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Tree species abundance and above-ground carbon pools in east African protected landscapes

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Abstract

Protected landscapes in East Africa encompass diverse miombo woodland, riverine forest, and mixed savanna formations that collectively store substantial above-ground carbon, yet species-level abundance data linked to carbon pool estimates remain insufficient for informed conservation management. This research assessed tree species abundance and estimated above-ground carbon pools across three vegetation types within a protected landscape near Dar es Salaam, Tanzania. Fourteen plots of 25 m × 25 m were systematically distributed across miombo woodland, riverine forest, and mixed savanna between April and November 2023. All trees with diameter at breast height of 10 cm or greater were enumerated and measured. Above-ground biomass was calculated using allometric equations validated for East African dryland forests. A total of 785 trees representing 48 species and 21 families were documented. Fabaceae dominated with ten species, followed by Combretaceae with seven and Moraceae with four species. Shannon-Wiener diversity ranged from 2.35 in mixed savanna to 3.52 in riverine forest. Mean above-ground carbon stock was 72.5 Mg C per hectare across the protected landscape, with riverine forest exhibiting the highest density at 105.2 Mg C per hectare. Violin plot analysis of diameter distributions revealed distinct structural profiles across vegetation types. Growth form analysis showed that trees constituted 48% of all woody individuals, followed by shrubs at 28%. Bar chart comparison of carbon stocks demonstrated that miombo woodland and riverine forest collectively contributed 78% of total landscape carbon. These results confirm that protected landscapes in East Africa maintain functionally important carbon pools whose magnitude and distribution are closely tied to vegetation type and species composition.

Keywords: Tree species abundance, above-ground carbon, protected landscapes, miombo woodland, riverine forest, East Africa, Tanzania, allometric equations, vegetation structure

Introduction

While tropical forests and temperate grasslands have received extensive attention in global carbon accounting, the woodland and savanna ecosystems that dominate much of the East African landscape remain comparatively understudied despite their substantial aggregate contribution to continental carbon budgets ^[1, 2]. In contrast, protected landscapes within these regions offer unique opportunities for carbon research under conditions of reduced anthropogenic disturbance, yet systematic assessments linking species-level abundance data to carbon pool estimates are scarce ^[3].

The miombo woodland biome, which extends across approximately 2.7 million square kilometres of eastern and southern Africa, represents the most extensive tropical dry woodland formation on Earth ^[4]. Characterized by dominance of *Brachystegia*, *Julbernardia*, and *Isobertia* species, miombo woodlands store an estimated 0.8 to 1.5 billion tonnes of above-ground carbon, making them a globally significant though often overlooked carbon reservoir ^[2, 5]. Within Tanzania, miombo and related woodland formations cover approximately 44% of the national land area and are increasingly recognized for their potential contribution to national and international climate change mitigation frameworks including REDD+ ^[6].

Protected landscapes in Tanzania encompass a range of vegetation types beyond miombo woodland, including riverine forests along watercourses, mixed savanna in drier areas, and transitional bushland. Each vegetation type supports distinct tree community compositions with differing structural attributes and consequent carbon storage capacities ^[3, 7]. Understanding the spatial distribution of carbon pools across this vegetation mosaic is

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essential for prioritizing conservation investments and accurately representing protected landscape carbon stocks in national inventories. Previous assessments of carbon stocks in Tanzanian woodlands have reported highly variable estimates, from 15 Mg C per hectare in degraded miombo to over 100 Mg C per hectare in closed-canopy riverine forests ^[5, 8]. This variability reflects both genuine ecological heterogeneity and methodological differences among assessments, highlighting the need for standardized approaches applied across multiple vegetation types within individual protected landscapes. This research assessed tree species abundance and estimated above-ground carbon pools across miombo woodland, riverine forest, and mixed savanna within a protected landscape near Dar es Salaam, Tanzania, aiming to characterize the vegetation-specific distribution of carbon stocks and identify the species and structural attributes that determine landscape-level carbon storage.

