

A COST-BENEFIT ANALYSIS OF CARBON SEQUESTRATION IN TREES IN THE NORTHERN PART OF ADAMAWA STATE

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ABSTRACT

Trees are among the most effective and readily deployable natural mechanisms for removing atmospheric carbon dioxide, yet the economic value of this service remains poorly quantified for the savanna woodlands of northern Adamawa State, Nigeria. This study estimated the above-ground biomass (AGB), below-ground biomass (BGB), total biomass and carbon storage of sixteen dominant tree entries recorded across a GIS- and remote-sensing-supported field inventory of the study area and evaluated the monetary cost and benefit of the resulting carbon sequestration. AGB per tree was derived using the pantropical allometric model of Chave et al. (2014), which combines diameter at breast height, total height and species wood density; BGB was estimated using a root-to-shoot ratio of 0.24, and carbon content was derived by applying the IPCC (2006) default carbon fraction of 0.47 to total dry biomass. A total of 3,219 trees across the sixteen entries were assessed, yielding an estimated 4,621 tons of total biomass, 2,172 tons of stored carbon, and 7,964 tons of carbon dioxide equivalent (CO₂e). On average, a single tree in the inventory sequesters approximately 2.47 tons of CO₂e, valued between US\$17 and US\$59 (~~≈~~₦23,639-~~₦~~81,046) depending on the carbon-price scenario applied, with a base-case value of approximately US\$24.74 per tree. At a conservative voluntary-carbon-market price of US\$10/tCO₂e, the entire inventory represents a stored-carbon asset worth approximately US\$79,636 (~~≈~~₦108,703,496), against an estimated establishment and protection cost of US\$451-US\$14,486, producing benefit-cost ratios ranging from 5.5 to 176.7. *Anogeissus leiocarpus*, *Khaya senegalensis* and *Vitellaria paradoxa* together accounted for approximately 70% of total carbon stock. The results demonstrate that conserving existing savanna trees in northern Adamawa State is a highly cost-effective climate mitigation strategy and provide a replicable framework for scaling carbon stock assessment across the wider Sudano-Sahelian belt of the state.

Keywords: Above-ground biomass, Allometric model, Carbon stock, Cost-benefit analysis, Savanna woodland

1. INTRODUCTION

Forests and woodlands are among the most effective and immediately deployable mechanisms for removing carbon dioxide from the atmosphere, storing an estimated hundred billion tons of carbon in living biomass worldwide. As global efforts to limit warming intensify, growing attention has turned to the role that even non-forest tree cover such as parklands, woodlands and scattered savanna trees can play in national and sub-national carbon budgets. Unlike many industrial abatement options, tree-based carbon sequestration is comparatively low-cost, delivers substantial co-benefits for soil, water, and biodiversity, and can be implemented and monitored at the community level, making it particularly attractive for resource-constrained regions such as northern Nigeria (Samuel, Peter & David. 2024).

Adamawa State lies at the southern fringe of the Sudano Sahelian ecological belt, and its northern Local Government Areas (Maiha Mubi North, Mubi South, Michika and Madagali) are increasingly exposed to the pressures of rainfall variability, land degradation and vegetation loss that have driven Nigeria's participation in the Africa-wide Great Green Wall initiative. The savanna and parkland trees that remain across this landscape are therefore not merely a source of fuelwood, fodder, shea butter and other non-timber products, they are a standing carbon asset whose sequestration value has rarely been quantified for the state, let alone translated into a cost benefit framework that policymakers, development partners or communities can act upon.

Despite this methodological progress, published, economically grounded estimates of tree carbon stock for northern Adamawa State remain scarce. Existing regional studies have tended to focus on gazette forest reserves further south within the state (Samuel, Peter & David. 2024) or on vegetation-cover change more broadly (Gadiga, 2015), leaving the carbon and monetary value locked up in the everyday savanna and parkland trees of the northern Local Government Areas undocumented. This gap limits the ability of the state and its development partners to make an evidence-based case for tree conservation, to access results-based carbon finance and to weigh the true opportunity cost of converting wooded land to other uses.

