodiversity and ecosystem function [11].

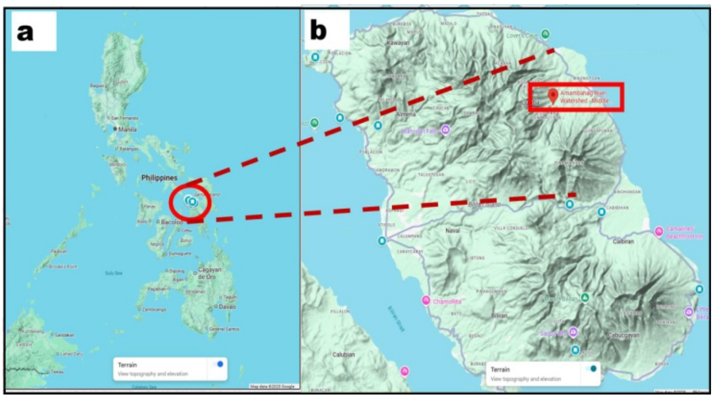

Figure 1. Location of the Amambahag River Watershed - Middle section in Culaba, Biliran Island, Philippines, shown within the national (a) and local (b) context using Google Maps Terrain View (2025).

3.2 Data Collection

A 2-km transect served as the baseline, with 20 m x 20 m quadrats established every 250 meters along the transect. A total of three transects was laid out, with a total of nine plots per transect. In each plot, adult trees with a diameter equal to or greater than 10 centimeters had measurements of diameters at breast height (DBH), merchantable height (MH), and total height (TH) were recorded (Figure 6). The approach complemented the Biodiversity Monitoring System (BMS) transects currently used by the Biodiversity Management Bureau (BMB) for faunal assessments. Each plot was placed to ensure adequate representation of both disturbed and undisturbed forest types, allowing for a comprehensive understanding of forest dynamics.

Further, key data collected for each tree included the DBH, total height, and species identity. To inform conservation assessments, the conservation status of each tree species was documented by consulting the International Union for Conservation of Nature (IUCN) Red List and the Philippine Department of Agriculture's DAO 2017-11 classification, which provides vital information regarding the risk of extinction and necessary conservation measures for the species [12].

3.3 Data Analysis

The analysis of forest metrics involved calculating the basal area (BA) using the formula: BA = pi (3.1416) x DBH/2)2, which provides a standard measure of tree stand density at the plot level (Estavillo et al., 2013). The biomass of trees (measured in kilograms) was estimated using a simplified allometric equation that incorporates DBH, height, and wood density; this estimation facilitates comparability across plots and aids in understanding carbon storage potential [13]. Data from each plot were summarized by averaging DBH, mean tree height, total basal area, total biomass, and the number of species designated as threatened under both the IUCN and DAO classifications.

In addition, to quantitatively assess the influence of disturbance and elevation on biomass, basal area, and species richness, linear models were employed. Furthermore, pie charts were generated to visually represent the distributions of conservation statuses across the recorded species, enhancing the interpretability of the data. All statistical analyses and visualizations were conducted using R statistical software, which is well-suited for ecological data analysis and graphical representation, allowing for robust conclusions regarding the ecological significance of the studied forest areas [14].

3. Results and Discussion

The forest structure and conservation value across the 27 analyzed plots in the Amambahag River Watershed exhibit a noteworthy variability that reflects both ecological and anthropogenic influences. The mean tree diameter at breast height (DBH) ranged from 13.9 to 29.2 cm with an overall average of 20.6 cm, while the mean tree height was approximately 9.15 meters, indicative of a relatively mature forest structure [15]. Basal area measurements spanned from 0.22 m^2 to 1.88 m^2 per plot (Table 1; Figure 2), supporting the notion of substantial ecological differences within the watershed [16]. Biomass estimates showed considerable variations, from about 3,125 kg to over 30,650 kg per plot. Importantly, undisturbed forest areas demonstrated higher basal area and biomass values due to reduced human impact, corroborating findings of studies that highlight intact forests as critical for biodiversity and carbon storage [17].