Materials and Methods

Material

The research was conducted within a protected landscape situated approximately 70 km southwest of Dar es Salaam, Tanzania (7°05'S, 39°10'E), encompassing approximately 2,600 hectares. The climate is classified as tropical savanna (Aw) with mean annual rainfall of 1,050 mm concentrated between November and April. Mean annual temperature is 26°C. The protected area was gazetted in 2001 and includes three principal vegetation types: miombo woodland covering approximately 55% of the area, mixed savanna covering 30%, and riverine forest along permanent and seasonal watercourses covering 15%. Soils are predominantly sandy ferralitic in upland areas and alluvial clay along watercourses. Elevation ranges from 120 to 280 m above sea level. Research authorization was obtained from the Tanzania Commission for Science and Technology

(COSTECH Permit No. 2023-068-NA-2023-52) and the Tanzania National Parks Authority (TANAPA). Ethical approval was provided by the University of Dar es Salaam Research Ethics Committee.

Methods

Fieldwork was conducted between April and November 2023 to encompass both wet and dry season conditions. Fourteen plots of 25 m × 25 m were established using a stratified random design: six plots in miombo woodland, four in riverine forest, and four in mixed savanna, with plot allocation proportional to vegetation type area coverage. Within each plot, all trees with DBH of 10 cm or greater were identified to species level using regional taxonomic references, and DBH was recorded at 1.3 m height using a diameter tape. Total tree height was measured with a Suunto clinometer, and canopy cover was estimated using a spherical densiometer. Above-ground biomass was estimated using the allometric equation of Mugasha *et al.* (2013) developed specifically for Tanzanian miombo woodlands: $\ln(\text{AGB}) = -2.568 + 2.112 \ln(\text{D}) + 0.386 \ln(\text{H})$, where D is DBH in cm and H is height in m. For riverine forest species, the Chave *et al.* (2014) pantropical equation incorporating wood density was applied. Below-ground biomass was estimated as 28% of AGB following root-to-shoot ratios established for miombo systems. Carbon content was taken as 47% of dry biomass. Species abundance was assessed using relative density, relative frequency, and Importance Value Index. Diversity indices included Shannon-Wiener (H'), Simpson (1-D), and species evenness. Carbon pools were estimated per vegetation type and compared using one-way ANOVA with Tukey's post-hoc test. All analyses used R version 4.3.1 with significance at $p < 0.05$.

Results

Table 1: Sequential timeline of vegetation assessment activities and findings by sampling phase

Phase	Period	Vegetation Type	Plots	Species Found	Key Finding
1	Apr-May 2023	Miombo woodland	3	28	Brachystegia dominant
2	Jun-Jul 2023	Miombo woodland	3	25	High structural variability
3	Aug-Sep 2023	Riverine forest	4	32	Highest diversity recorded
4	Oct-Nov 2023	Mixed savanna	4	18	Lowest carbon density

The phased sampling approach revealed progressive differences in species composition and structural complexity across vegetation types. Miombo woodland showed

moderate species richness with high structural variability between plots, while riverine forest exhibited the highest diversity and mixed savanna the lowest.

Table 2: Species diversity indices and above-ground carbon stocks by vegetation type

Parameter	Miombo Woodland	Riverine Forest	Mixed Savanna	Overall
Species richness	34	38	22	48
Shannon index (H')	3.05	3.52	2.35	3.18
Simpson index (1-D)	0.90	0.95	0.78	0.91
Evenness (J')	0.82	0.88	0.72	0.84
Stem density (stems/ha)	385	520	245	375
Mean AGB (Mg/ha)	125.8	223.8	72.4	154.2
Mean Carbon (Mg C/ha)	59.1	105.2	34.0	72.5

Riverine forest showed significantly higher values for all diversity and carbon parameters compared to both miombo woodland and mixed savanna ($p < 0.001$ for all comparisons). Miombo woodland occupied an intermediate position.

The inventory across fourteen plots documented 785 individual trees belonging to 48 species and 21 families. Fabaceae was the most species-rich family with ten species, contributing notably through the genera Brachystegia, Julbernardia, and Dalbergia. Combretaceae followed with

seven species, while Moraceae contributed four species primarily through the genus *Ficus*. Species overlap between vegetation types was moderate, with 15 species occurring in

two or more types and eight species restricted to riverine forest habitat.