This study addresses this gap by using tree inventory of sixteen dominant tree entries in the northern part of Adamawa State to estimate above-ground biomass (AGB), below-ground biomass (BGB), total biomass, carbon stock and carbon dioxide equivalent (CO₂e), and by conducting a cost-benefit analysis of the resulting carbon sequestration service. Specifically, the study sought to:

- i. Estimate the above-ground and below-ground biomass of the selected tree species using validated allometric models.
- ii. Determine total biomass, carbon stock and CO₂ equivalent for each species and for the inventory.
- iii. Estimate the average amount of carbon sequestered per tree and its monetary value.
- iv. Conduct a cost-benefit analysis comparing the value of sequestered carbon with representative tree establishment and protection costs; and

1.1 The Concept of Carbon Sequestration in Trees

Carbon sequestration refers to the capture and long-term storage of atmospheric carbon dioxide, primarily through photosynthesis, in living plant tissue, dead organic matter and soil. In trees, carbon accumulates in several pools above ground biomass (stems, branches, bark, and foliage), below ground biomass (roots), litter, and soil organic carbon of which the present study addresses the first two, which together typically account for much of the carbon stored in a woody savanna ecosystem. Because half of dry plant biomass is carbon by mass (IPCC, 2006), tree biomass is the standard entry point for estimating both the physical carbon stock of a landscape and, by extension, its monetary value under carbon-pricing schemes.

1.2 Allometric Biomass Models

Because felling trees to weigh their biomass directly (destructive sampling) is costly, time-consuming, and ecologically undesirable at scale, biomass is universally estimated indirectly through allometric equations relating easily measured tree dimensions principally diameter at breast height (DBH) and total height of tree, biomass were established from a smaller, destructively sampled reference dataset. Chave *et al.* (2014) developed one of the most widely applied pantropical models by combining DBH, height and wood specific gravity, demonstrating that including height alongside diameter and wood density improves accuracy relative to diameter-only models across contrasting forest and woodland types. At a more regional scale, Sawadogo *et al.* (2010) developed species-specific allometric models for eleven dominant woody species of the Sudanian savanna-woodland of Burkina Faso several of which, including *Anogeissus leiocarpa* and *Pterocarpus erinaceus*, are shared with the present study area using destructive sampling of over 4,750 trees, underlining both the applicability of the savanna allometric approach to the present dataset and the continuing value of developing further site-specific models

within Nigeria itself. Below-ground biomass is more rarely measured directly because root excavation is highly labor-intensive.

Studies therefore apply a root to shoot ratio derived from meta-analyses such as Cairns *et al.* (1997), who reported a mean ratio of 0.24-0.26 kilograms of root biomass per kilogram of shoot biomass across tropical forest biomes, a value subsequently adopted as a default by the IPCC (2006) Guidelines for National Greenhouse Gas Inventories.

1.3 Economic Valuation and Cost-Benefit Analysis of Carbon Sequestration

Once a physical carbon stock has been estimated, it can be translated into a monetary value by applying a price per ton of CO₂ equivalent, typically drawn from voluntary carbon market (VCM) transaction data, compliance-market prices, or estimates of the social cost of carbon. Nature-based and forestry credits originating in Africa have historically traded at a discount to global averages and to engineered-removal credits, with recent market analyses placing typical 2026 nature-based credit prices in the range of roughly US\$7 to US\$24 per ton of CO₂e, within a wider global blended range spanning single digits to over US\$100 per ton for high-durability removals (Sylvera, 2026). A cost-benefit analysis compares this monetized benefit against the cost of establishing and/or protecting the trees responsible for it; restoration-economics studies report an extremely wide range, from as little as US\$14-185 per hectare for farmer-managed natural regeneration or basic forest-management interventions in Africa, up to several thousand dollars per hectare for fully commercial afforestation, reflecting differences in labor cost, survival rates and the intensity of aftercare (Trillion Trees/WCS, 2022). As one Africa Union Great Green Wall coordinator has observed, a tree can be planted for a dollar, but it cannot be grown to maturity for a dollar a distinction this study's cost-benefit framework explicitly accounts for through low, mid, and high-cost scenarios.

1.4 Related Studies in Adamawa State and Northern Nigeria

Within Adamawa State, Gadiga (2015) used multi-temporal satellite imagery to monitor vegetation-cover dynamics in the Mubi region, confirming both the Sudan-savanna character of the local vegetation and its sensitivity to progressive cover loss. At the forest-reserve scale, Samuel, Peter & David. 2024 quantified carbon stock in the Karlahi Forest Reserve, Adamawa State, using a comparable allometric approach, providing one of the few published, locally grounded benchmarks against which the savanna and parkland tree carbon values estimated in the present study can be compared. Together, these studies establish both the methodological

precedent and the pressing rationale for extending carbon stock assessment and, crucially, its economic valuation to the wider tree resource of northern Adamawa State.

3. STUDY AREA

The study covers the northern part of Adamawa State, in the north-eastern geopolitical zone of Nigeria, broadly encompassing the Mubi North, Mubi South, Michika, Madagali and Hong Local Government Areas, centered on Mubi town (10°16'N, 13°16'E). The area lies along the state's eastern border with the Republic of Cameroon and is flanked by the Mandara Mountains, giving it a distinctive relief that ranges from lowland plains to highland zones of 400-1,500 m above sea level Figure 1 (Gadiga, 2015).

