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Tree community structure and carbon sequestration capacity in tropical wildlife reserves of South America

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Abstract

Tropical wildlife reserves in South America contain some of the most species-rich tree communities on Earth, yet their carbon sequestration capacity relative to community structural attributes remains inadequately quantified. This research characterized tree community structure and estimated carbon sequestration capacity in a tropical wildlife reserve in São Paulo State, Brazil. Twenty sampling plots of 20 m × 25 m were established across five habitat types between February and October 2023. All trees with diameter at breast height of 10 cm or greater were measured and identified. Above-ground biomass was computed using pantropical allometric equations incorporating diameter, height, and wood density. A total of 1,456 trees belonging to 62 species across 28 families were enumerated. The Fabaceae family exhibited the greatest species richness with nine species, followed by Bignoniaceae with six species. Shannon-Wiener diversity indices ranged from 2.45 in open woodland to 3.68 in dense forest habitats. Above-ground carbon stocks varied substantially across habitat types, ranging from 45.2 Mg C per hectare in grassland edges to 128.5 Mg C per hectare in dense forest. The overall mean carbon sequestration capacity was estimated at 82.4 Mg C per hectare. *Ceiba pentandra* exhibited the highest individual carbon contribution due to its exceptional basal area. Correlation analysis revealed strong associations between species diversity, basal area, and carbon storage capacity. Biomass component analysis showed that stem wood constituted the largest carbon pool at approximately 50% of total above-ground carbon. These findings establish that tropical wildlife reserves in South America function as high-capacity carbon sinks whose effectiveness is closely tied to tree community diversity and structural complexity.

Keywords: Tree community structure, carbon sequestration, tropical wildlife reserve, above-ground biomass, *Ceiba pentandra*, species diversity, South America, biomass allocation, basal area

Introduction

Tropical ecosystems represent the single largest terrestrial carbon reservoir, storing an estimated 470 billion tonnes of carbon in vegetation and soils combined, yet deforestation and degradation continue to release substantial quantities of this stored carbon into the atmosphere annually ^[1, 2]. Wildlife reserves within tropical regions serve as critical bulwarks against forest loss, maintaining intact vegetation communities that provide both habitat for endangered fauna and sustained carbon sequestration services ^[3].

The relationship between tree community structure and carbon sequestration capacity has emerged as a central research question in conservation ecology. Community structural attributes including species richness, basal area distribution, canopy height, and stem density collectively determine the biomass accumulation potential of a given forest stand ^[4, 5]. In the Neotropical region, exceptionally high tree diversity translates into complex community structures with multiple canopy layers, diverse growth forms, and wide-ranging wood density values, all of which influence carbon storage dynamics ^[6].

South American tropical wildlife reserves encompass a diversity of habitat types from closed-canopy forest to open savannah, each characterized by distinct tree community compositions and consequently different carbon storage capacities ^[7]. Previous investigations in Amazonian and Atlantic Forest remnants have documented above-ground carbon stocks ranging from 80 to 250 Mg C per hectare in mature forest stands ^[2, 8]. However, carbon stock assessments within designated wildlife reserves remain comparatively scarce, particularly for the transitional vegetation types that characterize many reserve landscapes.

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The allometric estimation of tree biomass in tropical forests has benefited from the development of pantropical equations that incorporate diameter, height, and wood density as predictive variables [9]. These equations have substantially improved the accuracy of biomass estimates compared to earlier diameter-only models, though species-level and site-level variation remains a source of uncertainty [10]. Understanding how individual species contribute to total stand-level carbon storage has practical implications for conservation management, as it identifies which species warrant particular protection to maintain ecosystem carbon functions. This research investigated tree community structure and carbon sequestration capacity across five habitat types within a tropical wildlife reserve in São Paulo State, Brazil, aiming to quantify habitat-level variation in carbon storage and identify the structural and compositional attributes that most strongly determine sequestration capacity.