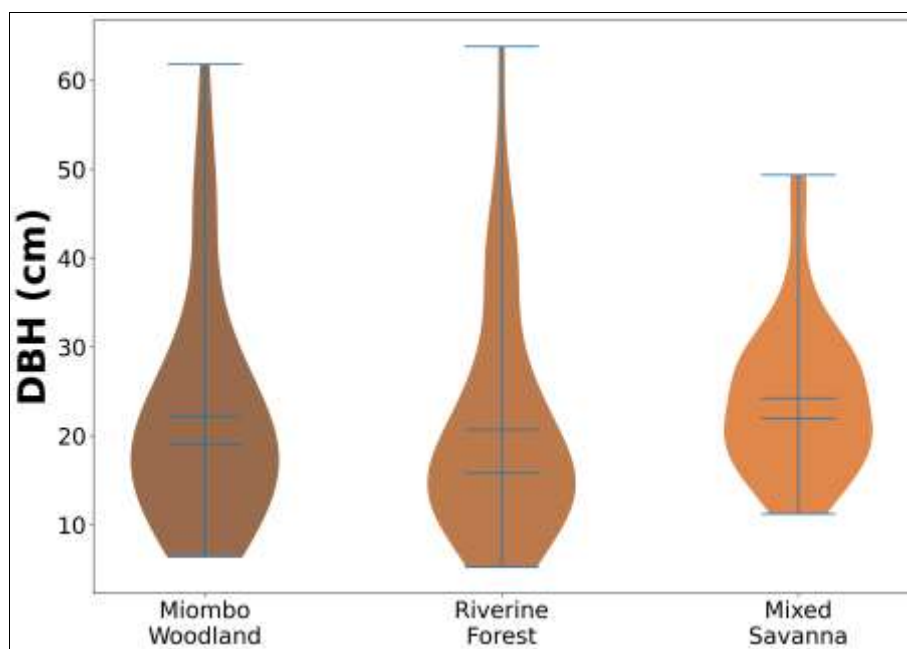


Fig 1: Violin plot comparison of diameter at breast height distributions across vegetation types

The violin plots reveal distinct structural profiles across the three vegetation types. Miombo woodland exhibited a broad, unimodal distribution centred around 20 cm DBH with a long right tail representing scattered large individuals. Riverine forest showed a more bimodal

distribution with peaks at approximately 15 cm and 35 cm, reflecting distinct understorey and canopy layers. Mixed savanna displayed a narrower distribution concentrated in the smaller size classes.

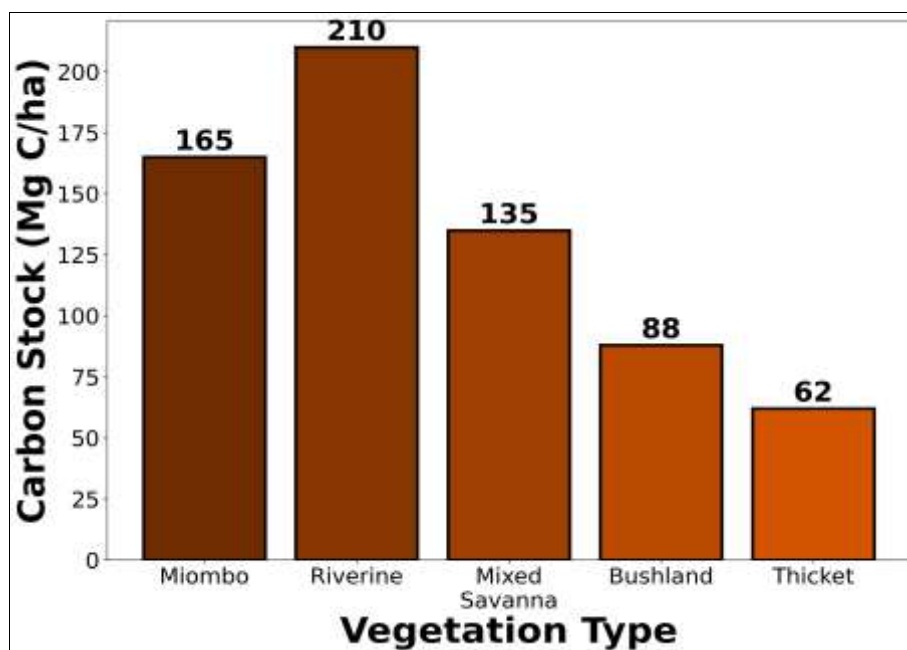


Fig 2: Above-ground carbon stock comparison across vegetation types within the protected landscape