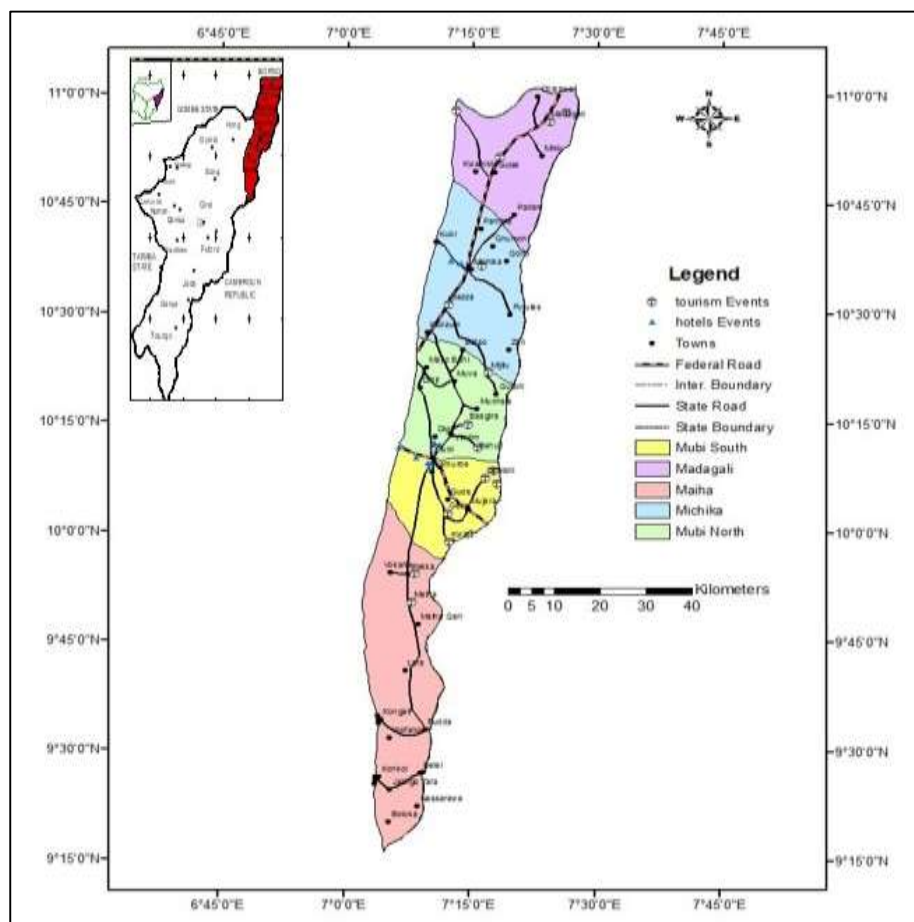


Figure 1: Study Area

Source: ADSU GIS Lab

The climate follows the tropical wet-and-dry (Kappen Aw) regime typical of the wider Sudano-Sahelian belt, with a single rainy season running from May to September and a pronounced dry season from October to April, during which the Harmattan brings cool, dust-laden winds from the Sahara. Mean annual rainfall in the Mubi region is estimated at 900-1,050 mm (Gadiga, 2015), while temperatures across the state range from as low as 15°C during the Harmattan to over 40°C in the hottest pre-rains months (Adamawa State Bureau of Statistics, 2026). Vegetation across the study area falls within the Sudan savanna and Sub-Saharan/Northern Guinea savanna transition zones, characterized by an open tree-and-shrub layer over a grass understory, interspersed with the parkland species. This combination of climatic marginality, proximity to the advancing edge of Sahelian degradation, and a tree resource under continuous pressure from farming, fuel wood collection and settlement expansion makes northern Adamawa State a policy relevant setting in which to quantify, and place an economic value on, the carbon sequestration service that its remaining trees provide.

2. MATERIALS AND METHODS

2.1 Research Design and Data Source

This study adopts a quantitative, allometric-modelling design built on a field tree inventory conducted across the northern Adamawa study area. Tree stems were identified to species, and diameter at breast height (1.3 m) and total height were recorded for qualifying stems within GPS-referenced sampling locations distributed across the woodland and parkland strata identified from satellite-based land-cover classification. For the present analysis, records were aggregated to species level, yielding the total number of trees enumerated and the mean DBH and mean height recorded for each of sixteen tree entries (Table 1); these species-level summary statistics form the direct empirical basis for the biomass and carbon calculations that follow.