Moreover, conservation metrics reveal considerable variation in the number of IUCN-listed threatened species per plot, ranging from 0 to 6, with a mean of 2.63 [17]. The Philippine DAO 2017-11 classification, the plots supported up to 15 species classified as threatened or vulnerable, averaging 5.33 species per plot, aligning with patterns observed in other forest types where biodiversity declines with disturbance levels [18]. Higher elevation plots, peaking at 932 masl, reinforced the ecological importance of undisturbed mountainous forests, as they generally exhibited greater representation of conservation-relevant species. Such findings resonate with previous literature highlighting the correlation between elevation and biodiversity conservation potential [19, 20].

The multiple linear regression analyses conducted in this study elucidate significant relationships between forest disturbance, elevation, and key ecological metrics (Table 3). Notably, elevation positively influenced the number of IUCN-listed threatened species (Estimate = 0.00, 95% CI: 0.00–0.01, $p = 0.022$), signifying that higher elevations correlate with greater conservation value [21]. While the effect size was minimal due to the scale of elevation, the statistical significance highlights its ecological implications. Disturbance conditions emerged as strong predictors of total biomass and basal area. Specifically, undisturbed plots outperformed disturbed plots by an average of 7,522 kg in biomass (95% CI: 2,921–12,123 kg, $p = 0.002$) and 0.49 m^2 in basal area (95% CI: 0.22–0.77 m^2, $p = 0.001$), echoing findings from regional studies that connect forest disturbance with decreased structural integrity [22].

Illustrative evidence from boxplots indicates a marked biomass disparity between disturbed and undisturbed plots (Figure 3). The undisturbed forests frequently surpassed 30,000 kg in biomass, while disturbed areas typically remained below 15,000 kg [23].

This pattern emphasizes the significance of preserved forests for biomass storage, crucial for carbon sequestration and habitat maintenance, while also highlighting the detrimental impact of disturbance on forest structure. Basal area metrics further reinforced this argument, with undisturbed plots boasting a mean of approximately 1.1 m^2 compared to 0.6 m^2 in disturbed plots, highlighting degradation in structural capacity due to human interventions [24, 25].

Lastly, the positive correlation between elevation and the number of IUCN-listed threatened species per plot (Figure 4), observed through scatter plot analyses, affirms the role of montane forests as critical refugia for species of conservation concern within the Amambahag River Watershed. Higher elevation zones, particularly over 700 masl, showed increased counts of threatened species in less disturbed contexts, which aligns with ecological patterns documented in various tropical and subtropical forest studies [26, 27].

