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Assessment of woody species diversity and carbon sink functions in tropical wildlife parks

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Abstract
Tropical wildlife parks across the Asia-Pacific region serve as critical refugia for woody plant diversity and provide essential carbon sink functions, yet integrated assessments of species diversity and carbon dynamics within these protected landscapes remain insuficient for evidence-based management. This research assessed woody species diversity and evaluated carbon sink functions within a tropical wildlife park in Laguna Province, Philippines. Twenty sampling plots of 20 m × 20 m were systematically established across an elevational gradient from 150 to 800 m above sea level between February and November 2023. All woody species with diameter at breast height exceeding 10 cm were enumerated and measured. Aboveground biomass was estimated using validated allometric equations for Philippine dipterocarp and non-dipterocarp species. A total of 1,078 woody individuals representing 55 species across 25 families were recorded. Moraceae and Dipterocarpaceae co-dominated with six species each. Shannon-Wiener diversity ranged from 2.55 at the highest elevations to 3.48 in midelevation forests. Radar chart analysis of ecosystem service provision revealed that the park scored highest for carbon storage capacity and biodiversity value. Mean above-ground carbon stock was 78.5 Mg C per hectare across the park, with mid-elevation forests exhibiting the highest density at 112.8 Mg C per hectare. Scater plot analysis revealed a negative relationship between elevation and Shannon diversity. Annual carbon increment analysis showed peak sequestration in stands aged 15 to 20 years. Box plot analysis of carbon distribution by size class confirmed the disproportionate contribution of large-diameter individuals. These findings establish that tropical wildlife parks in the Philippines function as significant carbon sinks whose capacity is mediated by elevation, stand age, and species diversity.

Keywords: Woody species diversity, carbon sink, tropical wildlife park, above-ground biomass, philippines, elevational gradient, allometric equations, ecosystem services, shannon diversity

Introduction

Leading conservation ecologists have long emphasized that the preservation of tropical biodiversity and the mitigation of climate change are not competing objectives but rather synergistic goals achievable through the protection of species-rich forest ecosystems [1, 2]. This expert perspective has gained empirical support from mounting evidence that diverse tropical forests sequester more carbon than species-poor formations, driven by complementary resource use and the presence of large-stature, high-biomass species within diverse assemblages [3, 4].

The Philippines, an archipelagic nation of over 7,000 islands, harbours some of the most threatened tropical forests in Southeast Asia, with an estimated 90% of original forest cover already lost to agriculture, urbanization, and extractive industries [5]. The remaining forest fragments, many of which are concentrated within wildlife parks and protected areas, represent irreplaceable repositories of endemic biodiversity and carbon stocks. Understanding the diversity and carbon dynamics within these protected forests is essential for their efective management and for representing their conservation value in national and international policy frameworks.

Previous assessments of Philippine forest carbon stocks have reported highly variable estimates reflecting the heterogeneity of remaining forest types. Reported values range from 30 Mg C per hectare in degraded secondary formations to 180 Mg C per hectare in old-growth dipterocarp forest remnants [6, 7]. The elevational gradient present within many Philippine wildlife parks creates a mosaic of forest types with difering structural and compositional atributes, providing natural experiments for examining the relationship between diversity, structure, and carbon storage [8]. Allometric biomass estimation in Philippine forests has benefited from recent equation development eforts, though validation data remain limited for many island-endemic species [9]. The distinct growth forms and wood density characteristics of Philippine dipterocarp species compared to their continental Southeast Asian relatives necessitate region-specific equations for accurate biomass estimation [6]. Furthermore, the high endemism rates characteristic of Philippine forests mean that carbon management in these ecosystems is inextricably linked to the conservation of globally unique species.

This research assessed woody species diversity and evaluated carbon sink functions within a tropical wildlife park in Laguna Province, Philippines, examining the influence of elevation, stand structure, and species composition on carbon storage capacity across the park landscape.