2.2 Above-Ground Biomass (AGB) Estimation

AGB per tree was estimated using the pantropical allometric model of Chave et al. (2014):

$$AGB = 0.0673 \times (\rho D^2 H)^{0.976}$$

Where AGB is above-ground biomass in kilograms,
 ρ is species wood density in g/cm³,
D is diameter at breast height in centimetres, and

H is total tree height in meters

This model was selected because it incorporates height alongside diameter and wood density, which improves accuracy relative to diameter-only models and is considered appropriate across the range of woodland and dry-forest conditions represented in the study area (Chave et al., 2014).

Because destructive sampling of the sixteen tree entries inventoried was outside the scope of this study, species wood-density values were obtained primarily from the Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009) and the African Wood Density Database (Carsan et al., 2012), cross checked against Nigerian and West African timber property studies for species *Vitellaria paradoxa* and *Adansonia digitata* in particular whose properties diverge markedly from the regional average (Table 3). *Vitellaria paradoxa* is confirmed in multiple independent Nigerian sources as an unusually dense, termite-resistant hardwood, while *Adansonia digitata* is confirmed as exceptionally light-wooded owing to its water-storing, parenchyma-rich stem tissue; both characteristics are reflected in the density values applied (Table 3) and materially affect the biomass results (Section 5). Because the field data record only genus for the *Ficus* specimens, a representative genus-mean wood density was applied for this entry, which should be treated as a lower-confidence estimate relative to the fully identified species.

Table 3. Wood density values applied and their primary data source. * Applied to both *Anogeissus leiocarpus* inventory entries, (i) and (ii) — see Section 4.7

Species	Wood Density (g/cm ³)	Primary Source
<i>Pterocarpus erinaceus</i>	0.79	Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009); African Wood Density Database (Carsan et al., 2012)
<i>Tamarindus indica</i>	0.83	Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009); African Wood Density Database (Carsan et al., 2012)
<i>Burkea africana</i>	0.72	Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009); African Wood Density Database (Carsan et al., 2012)
<i>Terminalia glaucescens</i>	0.65	Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009); African Wood Density Database (Carsan et al., 2012)
<i>Parkia biglobosa</i>	0.55	Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009); African Wood Density Database (Carsan et al., 2012)

Species	Wood Density (g/cm ³)	Primary Source
<i>Prosopis africana</i>	0.85	Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009); African Wood Density Database (Carsan et al., 2012)
<i>Piliostigma thonningii</i>	0.65	Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009); African Wood Density Database (Carsan et al., 2012)
<i>Anogeissus leiocarpus</i> *	0.79	Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009); African Wood Density Database (Carsan et al., 2012)
<i>Vitex doniana</i>	0.58	Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009); African Wood Density Database (Carsan et al., 2012)
<i>Daniellia oliveri</i>	0.48	Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009); African Wood Density Database (Carsan et al., 2012)
<i>Ziziphus spina-christi</i>	0.68	Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009); African Wood Density Database (Carsan et al., 2012)
<i>Ficus</i> spp.	0.43	Genus-mean value, Global Wood Density Database (species unresolved in field data)
<i>Vitellaria paradoxa</i>	0.85	Regional literature (Nigerian/West African timber-property studies)
<i>Khaya senegalensis</i>	0.60	Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009); African Wood Density Database (Carsan et al., 2012)
<i>Adansonia digitata</i>	0.16	Regional/species-specific literature (baobab wood-property studies)

2.3 Below-Ground Biomass (BGB) Estimation

BGB was estimated by applying a root-to-shoot ratio of 0.24 to the AGB of each tree, following Cairns et al. (1997) and consistent with the IPCC (2006) default for tropical forest biomass:

$$BGB = 0.24 \times AGB$$

Total biomass per tree is the sum of AGB and BGB; multiplying by the number of enumerated trees per species yields the species-level Total AGB, BGB and Total Biomass reported in

Table 1.

2.4 Carbon Stock and CO₂ Equivalent

Carbon stock was obtained by applying the IPCC (2006) default carbon fraction of dry biomass (CF = 0.47):

$$\text{Carbon (kg C)} = \text{Total Biomass (kg)} \times 0.47$$

Carbon stock was then converted to carbon dioxide equivalent using the molecular-weight ratio of CO₂ to carbon (44/12 = 3.667):

$$\text{CO}_2\text{e (kg)} = \text{Carbon (kg C)} \times 3.667$$

2.5 Economic Valuation and Cost-Benefit Framework

The monetary value of stored carbon was estimated by applying three carbon-price scenarios reflecting the observed 2026 range for nature-based, Africa-relevant voluntary-carbon-market credits: a low scenario of US\$7/tCO₂e, a base scenario of US\$10/tCO₂e, and a high scenario of US\$24/tCO₂e, synthesized from the market analyses reviewed in Section 2.5. United States Dollar values are additionally reported in Nigerian Naira (NGN) using the Central Bank of Nigeria official reference rate of approximately ₦1,365 = US\$1 prevailing in mid-August 2026; because this rate fluctuates, Naira figures should be treated as indicative.