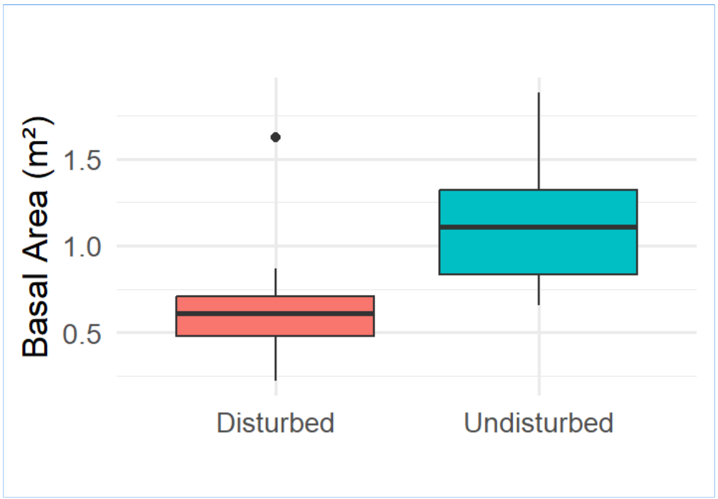

Figure 2. Basal area (m^2) comparison between disturbed and undisturbed plots

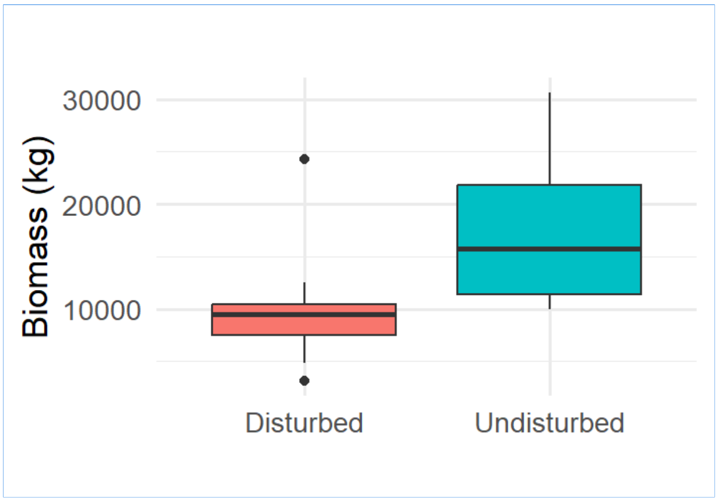

Figure 3. Aboveground biomass (kg) in disturbed and undisturbed plots.

Table 1. Summary of forest structural attributes and conservation indicators across 27 forest plots in the Amambahag River Watershed, Biliran Island. Values include mean DBH, tree height, basal area, biomass, elevation, disturbance type, and number of threatened species based on IUCN and DAO 2017-11 classifications.

Disturbance	Plot_No	Mean_DBH_cm	Mean_Height_m	Total_Basal_Area_m2	Total_Biomass_kg	Threatened_Species_IUCN	Threatened_Species_DAO	Elevation_masl
	1	23.7	11.3	0.507603	10000.99	0	0	680
	2	20.27027	8.216216	1.624675	24326.53	2	3	723
	3	23.92857	8.642857	0.669866	9493.108	3	3	916
	4	26.27273	10.72727	0.618815	10385.4	3	5	932
	5	25.26667	8.733333	0.866687	12480.76	4	1	927
	6	23.69231	9.538462	0.613239	9718.831	3	4	906
	7	17.4	8.84	0.740866	10532.9	5	7	824
Disturbed	8	14.14634	8.219512	0.677799	8529.188	4	11	401
	9	16.68182	9.590909	0.530222	8393	2	11	410
	10	18.27273	10	0.306698	4832.437	1	1	424
	11	13.92308	10.38462	0.220933	3124.667	0	0	407
	12	20	8.785714	0.520405	8153.493	2	2	450
	13	16.41176	8.823529	0.791681	10773.23	0	0	498
	14	18.11111	8.666667	0.301514	5222.387	0	0	468
	15	22	9.4	0.445321	6934.752	0	1	470
	16	19.45833	8.25	0.834957	11130.78	2	2	729
	17	17.02778	7.472222	0.949625	11464.18	0	2	754
	18	21.38889	8.777778	1.881029	30651.15	5	9	754
	19	16	8.891892	0.830794	11699.21	4	8	623
	20	20.425	9.55	1.419921	21459.51	5	15	689
Undisturbed	21	19.51351	8.27027	1.261349	16821.34	5	13	748
	22	17.65625	8.5625	0.991879	14615.12	5	9	689
	23	29.21053	10.47368	1.372955	22760.25	2	10	857
	24	24.08696	8.695652	1.302504	18435.93	6	6	902
	25	25.30769	9.076923	0.741494	10125.39	4	5	907
	26	25.66667	9.2	1.22907	25434.41	3	7	907
	27	20.66667	10.05556	0.658164	9985.434	1	9	473

Multiple linear regression models revealed important relationships between forest disturbance, elevation, and key ecological metrics. Elevation was significantly associated with the number of IUCN-listed threatened species (Estimate = 0.00, 95% CI: 0.00–0.01, $p = 0.022$), suggesting that higher elevation plots support greater conservation value. While the effect size is small due to the unit scale of elevation (masl), the trend remains statistically meaningful.