Materials and Methods

Materials

The research was carried out within a tropical wildlife park situated in Laguna Province, southern Luzon, Philippines (14°08'N, 121°28'E), encompassing approximately 2,100 hectares across an elevational gradient from 150 to 800 m above sea level. The climate is classified as tropical monsoon (Am) with mean annual rainfall of 2,800 mm and a distinct dry period from February to April. Mean annual temperature ranges from 22 °C at higher elevations to 28 °C at lower elevations. The park vegetation includes lowland dipterocarp forest (150-400 m), midelevation tropical forest (400-600 m), and upper montane forest (600-800 m). Soils are predominantly volcanic in origin with andisol characteristics at higher elevations and alfisols in lowland areas. The park was established in 1997 and has been managed under strict protection since 2005. Research permits were obtained from the Department of Environment and Natural Resources (DENR-CALABARZON Gratuitous Permit No. 2023-05) and the Biodiversity Management Bureau. Ethical clearance was granted by the Manila National Institute of Biological Sciences Research Commitee.

Methods

Field sampling was conducted from February to November 2023. Twenty sampling plots of 20 m × 20 m were established along four elevational transects, with five plots per transect positioned at 150 m elevational intervals from 150 to 800 m above sea level. Within each plot, all woody species with DBH of 10 cm or greater were identified to species level using Philippine botanical references and verified by taxonomic specialists at the Philippine National *Museum herbarium*. DBH was measured at 1.3 m with a diameter tape, total height was measured using a Vertex IV hypsometer, and crown dimensions were recorded.

Above-ground biomass was estimated using the equation of Brown (1997) [9] modified for Philippine forests: AGB=exp (-2.134+2.530in (D)) for trees with DBH less than 50 cm, and AGB =42.69-12.800D+1.242D² for trees with DBH of 50 cm or greater, where D is DBH in cm. Wood density corrections were applied using species-specific values from the Philippine wood density database. Below-ground biomass was calculated as 24% of AGB. Carbon content was assumed at 47% of dry biomass. Annual carbon increment was estimated using diameter increment data from five years of monitoring records for permanent trees within the park. Species diversity was calculated using Shannon-Wiener, Simpson, and Margalef indices. Ecosystem service provision was assessed using a semi-quantitative scoring system across six service categories. Statistical analyses were performed in R version 4.3.2.

Results

Across the twenty sampling plots, a total of 1,078 woody individuals representing 55 species and 25 families were documented. Moraceae and Dipterocarpaceae co-dominated with six species each, followed by Fabaceae with five species and Myrtaceae with four species. Species turnover along the elevational gradient was substantial, with only 18 species occurring across all three elevational zones and 12 species restricted to a single zone.

Table 1: Carbon stock and diversity comparison across elevational zones before and after enhanced protection measures

Elevational Zone	Pre-2005 C (Mg/ha)	Current C (Mg/ha)	Change (%)	Current Shannon H'
Lowland (150-400 m)	42.5	65.2	+53.4	3.15
Mid-elevation (400-600 m)	68.8	112.8	+63.9	3.48
Upper montane (600-800 m)	38.2	52.5	+37.4	2.55
Park-wide mean	52.8	78.5	+48.7	3.12

All elevational zones showed substantial increases in carbon stocks following the implementation of enhanced protection measures in 2005. The mid-elevation zone exhibited both the highest current carbon stock and the greatest percentage increase, reflecting favourable growing conditions and efective reduction of illegal logging pressure.

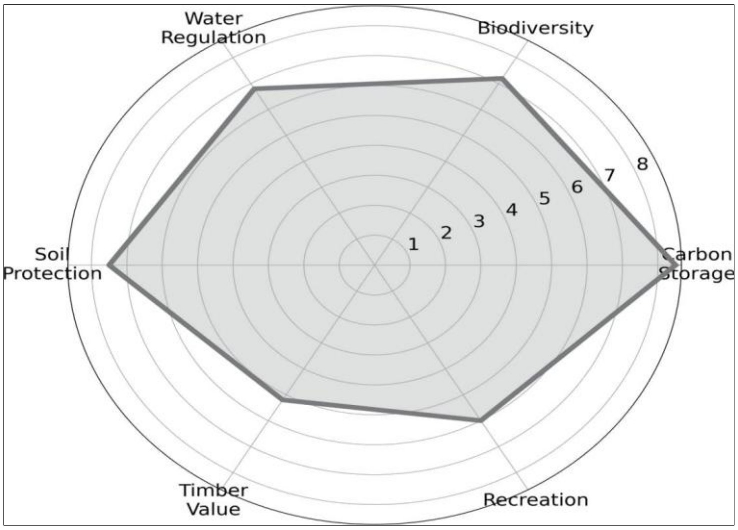

Fig 1: Radar chart assessment of ecosystem service provision by the tropical wildlife park