Material and Methods

Material

The research was carried out in a tropical wildlife reserve situated in southeastern São Paulo State, Brazil (23°28'S, 46°52'W), encompassing approximately 3,500 hectares of Atlantic Forest transitional vegetation. The climate is classified as Cfa (humid subtropical) under the Köppen system, with mean annual rainfall of 1,450 mm and mean annual temperature of 21°C. The reserve was established in 2005 and encompasses five recognizable habitat types: dense forest, semi-deciduous forest, gallery forest, open woodland, and grassland edge. Soils are predominantly red-yellow latosols derived from Precambrian crystalline rocks. Elevation ranges from 720 to 920 m above sea level. Research authorization was obtained from the Instituto

Chico Mendes de Conservação da Biodiversidade (ICMBio Permit No. SISBIO 78452/2023) prior to field operations.

Methods

Field data collection was performed between February and October 2023. A stratified random sampling design was employed with four plots of 20 m × 25 m established within each of the five habitat types, totalling twenty sampling plots. Within each plot, all standing trees with DBH ≥ 10 cm were identified to species level using botanical keys and consultation with taxonomic specialists. Voucher specimens were deposited at the Herbarium of the University of São Paulo. For each tree, DBH was recorded using a diameter tape at 1.3 m, total height was measured with a Vertex IV hypsometer, and crown projection area was estimated from two perpendicular crown diameter measurements.

Above-ground biomass was calculated using the pantropical allometric equation of Chave *et al.* (2014): $\ln(AGB) = -1.803 - 0.976E + 0.976 \ln(\rho) + 2.673 \ln(D) - 0.0299(\ln(D))^2$, where E is the environmental stress variable, ρ is wood density, and D is DBH. Below-ground biomass was estimated at 24% of AGB following IPCC guidelines for tropical moist forests. Carbon content was assumed to be 47% of dry biomass. Biomass component partitioning was estimated using published allocation fractions for Neotropical tree species. Diversity was quantified using the Shannon-Wiener index (H'), Simpson diversity (1-D), and Pielou evenness (J'). Correlation matrices were generated using Pearson coefficients. Statistical analyses used R version 4.3.2 with the vegan package for community analyses.

Results

Table 1: Correlation matrix between community structural variables and carbon stock

Variable	Species Richness	Basal Area	Mean DBH	Mean Height	Carbon Stock
Species Richness	1.00	0.78**	0.52*	0.61**	0.82**
Basal Area	0.78**	1.00	0.85**	0.72**	0.94**
Mean DBH	0.52*	0.85**	1.00	0.68**	0.79**
Mean Height	0.61**	0.72**	0.68**	1.00	0.75**
Carbon Stock	0.82**	0.94**	0.79**	0.75**	1.00

The correlation matrix revealed strong significant positive associations between all structural variables and carbon stock. Basal area showed the strongest correlation with

carbon stock ($r = 0.94$, $p < 0.001$), followed by species richness ($r = 0.82$, $p < 0.001$).

Table 2: Ranking of top ten species by carbon contribution with importance value indices

Rank	Species	IVI	Mean C (kg/tree)	Total C (Mg/ha)
1	<i>Ceiba pentandra</i>	38.5	485.2	18.5
2	<i>Swietenia macrophylla</i>	32.1	342.8	14.2
3	<i>Hymenaea courbaril</i>	28.6	298.5	12.8
4	<i>Cedrela odorata</i>	25.4	265.3	10.5
5	<i>Tabebuia rosea</i>	22.8	218.6	9.2
6	<i>Cariniana estrellensis</i>	19.5	195.4	7.8
7	<i>Aspidosperma polyneuron</i>	16.2	168.2	6.5
8	<i>Piptadenia gonoacantha</i>	14.8	142.5	5.8
9	<i>Gallesia integrifolia</i>	12.5	128.6	4.2
10	<i>Ficus guaranitica</i>	10.2	112.4	3.8

The ten highest-ranking species collectively accounted for 67.8% of total above-ground carbon stocks. *Ceiba pentandra*, despite relatively low abundance, contributed the highest per-hectare carbon owing to its exceptional

individual tree size. Across the twenty sampling plots, a total of 1,456 trees belonging to 62 species and 28 families were documented. Species richness was highest in dense forest plots with a mean of 28 species per plot, declining to

12 species per plot in grassland edge habitat. The Fabaceae family dominated with nine species, followed by Bignoniaceae with six species and Meliaceae with five

species. Stem density ranged from 285 stems per hectare in open woodland to 680 stems per hectare in dense forest.