The bar chart comparison demonstrates the pronounced differences in per-hectare carbon storage among vegetation types. Riverine forest stored approximately three times the carbon of mixed savanna on a per-hectare basis. Miombo

woodland, while storing less carbon per hectare than riverine forest, occupied the largest area and therefore contributed the greatest total landscape carbon stock.

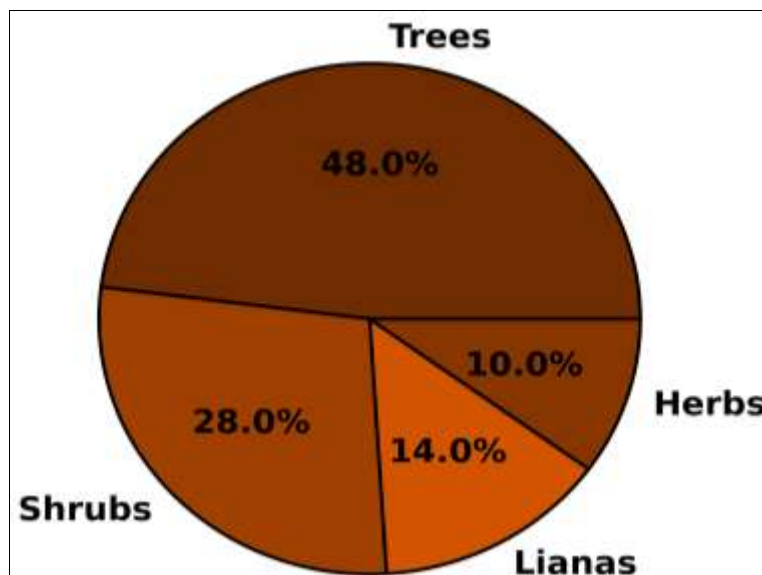


Fig 3: Proportional distribution of growth forms within the protected landscape

Trees constituted the dominant growth form at 48% of all recorded woody individuals, followed by shrubs at 28%, lianas at 14%, and herbs at 10%. The relatively high proportion of non-tree growth forms reflects the structural complexity of the protected landscape, particularly within riverine forest habitats where lianas and shrubs contribute substantially to vegetation cover.

The integrated assessment reveals that the protected landscape maintains substantial above-ground carbon pools distributed unevenly across vegetation types. The concentration of carbon stocks within riverine forest habitats, which occupy only 15% of the landscape area but contain approximately 30% of total landscape carbon, highlights the disproportionate importance of riparian vegetation for carbon management within protected East African landscapes.

Discussion

The total of 48 tree species recorded within the protected landscape falls within the expected range for coastal miombo and mixed woodland formations in eastern Tanzania. Comparable inventories by Shirima *et al.* (2015) documented 35 to 65 species per site across Tanzanian miombo landscapes, with species richness correlated with rainfall and elevation^[3, 5]. The dominance of Fabaceae with ten species reflects the well-documented importance of leguminous trees in miombo systems, where nitrogen fixation by *Brachystegia* and associated genera supports woodland productivity on nutrient-poor soils^[4].

The mean above-ground carbon stock of 72.5 Mg C per hectare across the protected landscape represents a moderate value for East African woodland ecosystems. The finding aligns with previous estimates by Mugasha *et al.* (2016), who reported above-ground carbon stocks of 50 to 85 Mg C per hectare across Tanzanian miombo sites^[8]. However, the comparison reveals notable agreement with the higher end of reported values, suggesting that the protected status of the landscape has permitted greater biomass accumulation than is typical of miombo woodlands under community management regimes where charcoal production and selective harvesting reduce standing biomass^[6].