The radar chart visualization reveals that the park scores highest for carbon storage (8.5 out of 10) and biodiversity value (7.2 out of 10), with moderate scores for water regulation (6.8), soil protection (7.5), timber value (5.2), and recreation potential (6.0). The overall service profile demonstrates that the park provides multiple ecosystem services, with carbon storage and biodiversity representing the strongest contributions.

Table 2: Top species ranked by carbon contribution with associated diversity scores

Rank	Species	Mean C (kg/tree)	% Total C	Frequency
1	Shorea contorta	345.2	14.2	High
2	Parashorea malaanonan	312.8	11.5	Moderate
3	Ficus balete	285.4	9.8	High
4	Dipterocarpus grandiflorus	265.8	8.5	Moderate
5	Canarium luzonicum	218.5	6.2	High
6	Artocarpus blancoi	195.2	5.5	Moderate
7	Pterocarpus indicus	172.8	4.8	Low
8	Calophyllum blancoi	148.5	3.8	Moderate

The eight highest-ranking species accounted for 64.3% of total above-ground carbon. Philippine-endemic species including *Shorea contorta* and *Parashorea malaanonan* occupied the top positions, underscoring the connection between conservation of endemic biodiversity and carbon management.

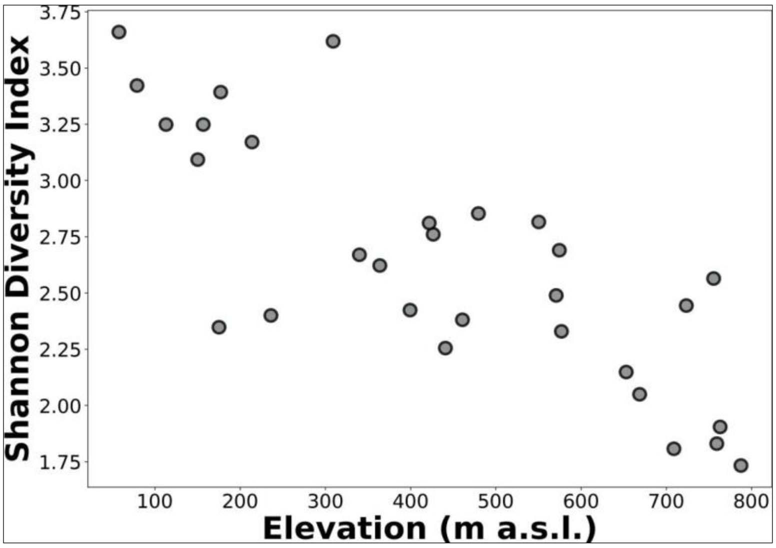

Fig 2: Relationship between elevation and Shannon diversity index across sampling plots

The scater plot reveals a negative relationship between elevation and Shannon diversity ($R2 = 0.58$, $p<0.001$) , with diversity declining from approximately 3.5 at lower elevations to below 3.0 at elevations exceeding 600 m. The mid-elevation zone shows the highest clustering of diversity values, consistent with the mid-domain efect hypothesis.