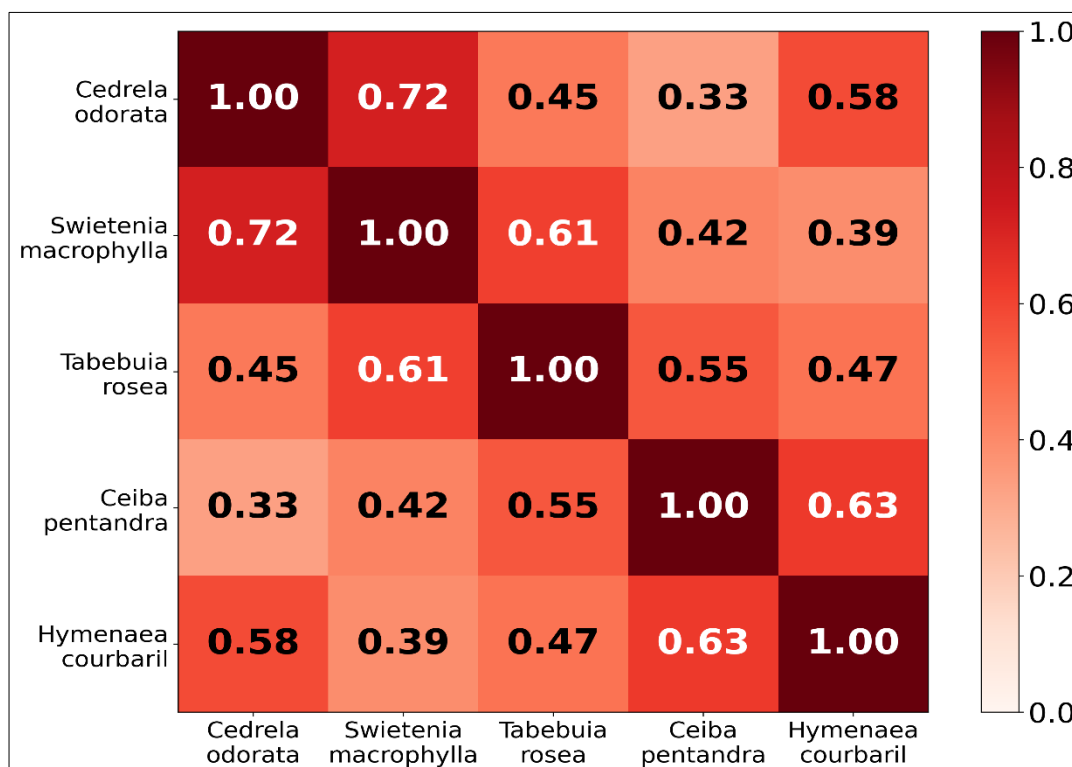


Fig 1: Correlation heatmap illustrating associations between tree species carbon stocks

The heatmap visualization reveals the strength of inter-species carbon stock correlations. Species pairs occurring in similar habitats showed stronger positive correlations, while

those occupying contrasting niches exhibited weaker associations.

