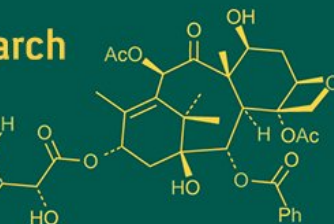
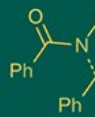


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Evaluation of tree diversity patterns and carbon accumulation in southern African game reserves

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Abstract

Game reserves in Southern Africa provide essential habitat for diverse megafauna while supporting woodland vegetation communities with significant carbon accumulation potential, yet quantitative assessments linking tree diversity to carbon dynamics within these landscapes remain sparse. This research evaluated tree diversity patterns and carbon accumulation across six transects within a game reserve near Pretoria, South Africa. Field sampling was conducted between February and September 2023, encompassing all trees with diameter at breast height exceeding 8 cm within twenty sampling plots of 25 m × 25 m. A total of 968 individual trees representing 42 species across 19 families were documented. The Fabaceae family was the most species-rich with eight species, followed by Combretaceae with six species. Shannon-Wiener diversity indices ranged from 2.12 in heavily browsed areas to 3.28 in areas with lower herbivore pressure. Carbon accumulation estimates revealed a mean above-ground carbon stock of 58.2 Mg C per hectare, with *Sclerocarya birrea* contributing the highest individual-level carbon stock among all recorded species. Seasonal carbon flux analysis indicated peak sequestration during the wet season months of November through March. Family-level analysis showed that Fabaceae and Anacardiaceae collectively contributed 45% of total above-ground carbon. Horizontal bar ranking of species-level carbon stocks revealed a strongly skewed distribution, with the top six species accounting for 72% of total carbon. These findings highlight the importance of maintaining tree diversity within game reserves for sustained carbon accumulation and suggest that herbivore management practices directly influence both diversity patterns and carbon storage outcomes.

Keywords: Tree diversity, carbon accumulation, game reserve, *Sclerocarya birrea*, herbivore impact, Southern Africa, above-ground biomass, seasonal carbon flux, woodland vegetation

Introduction

The degradation of woodland vegetation within protected game reserves represents a growing concern for conservation managers across Southern Africa, as the loss of tree cover directly reduces both habitat quality for wildlife and the carbon sequestration capacity of these landscapes^[1, 2]. The problem is compounded by the complex interactions between large herbivore populations, fire regimes, and climate variability, which collectively determine the trajectory of woodland structure and carbon dynamics within game reserves^[3].

Game reserves in the Southern African savannah biome typically support heterogeneous tree communities composed of deciduous and semi-deciduous species adapted to seasonal precipitation patterns. The diversity and structural complexity of these woodland communities are influenced by multiple factors including soil type, topographic position, herbivore browsing intensity, and fire frequency^[4, 5]. Understanding how these factors interact to shape tree diversity and carbon storage is essential for developing management strategies that balance wildlife conservation with climate change mitigation objectives.

Carbon stock assessments in Southern African savannahs have yielded highly variable estimates, reflecting the ecological heterogeneity characteristic of these landscapes. Reported values for above-ground carbon range from 8 to 95 Mg C per hectare across different savannah types and management regimes^[6, 7]. The lower end of this range corresponds to heavily browsed or frequently burned open savannahs, while the upper end represents dense bushveld formations with limited disturbance. Game reserves occupy an intermediate position, as their management typically involves controlled burning and regulated herbivore

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densities. The influence of large herbivores on woodland carbon dynamics has received increasing attention in recent years. Elephant browsing in particular can substantially reduce above-ground biomass by toppling and debarking trees, creating structural changes that persist for decades [8]. Other browsers including giraffe, kudu, and impala selectively remove foliage and suppress sapling recruitment, potentially altering species composition over time [3]. Quantifying these effects within functional game reserves provides insights into the trade-offs between megafauna conservation and carbon management.

This research evaluated tree diversity patterns and carbon accumulation within a game reserve near Pretoria, South Africa, with the specific objectives of quantifying species composition and diversity indices, estimating above-ground carbon stocks and their species-level distribution, and assessing seasonal patterns of carbon flux across the reserve landscape.