Representative tree establishment-and protection costs were derived from the wider reforestation-and-restoration-economics literature and converted to a per-tree basis using the standard forestry planting density convention of approximately 1,111 stems per hectare (3 m × 3 m spacing), giving a low-cost scenario of US\$0.14/tree (consistent with farmer-managed natural regeneration using largely unpaid labour), a mid-cost scenario of US\$2.00/tree (consistent with the global average cost of forest restoration), and a high-cost scenario of US\$4.50/tree (consistent with fully commercial African afforestation). Because the trees inventoried in this study are established, mature individuals rather than new seedlings, these figures are best interpreted as the cost of protecting an equivalent stock of carbon from loss, or of replacing it should it be lost, rather than as the historical cost of establishing the existing stand. The benefit-cost ratio (BCR) for each cost scenario was then calculated as:

$$\text{BCR} = \text{Total monetized carbon benefit (base price)} \div \text{Total establishment/protection cost}$$

3. RESULTS

Across the fifteen inventoried entries which is representing fifteen unique species, a total of 3,219 trees were assessed. Table 1 reports the completed biomass inventory, and Table 2 the corresponding carbon stock, CO₂ equivalent and monetary value.

Table 1. Completed tree biomass inventory for the northern Adamawa State study area (N = number of trees; DBH = diameter at breast height).

Species	N	Mean DBH (cm)	Mean Ht (m)	Total AGB (kg)	BGB (kg)	Total Biomass (kg)
<i>Pterocarpus erinaceus</i>	87	42	10.87	70,398	16,896	87,294
<i>Tamarindus indica</i>	178	49	9.70	182,729	43,855	226,584
<i>Burkea Africana</i>	137	37	8.60	62,906	15,097	78,003
<i>Terminalia glaucescens</i>	86	21	7.30	10,081	2,419	12,500
<i>Parkia biglobosa</i>	198	49.7	12.30	176,323	42,318	218,641
<i>Prosopis Africana</i>	119	45	11.00	119,714	28,731	148,445
<i>Piliostigma thonningii</i>	87	32	7.40	23,516	5,644	29,160
<i>Vitex doniana</i>	126	42	10.80	74,937	17,985	92,922
<i>Daniellia oliveri</i>	87	37	14.00	43,269	10,385	53,654
<i>Ziziphus spina-christi</i>	142	32	9.80	52,762	12,663	65,425
<i>Ficus spp.</i>	87	41	13.00	44,174	10,602	54,775
<i>Vitellaria paradoxa</i>	300	50	12.10	406,853	97,645	504,497
<i>Khaya senegalensis</i>	457	63	12.78	730,624	175,350	905,973
<i>Anogeissus leiocarpus (ii)</i>	762	61	12.40	1,452,772	348,665	1,801,437
<i>Adansonia digitata</i>	187	97	12.10	181,157	43,478	224,634
TOTAL	3219	—	—	3,726,661	894,399	4,621,060

The inventory yields an estimated 3,726,661 kg (3,726.7 t) of above-ground biomass and 894,399 kg (894.4 t) of below-ground biomass, for a total biomass of 4,621,060 kg — approximately 4,621 tons (Figure 1). Applying the carbon fraction and CO₂ conversion factor described in Sections 4.4-4.5, this represents 2,171,898 kg (2,171.9 t) of stored carbon and 7,963,626 kg — approximately 7,964 tons — of carbon dioxide equivalent (Table 2).

Table 2. Total biomass, carbon stock, CO₂ equivalent and monetary value by species, with three carbon-price scenarios (Section 4.6).