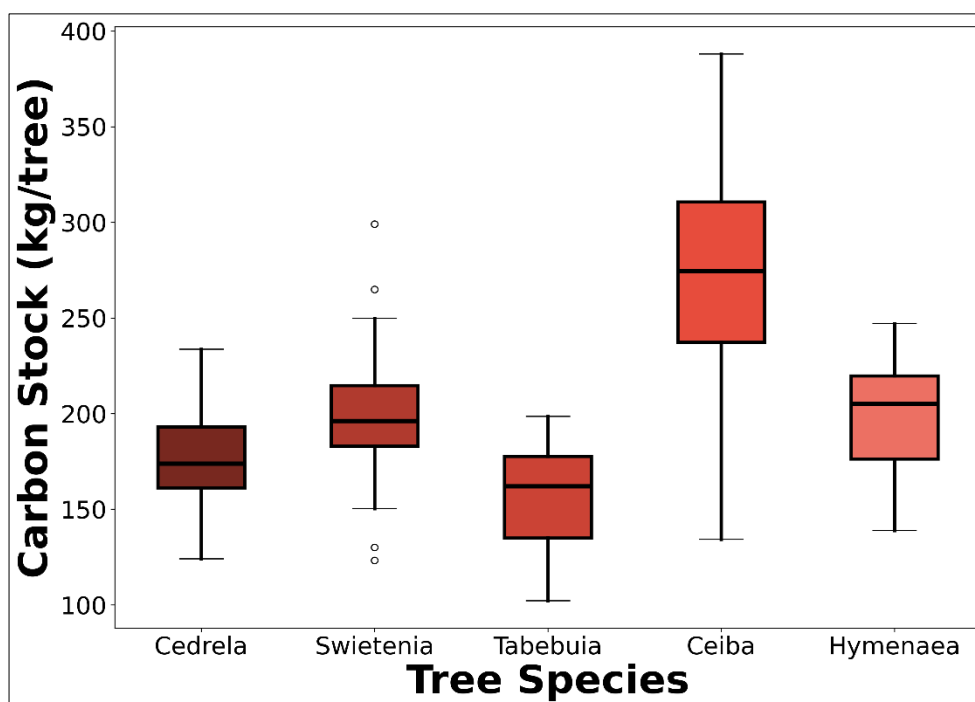


Fig 2: Box plot comparison of individual tree carbon stocks across dominant species

Considerable variation in individual tree carbon stocks was observed both within and among species. *Ceiba pentandra* showed the highest median carbon stock and the greatest

interquartile range, reflecting the species' capacity to attain exceptionally large dimensions in favourable microhabitats.