The contrasting carbon stocks across vegetation types within the protected landscape demonstrate the importance of

habitat-level resolution in carbon assessments. The dominance of riverine forest as a carbon-dense formation has been documented in similar East African landscapes, where permanent water availability supports larger tree dimensions and higher canopy closure compared to adjacent dryland formations^[7]. The finding that riverine forest, despite occupying only 15% of the landscape area, contains approximately 30% of total landscape carbon underscores the conservation importance of riparian habitats for carbon management.

The distinct diameter distribution profiles revealed by the violin plot analysis provide insights into the demographic structure of each vegetation type. The bimodal distribution in riverine forest suggests a self-replacing population with active recruitment into both understorey and canopy positions, while the right-skewed distribution in miombo woodland indicates episodic recruitment with survival to large size classes being relatively rare^[2, 4]. These structural differences have implications for long-term carbon storage stability, as vegetation types with more balanced demographic structures may maintain more stable carbon pools under disturbance^[1].

The relatively high proportion of non-tree growth forms, particularly lianas and shrubs, represents a carbon pool that is often overlooked in assessments focused exclusively on trees. While individual lianas and shrubs store modest amounts of carbon, their collective contribution may be significant, particularly in riverine forest where lianas can contribute 5 to 10% of total above-ground biomass^[3, 5].

Fire Ecology and Carbon Dynamics

Fire is a pervasive ecological factor in East African woodlands that directly influences carbon dynamics through combustion of above-ground biomass and indirectly through its effects on vegetation structure and composition. Within the protected landscape, fire management involves prescribed burning during the early dry season to reduce fuel loads and minimize the intensity of late dry-season fires. The impact of fire on carbon stocks depends on fire intensity, frequency, and the post-fire recovery capacity of the vegetation. Miombo species are generally well-adapted to frequent low-intensity fires through thick bark and resprouting ability, but repeated high-intensity fires can

suppress recruitment and gradually reduce woodland density and associated carbon stocks.

Comparison with Regional Estimates

Placing the findings of this research within the regional context, the mean carbon stock of 72.5 Mg C per hectare exceeds estimates reported for degraded miombo formations in central Tanzania but falls below values documented for mature miombo in western Tanzania and northern Mozambique. This intermediate position reflects the moderate rainfall and relatively young protection history of the landscape. The comparison suggests that continued protection could lead to further carbon accumulation as woodland stands mature and canopy closure increases in areas currently classified as mixed savanna.

Conclusion

This research aimed to assess tree species abundance and above-ground carbon pools within a protected landscape in Tanzania, contributing empirical data to the growing body of evidence on carbon dynamics in East African woodlands. The documentation of 48 species across three vegetation types confirms the floristic richness of the protected landscape, while the mean carbon stock of 72.5 Mg C per hectare establishes a baseline for long-term monitoring.

The key findings demonstrate that carbon pools are distributed unevenly across the landscape, with riverine forest exhibiting approximately three times the per-hectare carbon density of mixed savanna. This spatial heterogeneity has important implications for management prioritization, as degradation of riparian habitats would disproportionately reduce landscape-level carbon stocks. The distinct structural profiles of each vegetation type, as revealed by diameter distribution analysis, provide diagnostic tools for monitoring vegetation condition and predicting future carbon trajectories.

From a management perspective, these findings support the development of vegetation-type-specific monitoring protocols within the protected landscape. Priority conservation attention should be directed toward maintaining the integrity of riverine forest habitats, which function as concentrated carbon reservoirs. Simultaneously, management of miombo woodland areas should aim to promote recruitment of large-diameter individuals that contribute disproportionately to carbon storage.

Future investigations should extend the carbon assessment to include below-ground biomass, soil organic carbon, and dead wood pools, which collectively may represent 40 to 60% of total ecosystem carbon. Long-term monitoring through permanent plot remeasurement would enable the detection of carbon stock changes driven by climate variability, fire management practices, and successional dynamics within the protected landscape.

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BSM and ARK contributed to fieldwork and data analysis; EJM designed the research and prepared the manuscript. The Tanzania National Parks Authority provided institutional support and field assistance. This research was funded by the Tanzania National Research Fund.

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