Species	Biomass (t)	Carbon (tC)	CO ₂ e (t)	Value @ \$7/t	Value @ \$10/t (base)	Value @ \$24/t
<i>Pterocarpus erinaceus</i>	87.3	41.0	150.4	\$1,053	\$1,504	\$3,610
<i>Tamarindus indica</i>	226.6	106.5	390.5	\$2,733	\$3,905	\$9,372
<i>Burkea Africana</i>	78.0	36.7	134.4	\$941	\$1,344	\$3,226
<i>Terminalia glaucescens</i>	12.5	5.9	21.5	\$151	\$215	\$517
<i>Parkia biglobosa</i>	218.6	102.8	376.8	\$2,638	\$3,768	\$9,043
<i>Prosopis Africana</i>	148.4	69.8	255.8	\$1,791	\$2,558	\$6,140
<i>Piliostigma thonningii</i>	29.2	13.7	50.3	\$352	\$503	\$1,206
<i>Anogeissus leiocarpus</i> (i)	117.1	55.0	201.8	\$1,413	\$2,018	\$4,844
<i>Vitex doniana</i>	92.9	43.7	160.1	\$1,121	\$1,601	\$3,843
<i>Daniellia oliveri</i>	53.7	25.2	92.5	\$647	\$925	\$2,219
<i>Ziziphus spina-christi</i>	65.4	30.7	112.7	\$789	\$1,127	\$2,706
<i>Ficus</i> spp.	54.8	25.7	94.4	\$661	\$944	\$2,266
<i>Vitellaria paradoxa</i>	504.5	237.1	869.4	\$6,086	\$8,694	\$20,866
<i>Khaya senegalensis</i>	906.0	425.8	1,561.3	\$10,929	\$15,613	\$37,471
<i>Anogeissus leiocarpus</i> (ii)	1,801.4	846.7	3,104.5	\$21,731	\$31,045	\$74,507
<i>Adansonia digitata</i>	224.6	105.6	387.1	\$2,710	\$3,871	\$9,291
TOTAL	4,621.1	2,171.9	7,963.6	\$55,745	\$79,636	\$191,127
<i>Average per tree (n = 3219)</i>	<i>1.436</i>	<i>0.675</i>	<i>2.4739</i>	<i>\$17.32</i>	<i>\$24.74</i>	<i>\$59.37</i>

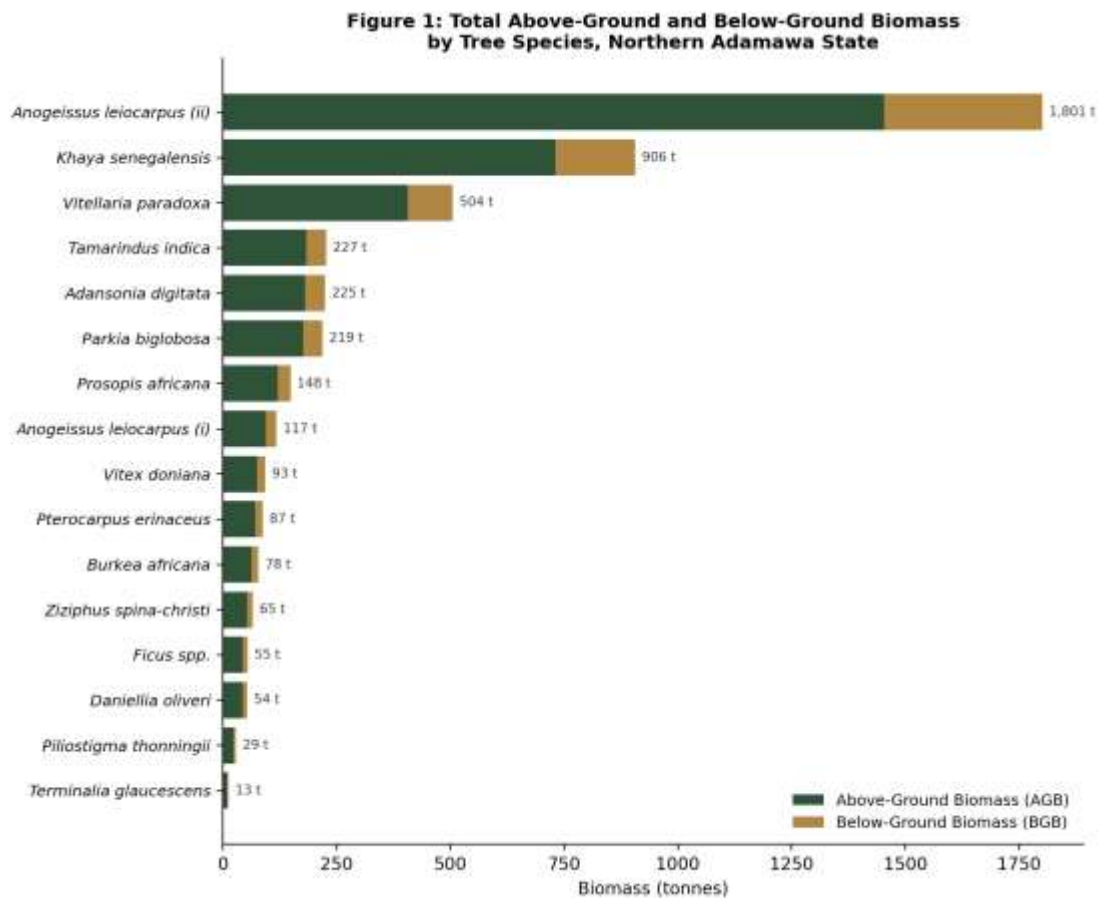


Figure 1. Total above-ground and below-ground biomass by tree species/entry, northern Adamawa State.