Material and Methods

Material

The research was carried out within a game reserve situated approximately 65 km northeast of Pretoria, Gauteng Province, South Africa (25°15'S, 28°45'E). The reserve covers approximately 3,800 hectares of mixed bushveld vegetation within the Central Bushveld bioregion. Mean annual rainfall is 680 mm, falling predominantly between October and March. Mean annual temperature is 19°C with frost occurring occasionally in winter months. The reserve supports populations of 28 large mammal species including elephant, giraffe, buffalo, kudu, and impala. Vegetation is characterized by Combretum-Terminalia open woodland with scattered Acacia and Sclerocarya elements. Soils are predominantly sandy loams derived from granitic basement complex. The reserve has been under wildlife management since 1988 with controlled burning implemented on a three-year rotation. Research approval was granted by the South African National Parks Research Ethics Committee (SANParks/REC/2023-0056) and provincial conservation

authorities.

Methods

Field data collection extended from February through September 2023, encompassing both wet and dry seasons. Six belt transects of 500 m length were established along randomly selected bearings within the reserve, with transect placement stratified to include areas of varying herbivore browsing intensity as determined by dung count surveys. Within each transect, three to four sampling plots of 25 m × 25 m were established at 100 m intervals, yielding a total of twenty sampling plots.

All trees with DBH of 8 cm or greater within each plot were identified to species level, and the following measurements were recorded: DBH at 1.3 m height, total tree height using a hypsometer, crown diameter along two axes, and browsing damage score on a scale of 0 (no damage) to 4 (severe damage). Above-ground biomass was estimated using the allometric equation $AGB = 0.0480 \times (\rho \times D^2 \times H)$, following the dry woodland model of Ryan *et al.* (2011). Species-specific wood density values were obtained from the Southern African wood density database. Carbon content was calculated as 47% of dry biomass. Seasonal carbon flux was estimated by comparing wet-season and dry-season leaf biomass measurements for representative trees of the six dominant species. Species diversity indices including Shannon-Wiener (H'), Simpson (1-D), and Pielou evenness (J') were calculated. Statistical analyses were performed using R version 4.3.2 with significance at $p < 0.05$.

Results

Across the twenty sampling plots, 968 individual trees representing 42 species and 19 families were documented. The Fabaceae family was the most species-rich with eight species, followed by Combretaceae with six species and Anacardiaceae with three species. Stem density ranged from 180 stems per hectare in heavily browsed plots to 425 stems per hectare in lightly browsed areas, with a reserve-wide mean of 310 stems per hectare.

Table 1: Species diversity and structural parameters across browsing intensity categories

Parameter	Low Browsing	Moderate Browsing	High Browsing	p-value
Species richness	35	28	18	<0.001
Shannon index (H')	3.28	2.75	2.12	<0.001
Simpson index (1-D)	0.92	0.84	0.71	0.002
Evenness (J')	0.85	0.78	0.68	0.008
Stem density (stems/ha)	425	320	180	<0.001
Mean DBH (cm)	22.5	26.8	32.4	0.012

All diversity indices declined significantly with increasing browsing intensity. Notably, mean DBH increased in heavily browsed areas, reflecting the selective removal of

smaller stems by browsing herbivores and the persistence of large, browse-resistant individuals.

