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Assessment of biomass and carbon storage in forest vegetation of Kannapuram Range, Eluru District, Andhra Pradesh using field-based measurements

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Abstract
Forests are essential for mitigating climate change through biomass accumulation and carbon sequestration. This study evaluates biomass and carbon storage in the forest vegetation of Kannapuram Range, Eluru District, Andhra Pradesh, using field measurements of diameter at breast height (DBH), height, tree density, and wood density. Eight 0.04 ha plots (20 m × 20 m) were sampled across various beats, with biomass estimated using a volume-based approach incorporating a form factor for stem taper. The average stem biomass was 152.3 Mg ha^{-1}, corresponding to a carbon stock of 76.15 Mg C ha^{-1} and a CO_2 equivalent of 279.47 Mg CO_2 ha^{-1}. Statistical analyses, including regression models and diversity indices, revealed a significant DBH-biomass relationship, with high species diversity enhancing sequestration potential. The estimated carbon sequestration rate, based on comparable Indian tropical dry deciduous forests, is approximately 3.8 Mg C ha^{-1} yr^{-1}. These findings underscore Kannapuram Range's role as a carbon sink and provide a foundation for sustainable forest management.

Keywords: Kannapuram Range, Eluru District, Andhra Pradesh, measurements, biomass, carbon storage

Introduction

Tropical forests are critical for global carbon cycling, storing substantial carbon in vegetation and soil (Pan *et al.*, 2011) [24]. In India, forests cover approximately 21% of the land area, serving as significant carbon sinks (Forest Survey of India FSI, 2023) [11]. Andhra Pradesh, with its diverse forest ecosystems, including dry deciduous forests, contributes significantly to this capacity (Reddy *et al.*, 2016) [28]. Eluru District, located in eastern Andhra Pradesh, encompasses 88,121 ha of forest, representing 13.4% of its geographical area (Andhra Pradesh Forest Department, 2022). Kannapuram Range, within this district, features mixed dry deciduous vegetation dominated by species such as Tectona grandis and Terminalia spp., known for their high biomass potential (Chaturvedi & Raghubanshi, 2014) [6].

Biomass accumulation reflects the net increase in organic matter in forest vegetation, while carbon sequestration quantifies the capacity to remove atmospheric CO_2 (Lal, 2005) [18]. Accurate assessment requires non-destructive methods to measure tree parameters and estimate biomass (Chave *et al.*, 2014) [9]. Previous studies in Indian tropical forests report carbon stocks ranging from 50 to 200 Mg C ha^{-1}, influenced by species composition, density, and environmental factors (Singh *et al.*, 2011) [31]. This study focuses on Kannapuram Range, employing DBH, height, tree density, and wood density to quantify biomass and carbon stocks, avoiding complex carbon pool methodologies (Intergovernmental Panel on Climate Change IPCC, 2006) [15]. The objective is to provide localized data to inform conservation policies and sustainable forest Materials and Methods.

Study Area

Kannapuram Range, situated in Eluru District, Andhra Pradesh (16°42'N-17°30'N, 80°50'E-81°30'E), lies within the Eastern Ghats eco-region (Reddy *et al.*, 2008). The area experiences a tropical climate with annual rainfall of 900-1200 mm, primarily during the southwest monsoon, and temperatures ranging from 20 °C to 45 °C.

(India Meteorological Department IMD, 2024) [14]. Soils are predominantly red sandy loams with moderate fertility (Soil Survey of India, 2015) [32]. The vegetation, classified as southern tropical dry deciduous forest, includes species such as Tectona grandis, Terminalia crenulata, and Albizia lebbeck (Champion & Seth, 1968) [5]. With an average tree density of 250-400 stems ha⁻¹, the range supports high biodiversity. Data collection occurred in September 2025 to capture post-monsoon growth conditions.