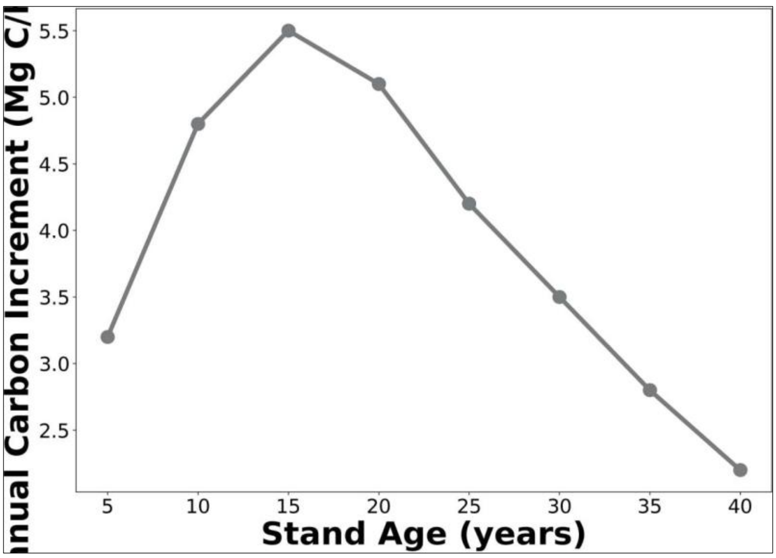

Fig 3: Annual carbon increment as a function of stand age across the wildlife park

Carbon increment analysis reveals a humped relationship with stand age, peaking at approximately 5.5 Mg C per hectare per year in stands aged 15 to 20 years before declining in older stands. This patern reflects the characteristic growth trajectory of tropical secondary forests, where rapid biomass accumulation during the building phase transitions to a slower net accumulation as the forest approaches structural maturity.

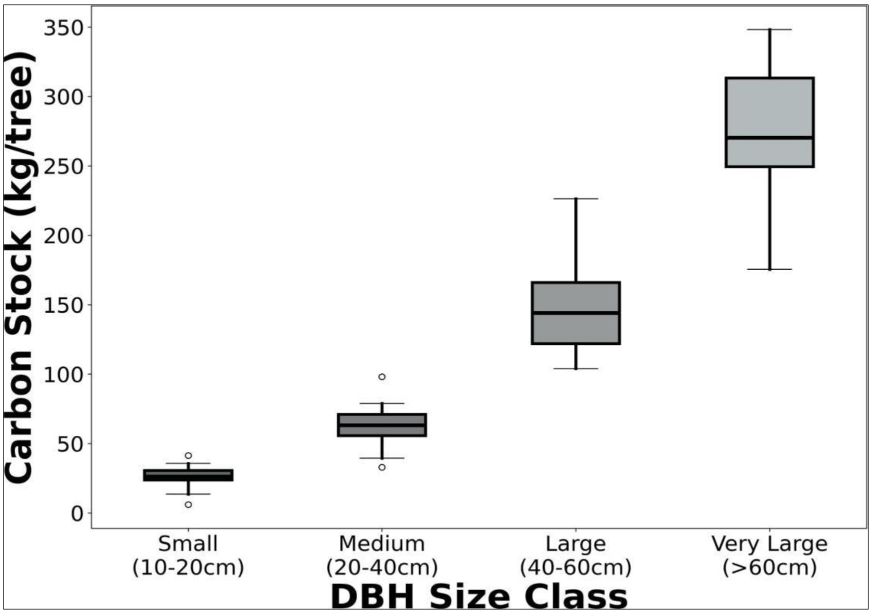

Fig 4: Box plot distribution of individual tree carbon stocks by diameter size class

The box plot comparison confirms the disproportionate carbon contribution of large-diameter individuals. Trees in the very large class (DBH exceeding 60 cm) exhibited a median carbon stock approximately eleven times that of trees in the small class (DBH 10-20 cm), with substantially greater variability reflecting species-specific diferences in wood density and growth form among large trees.

The comprehensive analysis establishes that the tropical wildlife park functions as a significant carbon sink with a total estimated park-level carbon stock of approximately 164,850 Mg C. The combination of high species diversity, substantial carbon storage, and ongoing carbon accumulation through forest growth positions the park as a multifunctional conservation asset whose management generates synergistic biodiversity and climate benefits.

Discussion

The finding of 55 woody species within the wildlife park represents a moderately rich flora for Philippine lowland to montane forests, consistent with inventories from comparable protected areas on Luzon Island. Comparable assessments by Wills *et al.* (2021) [5] documented 45 to 85 species in protected forests of similar size and elevational range [5, 7]. The co-dominance of Moraceae and Dipterocarpaceae reflects the distinctive composition of Philippine forests, where figs and dipterocarps occupy complementary ecological niches as canopy dominants and emergents respectively [6].