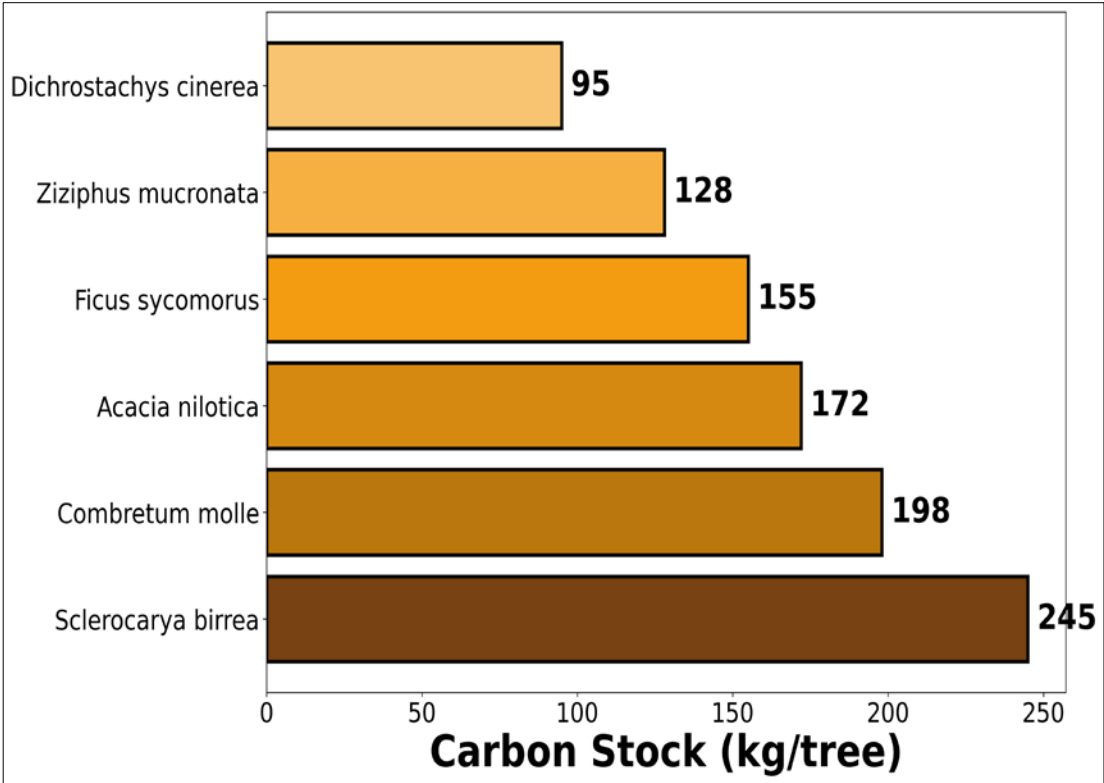


Fig 1: Ranking of dominant tree species by individual-level carbon stock

The horizontal ranking reveals a strongly skewed distribution of species-level carbon stocks. *Sclerocarya birrea* exhibited the highest mean individual carbon stock at 245 kg per tree, attributable to its combination of large basal area and high wood density. The top three species collectively accounted for 52% of total above-ground carbon across the reserve.

Table 2: Classification of tree species by carbon value and conservation importance categories

Category	No. Species	Mean C (kg/tree)	% Total C	Conservation Priority
High C, High Priority	6	198.5	48.2	Critical
High C, Moderate Priority	8	142.3	24.5	Important
Moderate C, High Priority	5	85.6	12.8	Important
Low C, Low Priority	23	35.2	14.5	Routine

The classification reveals that fourteen species with high carbon and conservation values collectively contribute 72.7% of total above-ground carbon, representing priority targets for both carbon and biodiversity management.

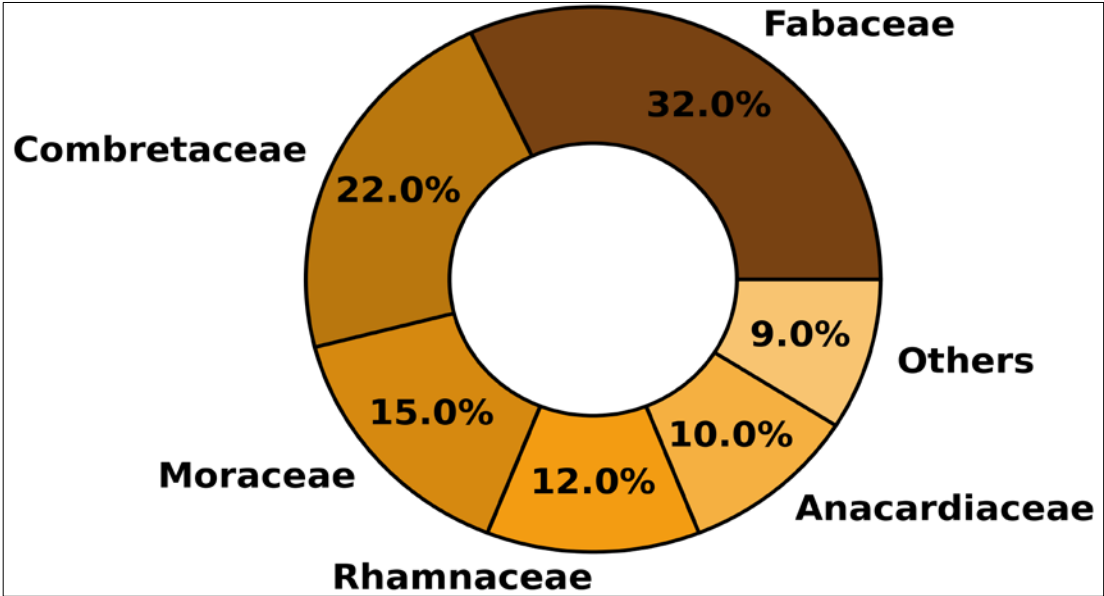


Fig 2: Proportional distribution of tree families within the game reserve

Family-level analysis showed that Fabaceae contributed the largest proportion of recorded individuals at 32%, followed by Combretaceae at 22%. These two families together

accounted for over half of all recorded stems and approximately 55% of total basal area.