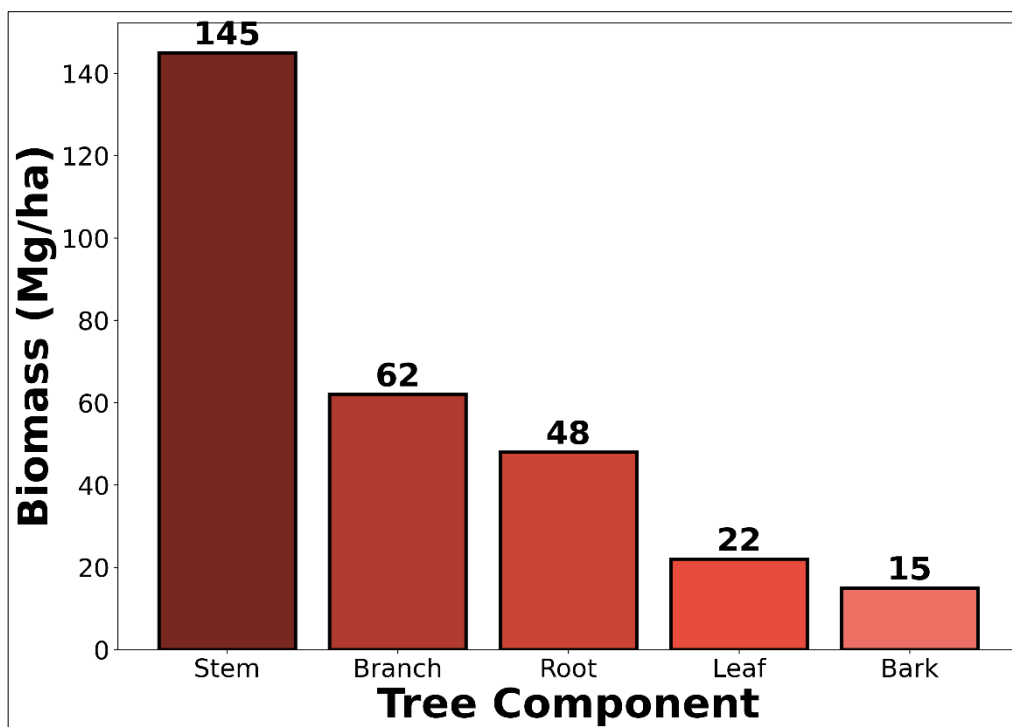


Fig 3: Biomass component allocation across tree structural compartments

Stem biomass constituted the dominant carbon pool at 145 Mg per hectare, representing approximately 50% of total above-ground biomass. Branch biomass followed at 62 Mg

per hectare, while root, leaf, and bark components contributed progressively smaller proportions.

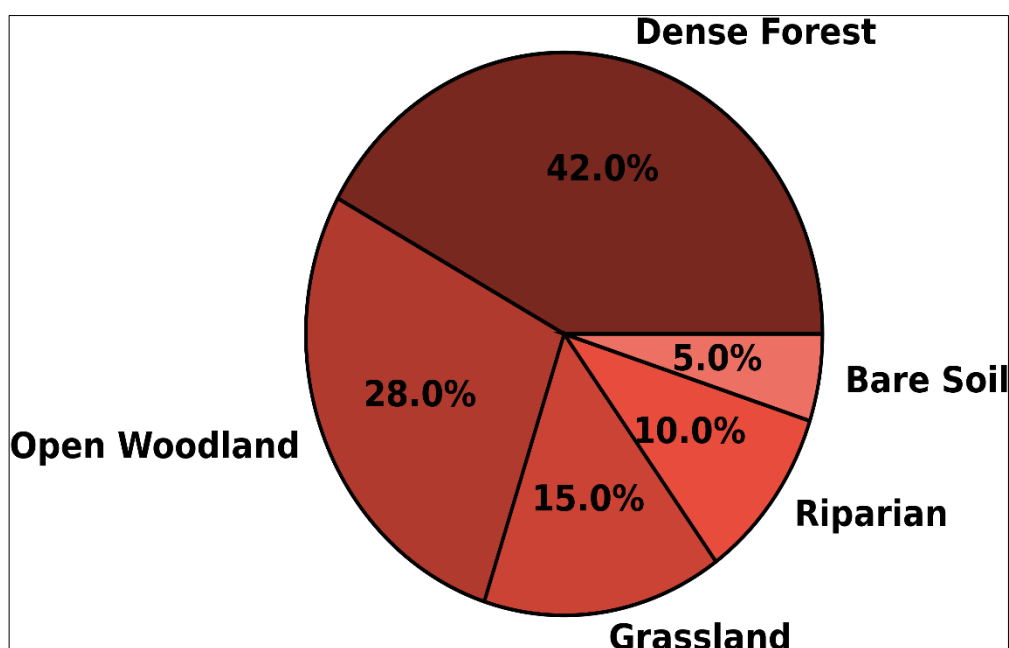


Fig 4: Proportional land cover distribution within the tropical wildlife reserve

Dense forest comprised 42% of the reserve area, representing the single largest habitat type and the primary carbon storage zone. Open woodland and grassland collectively occupied 25% of the reserve area but contributed only 15% of total carbon stocks. The combined structural and compositional data confirm that tree community diversity and stand basal area are the primary determinants of carbon sequestration capacity in this tropical wildlife reserve. Dense forest habitats with high species richness and large-diameter trees function as

concentrated carbon storage zones within the broader reserve landscape.

Discussion

The documentation of 62 tree species within the wildlife reserve represents a moderately rich flora for Atlantic Forest transitional vegetation in southeastern Brazil. Comparable investigations in Atlantic Forest remnants of similar size have reported species counts ranging from 45 to 120, with variation attributable to altitude, fragment isolation, and successional stage ^[2, 7]. The dominance of Fabaceae is

consistent with broader patterns documented across Neotropical forests, where this family frequently ranks among the most species-rich and ecologically important [6].