Disturbance condition was a significant predictor of both total biomass and basal area. Undisturbed plots had, on average, 7,522 kg more biomass (95% CI: 2,921–12,123 kg, $p = 0.002$) and 0.49 m^2 more basal area (95% CI: 0.22–0.77 m^2, $p = 0.001$) compared to disturbed plots. These findings highlight the structural degradation associated with disturbance. While disturbance had a positive effect on IUCN species count (Estimate = 1.03), it was not statistically significant ($p = 0.135$). The models explained 28–36% of the variance in the response variables, with the basal area model showing the highest adjusted R^2 (0.333).

Table 2. *Summary of multiple linear regression models assessing the effects of elevation and disturbance on (1) the number of IUCN-listed threatened tree species, (2) total aboveground biomass (kg), and (3) total basal area (m^2) across 27 forest plots in the Amambahag River Watershed. Significant predictors ($p < 0.05$) are highlighted in bold. Model outputs include estimated coefficients, 95% confidence intervals (CI), p-values, and both R^2 and adjusted R^2 values.*

	Threatened_Species_IUCN (1)			Total_Biomass_kg (2)			Total_Basal_Area_m² (3)		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	-0.78	-3.21 – 1.66	0.517	9526.78	6459.55 – 12594.00	**<0.001**	0.63	0.45 – 0.81	**<0.001**
Elevation masl	0.00	0.00 – 0.01	**0.022**						
Disturbance [Undisturbed]	1.03	-0.34 – 2.41	0.135	7521.78	2920.94 – 12122.62	**0.002**	0.49	0.22 – 0.77	**0.001**
Observations	27			27			27		
R^2 / R^2 adjusted	0.337 / 0.281			0.312 / 0.284			0.359 / 0.333		

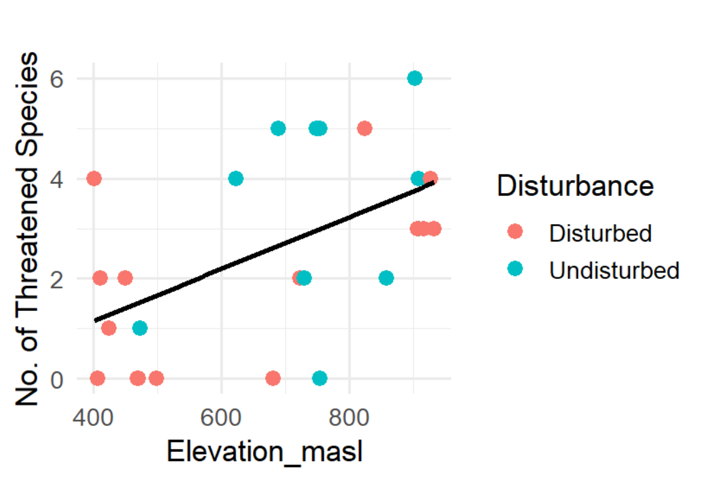

Figure 4. *Relationship between elevation and the number of IUCN-listed threatened species*

4. Conclusion

The study highlights the critical role of undisturbed and high-elevation forest areas in maintaining structural integrity and conservation value within the Amambahag River Watershed. Plots with minimal human disturbance exhibited significantly higher biomass and basal area, reinforcing the ecological function of intact forests as key carbon sinks and biodiversity reservoirs. Elevation also emerged as a strong ecological determinant, with higher-altitude plots supporting more IUCN-listed threatened species, particularly in less disturbed settings. These findings highlight the compounded effect of disturbance and elevation on forest health and conservation outcomes. Maintaining and protecting undisturbed upland forests is essential not only for sustaining carbon storage but also for safeguarding species of conservation concern. The integration of forest structure and species status data provides valuable insights for formulating targeted conservation strategies in tropical landscapes under increasing anthropogenic pressure.

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