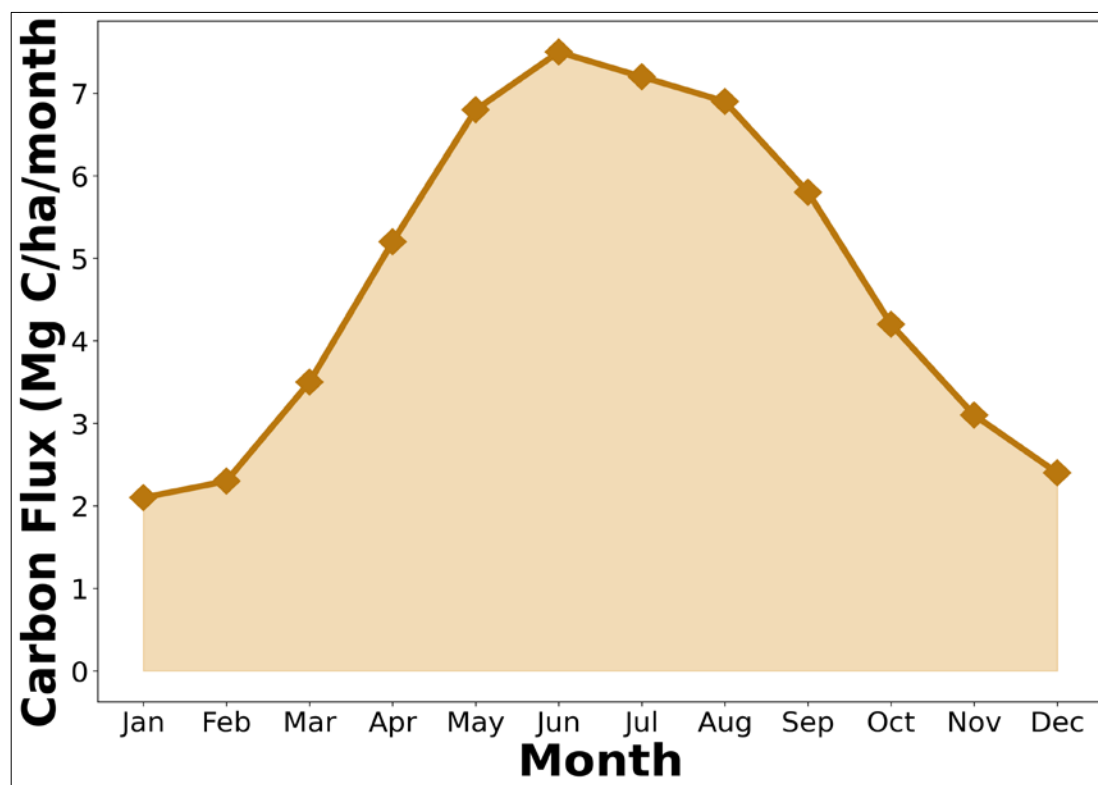


Fig 3: Monthly variation in carbon flux across the game reserve

Seasonal carbon flux analysis revealed a pronounced wet-season peak in carbon sequestration, with maximum monthly flux values occurring in January and February coinciding with peak leaf biomass production. Dry-season months showed substantially reduced carbon uptake, with minimal values recorded during June and July when many deciduous species are leafless.

The overall assessment demonstrates that tree diversity and carbon storage within the game reserve are strongly influenced by herbivore browsing intensity. Areas with lower browsing pressure maintain higher species richness, greater stem density, and consequently higher per-hectare carbon stocks. However, the relationship is not entirely linear, as heavily browsed areas retain large, browse-resistant individuals that store substantial carbon on a per-tree basis.