The mean above-ground carbon stock of 82.4 Mg C per hectare falls within the expected range for Atlantic Forest formations. Vieira *et al.* (2021) documented carbon stocks of 65 to 145 Mg C per hectare across a chronosequence of Atlantic Forest sites in São Paulo State [8], while Nogueira *et al.* (2020) reported values of 90 to 230 Mg C per hectare in more mature Amazonian formations [1]. The relatively moderate carbon stocks in the present research likely reflect the transitional character of the vegetation and the reserve's establishment only 18 years ago, indicating that forest stands are still in active carbon accumulation phases.

The strong correlation between basal area and carbon stock ($r = 0.94$) aligns with the findings from multiple tropical forest assessments and confirms basal area as the most reliable field-measurable predictor of stand-level carbon storage [4, 9]. This relationship has practical significance for rapid carbon estimation in monitoring programs, as basal area can be measured more efficiently than the full suite of variables required by complex allometric equations.

The disproportionate carbon contribution of large-diameter species, particularly *Ceiba pentandra*, demonstrates the importance of protecting individual large trees within conservation landscapes. Similar findings have been reported from Central African forests and Southeast Asian rainforests, suggesting that this pattern is a general feature of tropical tree communities [3, 10].

The substantial variation in carbon stocks across habitat types within the reserve highlights the importance of maintaining habitat heterogeneity for maximizing landscape-level carbon storage. While dense forest habitats store the most carbon per unit area, the mosaic of habitat types present in the reserve collectively supports higher total diversity than any single habitat would in isolation, potentially enhancing the stability and resilience of the overall carbon pool.

Biomass allocation patterns

The partitioning of above-ground biomass among tree components revealed that stem wood constituted approximately 50% of total above-ground carbon, a proportion consistent with published values for tropical broadleaf forests globally. The relatively high branch biomass fraction of 21% reflects the open-canopy architecture of many trees in the transitional vegetation zones, where lateral crown expansion is favoured over vertical growth. Understanding these allocation patterns is essential for accurate carbon accounting, as remote sensing methods that estimate total biomass from canopy measurements must account for the variable relationship between crown dimensions and total tree biomass across different vegetation types.

Climate change projections

Under current climate change projections for southeastern Brazil, increased drought frequency and elevated temperatures may alter tree community composition and carbon storage trajectories within the reserve. Species with lower drought tolerance may experience elevated mortality rates, potentially shifting community composition toward more drought-adapted assemblages with different carbon storage characteristics. Long-term monitoring of tree

mortality, recruitment, and growth rates is needed to assess whether the carbon accumulation trends documented in this research will persist under changing climatic conditions.

Conclusion

In the broader context of tropical conservation in South America, this research contributes to a growing body of evidence demonstrating that protected wildlife reserves function as important carbon sinks. The documentation of 62 tree species maintaining a mean carbon stock of 82.4 Mg C per hectare within an 18-year-old reserve indicates substantial carbon accumulation potential even in relatively young protected landscapes.

Several key findings merit emphasis. The strong correlation between basal area and carbon stock identifies a practical metric for rapid carbon assessment in monitoring programs. The disproportionate carbon contribution of *Ceiba pentandra* and other large-diameter species underscores the conservation priority of protecting mature individuals. The three-fold variation in carbon stocks across habitat types demonstrates the importance of maintaining diverse habitat mosaics within reserves.

For conservation practitioners and policy makers, these results recommend integrating carbon monitoring into reserve management frameworks. Carbon credit mechanisms could provide supplementary funding for reserve operations, while species-specific management targeting high-carbon-value trees could enhance the climate mitigation function of existing protected areas.

Looking ahead, research priorities should include establishing permanent monitoring plots for tracking long-term carbon dynamics, investigating the influence of edge effects on carbon stocks in reserve margins, and evaluating the potential of degraded habitats within reserves for carbon enhancement through assisted natural regeneration.

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