Biomass and carbon stock were highly concentrated in a small number of entries. The second *Anogeissus leiocarpus* record the single largest entry in the inventory, with 762 trees contributed approximately 39.0% of total CO₂e, followed by *Khaya senegalensis* (19.6%) and *Vitellaria paradoxa* (10.9%); these three entries together accounted for approximately 69.5% of the carbon stock represented by the entire inventory, despite comprising just under half (47.2%) of the enumerated trees.

Wood density, not diameter alone, drove much of this variation. *Adansonia digitata* recorded the largest mean diameter in the inventory (97 cm) yet ranked only sixth in biomass per tree (1,201 kg), because its wood density (0.16 g/cm³) is one-fifth that of the densest species recorded. By contrast, *Anogeissus leiocarpus* (ii) combined a large mean diameter (61 cm) with high wood density (0.79 g/cm³) to record the highest biomass per tree in the inventory (2,364 kg) a reminder that diameter alone is a poor proxy for the carbon value of a standing tree, and that wood-density aware allometric models meaningfully change conservation and management priorities relative to diameter only assessments.

On a per-tree basis the primary quantity motivating this study — the average tree in the inventory holds approximately 1,436 kg of total biomass, 675 kg of carbon, and 2.47 tons of CO₂ equivalent (Table 2). At the three carbon price scenarios applied, this equates to an average monetary value per tree of US\$17.32 (low), US\$24.74 (base case, ~~≈~~₦33,769), and US\$59.37 (high).

Table 4. Cost-benefit summary for the total inventory (n = 3,219 trees). *Total benefit held at the base carbon price of US\$10/tCO₂e; BCR = Benefit-Cost Ratio.

Cost Scenario	Cost / Tree	Total Cost (US\$)	Total Benefit* (US\$)	BCR	Net Benefit (US\$)
Low (natural regeneration / protection)	\$0.14	\$451	\$79,636	176.7	\$79,186
Mid (global forest-restoration average)	\$2.00	\$6,438	\$79,636	12.4	\$73,198
High (commercial afforestation)	\$4.50	\$14,486	\$79,636	5.5	\$65,151

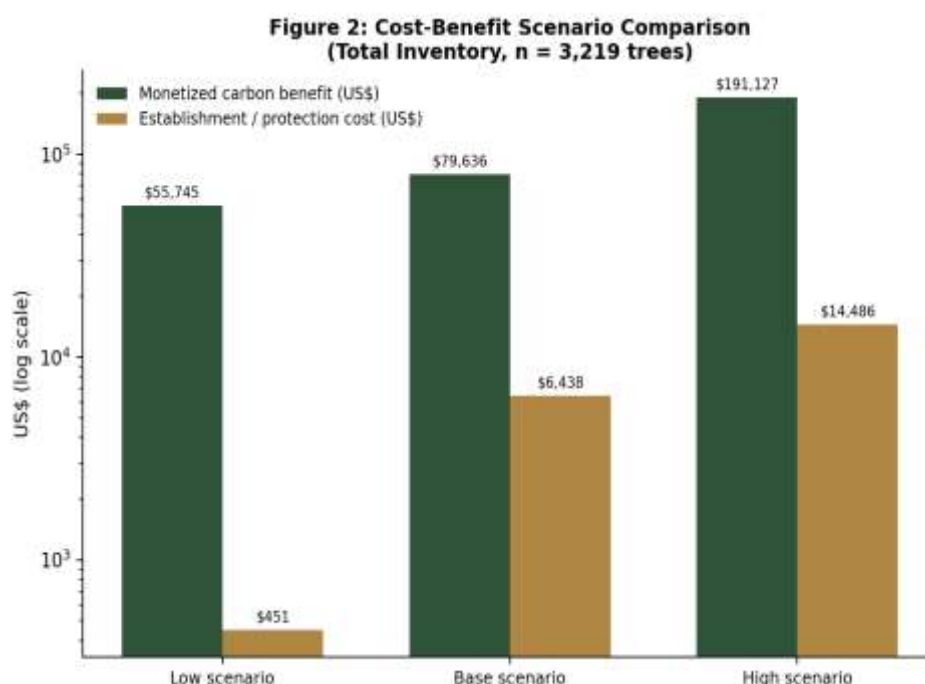


Figure 2. Cost-benefit scenario comparison for the total inventory (logarithmic scale).