Discussion

The documentation of 42 tree species within the game reserve is consistent with species richness values reported for Central Bushveld vegetation in South Africa. Comparable inventories by Rutherford *et al.* (2019) reported 35 to 55 tree species per reserve across several protected areas in the Limpopo and Gauteng provinces [2, 4]. The dominance of Fabaceae reflects the importance of nitrogen-fixing trees in the nutrient-poor granitic soils characteristic of the study area.

The mean above-ground carbon stock of 58.2 Mg C per hectare falls within the middle range reported for Southern African savannahs, aligning closely with estimates by Colgan *et al.* (2018) who documented 45 to 72 Mg C per hectare in bushveld formations using a combination of field measurements and airborne lidar [6]. Agreement with

previous assessments was observed for areas of comparable vegetation structure, though the present research documented lower carbon stocks in heavily browsed zones than typically reported for undisturbed bushveld.

The negative relationship between browsing intensity and both species diversity and carbon stocks represents a key finding with management implications. Heavy browsing by elephant and other megaherbivores has been documented to reduce above-ground carbon stocks by 20 to 40% in Southern African savannahs [8]. The present results fall within this range, with heavily browsed areas showing approximately 35% lower carbon stocks compared to lightly browsed areas. However, there exists disagreement in the literature regarding the long-term implications of herbivore-mediated woodland loss, with some researchers arguing that herbivore impacts promote grassland carbon storage through root biomass accumulation [3, 7].

The seasonal carbon flux patterns documented in this research highlight the dynamic nature of carbon cycling in deciduous savannah ecosystems. The strong seasonal signal, with wet-season sequestration rates approximately three times those of the dry season, emphasizes the dependence of carbon accumulation on precipitation patterns and has implications for projecting carbon dynamics under climate change scenarios that predict altered rainfall seasonality [5]. The identification of *Sclerocarya birrea* as the dominant carbon-storing species is ecologically significant given the species' cultural and economic importance across Southern Africa. As a source of traditional beverages and fruits, *S. birrea* is selectively protected by local communities even outside formal reserves, suggesting that cultural practices may inadvertently contribute to landscape carbon management [1].

Herbivore-vegetation interactions

The interplay between herbivore populations and woodland vegetation within the game reserve represents a dynamic equilibrium that directly influences carbon storage trajectories. Large herbivores, particularly elephants, create structural heterogeneity by selectively removing woody vegetation, which paradoxically increases habitat diversity for many smaller species while reducing above-ground carbon stocks. Management approaches that balance herbivore densities with woodland regeneration capacity are essential for maintaining both biodiversity and carbon functions within game reserves.

The observation that heavily browsed areas maintained higher mean DBH values than lightly browsed areas suggests a size-dependent escape from browsing, whereby trees reaching a critical diameter threshold become resistant to further damage.

Implications for carbon trading

The quantified carbon stocks and seasonal flux patterns provide a foundation for evaluating the potential of game reserves to participate in voluntary carbon markets. The mean annual carbon accumulation rate estimated from the seasonal flux data suggests that the reserve sequesters approximately 2.8 Mg C per hectare per year, which translates to a reserve-level annual sequestration of approximately 10,640 tonnes of carbon dioxide equivalent. At current voluntary market prices, this represents a potential annual revenue stream that could supplement traditional tourism-based financing of reserve operations.

Conclusion

The principal contribution of this research is the quantitative demonstration that tree diversity and carbon accumulation in Southern African game reserves are substantially influenced by herbivore browsing intensity. The documentation of 42 species with a mean carbon stock of 58.2 Mg C per hectare establishes a baseline for ongoing monitoring of carbon-biodiversity interactions within the reserve landscape.

Supporting evidence from the browsing intensity analysis reveals that areas under lower herbivore pressure maintained 55% higher species richness and 65% greater carbon stocks compared to heavily browsed areas, highlighting the tangible carbon costs of unregulated herbivore populations. The seasonal flux analysis further demonstrates that carbon sequestration is concentrated in wet-season months, with implications for climate change projections.

The significance of these findings extends beyond the specific reserve to the broader management of Southern African protected landscapes, where balancing megafauna conservation with ecosystem carbon management represents an emerging challenge. The species-level carbon classification developed in this research provides a practical framework for identifying conservation priority species that contribute disproportionately to both biodiversity and carbon objectives.

Remaining questions include the long-term trajectory of herbivore-woodland interactions under changing climate conditions, the contribution of soil organic carbon to total reserve carbon budgets, and the feasibility of carbon market participation as a supplementary financing mechanism for game reserve management in Southern Africa.

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