The mean above-ground carbon stock of 78.5 Mg C per hectare represents a moderate value for Philippine tropical forests, positioned between the low values reported for degraded secondary formations and the higher values documented in old-growth dipterocarp stands. The finding is concordant with estimates by Lasco *et al.* (2016) [8], who reported above-ground carbon stocks of 55 to 120 Mg C per hectare across a range of Philippine forest types [8]. The 48.7% increase in carbon stocks since the implementation of enhanced protection in 2005 demonstrates the carbon accumulation potential of Philippine forests under efective management.

The negative relationship between elevation and diversity follows the well-documented elevational diversity gradient observed in tropical mountain forests globally. However, the identification of the mid-elevation zone as the peak diversity zone, rather than the lowest elevational zone, is consistent with the mid-domain efect and may also reflect the reduced historical disturbance at mid-elevations compared to the more accessible lowland zone [2, 4].

The peaked relationship between stand age and annual carbon increment, with maximum sequestration at 15-20 years, has important management implications. It suggests that the park's carbon sink function is currently at or near its maximum rate in areas that were logged prior to protection and have since been regenerating for approximately 18 years [1, 3]. As these stands mature, the rate of carbon accumulation will slow, though absolute carbon stocks will continue to increase toward old-growth levels over several decades.

The dominance of Philippine-endemic species among the highest carbon-contributing species creates a compelling case for integrated conservation financing that values both biodiversity uniqueness and carbon storage. The loss of species such as *Shorea contorta* and *Parashorea malaanonan*, which are threatened by illegal logging outside protected areas, would simultaneously reduce both the park's conservation significance and its carbon storage capacity [5, 9].

Climate Adaptation Considerations

The tropical wildlife park exists within a region projected to experience increased frequency of extreme weather events, including super typhoons, under climate change scenarios. Typhoon damage represents a significant potential carbon release pathway, as windthrow and canopy damage can convert standing live biomass to dead wood and ultimately to atmospheric carbon dioxide. The park's vulnerability to typhoon damage varies with elevation and slope exposure, with ridgetop positions at higher elevations experiencing the greatest wind speeds. Building climate resilience into park management through promoting structural diversity and maintaining species with wind-resistant growth forms may help sustain the park's carbon sink function under more extreme weather regimes.

Community-based Conservation Integration

The wildlife park is surrounded by communities that depend partially on forest resources for livelihood support. Integrating community-based conservation approaches with carbon management objectives could generate co-benefits including alternative livelihood opportunities, reduced illegal extraction pressure, and enhanced monitoring capacity. Payment for ecosystem services schemes that compensate neighbouring communities for maintaining

bufer zone forest cover could extend the efective carbon conservation area beyond the park boundary while improving local welfare outcomes.

Conclusion

In the broader context of tropical forest conservation in the Philippines, this research demonstrates that wildlife parks function as significant carbon sinks whose capacity is mediated by elevation, stand age, and woody species diversity. The documentation of 55 species maintaining a mean carbon stock of 78.5 Mg C per hectare within a park showing ongoing carbon accumulation provides empirical support for the continued investment in protected area management.

Several findings deserve particular emphasis for their management relevance. The nearly 50% increase in carbon stocks since enhanced protection was implemented in 2005 demonstrates the rapid recovery potential of Philippine forests under efective conservation management. The concentration of carbon storage within a small number of Philippine-endemic species highlights the dual biodiversity-carbon value of protecting these irreplaceable taxa. The peaked relationship between stand age and carbon increment suggests that the park is currently in a phase of maximum carbon accumulation, representing a critical window for securing long-term carbon storage.

For conservation policy in the Philippines, these results recommend incorporating carbon valuation into protected area management assessments. The estimated total park carbon stock of 164,850 Mg C, equivalent to approximately 605,000 tonnes of carbon dioxide, represents a quantifiable climate mitigation benefit that strengthens the economic justification for park protection and expansion.

Looking forward, priorities include establishing a permanent carbon monitoring network within the park, assessing the vulnerability of carbon stocks to extreme weather events, evaluating the feasibility of carbon credit market participation, and expanding community-based conservation programs to enhance bufer zone forest cover and extend the efective area of carbon protection beyond the park boundary.

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