At the base carbon price of US\$10/tCO₂e, the entire inventory represents a stored-carbon asset worth approximately US\$79,636 (~~≈~~₦108,703,496). Against this, estimated establishment-or-protection costs range from US\$450.66 under

the low (natural-regeneration) scenario to US\$14,486 under the high (commercial-afforestation) scenario, producing benefit-cost ratios of 176.7, 12.4 and 5.5 respectively (Figure 2). Under every scenario tested including the most conservative combination of the lowest carbon price and highest establishment cost, the value of the carbon already sequestered in these trees substantially exceeds the cost of securing it, indicating a strongly positive net return to conservation of the existing tree resource.

4. DISCUSSION

The results confirm that the savanna trees of northern Adamawa State constitute a substantial, geographically concentrated carbon asset. A carbon stock of roughly 2,172 tons across 3,219 trees — an average of 675 kg of carbon, or 2.47 tons of CO₂e, per tree — sits within the range reported for comparable Sudanian savanna and dry woodland species elsewhere in West Africa (Sawadogo *et al.*, 2010), and is broadly consistent with, if somewhat lower on a per-stem basis than, the more strongly forested conditions reported for the Karlahi Forest Reserve further south in Adamawa State (Jerry *et al.*, 2024) — a plausible pattern given the more open, savanna structure of the present study area relative to a gazette forest reserve.

The strong concentration of carbon stock in three entries, *Anogeissus leiocarpus*, *Khaya senegalensis* and *Vitellaria paradoxa*, together accounting for roughly 70% of total CO₂e — has a direct conservation implication: protecting a comparatively small number of large, dense-wooded individuals of these species would secure the majority of the carbon value documented here, making targeted protection of large *Anogeissus*, *Khaya* and *Vitellaria* stems a cost-effective entry point for any local carbon-conservation or payment-for-ecosystem-services initiative, alongside broader efforts to maintain overall tree cover.

The *Adansonia digitata* result is a useful cautionary illustration for practitioners: diameter-based rules of thumb for prioritizing big trees for conservation or carbon-crediting can be misleading in landscapes, like this one, where exceptionally large-diameter but light-wooded species are present. Wood-density-aware models such as that of Chave *et al.* (2014) are therefore not merely a technical refinement but a practical necessity for credible carbon accounting in mixed-species Sudano Sahelian woodlands.

From a policy and financing perspective, the cost-benefit results are striking even under the most conservative pairing of carbon price and establishment cost tested,

the benefit-cost ratio for the inventoried trees exceeds five and rises above 170 under the most favourable but still literature grounded combination. This pattern echoes a wider finding in the restoration-economics literature that protecting existing trees and encouraging natural regeneration is very substantially cheaper, per ton of CO₂e secured, than commercial afforestation from bare land and strengthens the case for channelling scarce conservation resources in northern Adamawa State toward protecting the existing savanna and parkland tree stock alongside the new planting under initiatives such as Nigeria's Great Green Wall and ACREsAL program.

5. Conclusion and Recommendations

This study set out to quantify the above-ground biomass, below-ground biomass, total biomass, carbon stock and monetary value of sixteen dominant tree entries across the northern part of Adamawa State, and to place this value in a cost-benefit framework. Using the Chave et al. (2014) allometric model, a root to shoot ratio of 0.24 and the IPCC (2006) carbon fraction, the study estimates a total biomass of 4,621 tons, a carbon stock of approximately 2,172 tons, and a stored carbon dioxide equivalent of approximately 7,964 tons. On average, each tree in the inventory sequesters 2.47 tons of CO₂e, worth between US\$17 and US\$59 depending on the carbon price applied a best case value of approximately US\$24.74, or ₦33,769, per tree. Comparing this benefit against representative establishment-and-protection costs yields benefit-cost ratios of between 5.5 and 176.7, indicating that conserving the existing tree resource of northern Adamawa State is a cost-effective climate response.

On this basis, the study recommends that: (i) the Adamawa State Government and its development partners priorities the protection of large, dense-wooded individuals of *Anogeissus leiocarpus*, *Khaya senegalensis* and *Vitellaria paradoxa*, which together account for approximately 70% of the documented carbon stock; (ii) further destructive-sampling and local wood-density calibration be undertaken within Adamawa State to refine the allometric and economic assumptions applied here, particularly for *Vitellaria paradoxa*, *Adansonia digitata* and the unresolved *Ficus* entry; and (iii) tree conservation be explicitly costed and compared with new planting within Great Green Wall, ACREsAL and related programming in the state, given the substantially higher benefit-cost ratio documented here for protecting standing trees relative to commercial afforestation.

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