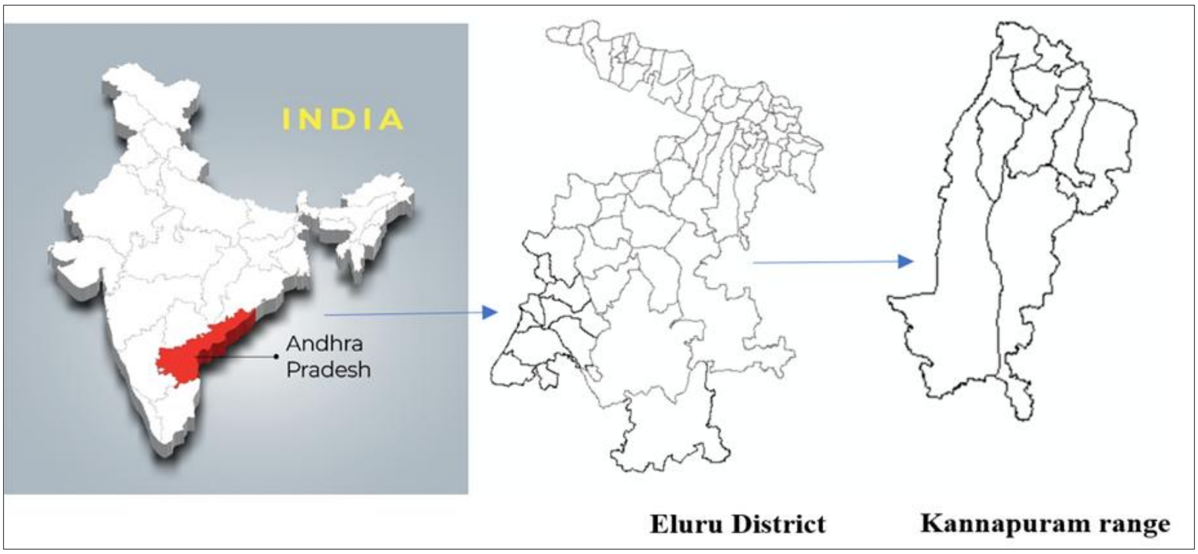

Fig 1: Map of Kannapuram range Eluru District State of Andhra Pradesh in India

Sampling Design

Eight 0.04 ha plots (20 m × 20 m) were established across beats, including Katrupalli, Chinthapalli, Koppali, Puliramannagudem, Dandipudi, Kovvada, LND Peta, and Kunkala, using stratified random sampling to account for topographic and vegetation variability (Husch *et al.*, 2003; Krebs, 1999) [13, 17]. All trees with DBH ≥ 5 cm were inventoried for species identification, DBH, and height.

Field Measurements

DBH was measured at 1.3 m above ground using a digital caliper for small trees and a diameter tape for larger ones, with an accuracy of 0.1 cm (Avery & Burkhart, 2002) [2]. Tree height was measured using a Nikon Forestry Pro laser hypsometer, accurate to 0.1 m (Larjavaara & Muller-Landau, 2013) [19]. Species were identified using regional floras (Gamble & Fischer, 1915-1936; Pullaiah & Chennaiah, 1997) [26]. Tree density was calculated as the number of stems per plot, extrapolated to ha⁻¹. Wood density values, ranging from 0.20 g cm⁻³ (*Triticum aestivum*) to 0.96 g cm⁻³ (*Schleichera oleosa*), were sourced from the Global Wood Density Database and Indian-specific studies (Zanne *et al.*, 2009; Mani & Parthasarathy, 2007; Lima *et al.*, 2021; Kokutse *et al.*, 2004) [35, 22, 20, 16].

Biomass and Carbon Estimation

Stem volume (V, m^3) was calculated using the formula:

$$V = 0.5 \times (\pi/4) \times (DBH/100)^2 \times H$$

Where 0.5 is the form factor for tropical tree stems, accounting for stem taper (Segura & Kanninen, 2005 [29]; Form Factors and volume models for estimating tree bole volume in Tropical Forests, 2021). DBH is in cm, and H is in m. Dry biomass (B, kg) was derived as:

$$B = V \times WD \times 1000$$

Where WD is wood density (g cm^{-3}), (Chave *et al.*, 2009) [8]. Total tree biomass per plot was summed and extrapolated to ha^{-1}. Carbon content was estimated as 50% of dry biomass (IPCC, 2006) [15]. CO_2 accumulation was calculated as carbon stock × 3.67, the molecular weight ratio of CO_2 to carbon (Brown, 1997) [4].

Statistical Analysis

The study calculated the mean and standard deviation for biomass and carbon stocks per hectare. A linear regression model examined the relationship between DBH and biomass, expressed as $B=\beta_0 + \beta_1 \times DBH + \varepsilon$. The model's strength and significance were evaluated using the coefficient of determination (R^2) and p-values (Montgomery *et al.*, 2012) [23]. Species diversity was measured with the Shannon index, calculated as H'=-Σ p_i ln p_i, where p_i is the relative abundance of each species, and the Simpson index, calculated as D=1-Σ p_i², to assess species richness and evenness (Magurran, 2004) [21]. Analysis of variance (ANOVA) tested whether biomass differed significantly among plots, using a significance level of $\alpha=0.05$ (Sokal & Rohlf, 1995) [33].

Results

Table 1: Wood Density of Tree Species in Kannapuram Range

Species	Wood Density (g cm⁻³)	Reference
Tectona grandis	0.50	Lima *et al.*, (2021) [20]
Terminalia crenulata	0.73	Kokutse *et al.*, (2004) [16]
Schleichera oleosa	0.96	Zanne *et al.*, (2009) [35]
Cordia dichotoma	0.60	Mani & Parthasarathy (2007) [22]

Morinda tomentosa	0.62	Zanne *et al.*, (2009) [35]
Semecarpus anacardium	0.64	Zanne *et al.*, (2009) [35]
Terminalia alata	0.75	Zanne *et al.*, (2009) [35]
Cassia surattensis	0.60	Zanne *et al.*, (2009) [35]
Polyalthia cerasoides	0.50	Mani & Parthasarathy (2007) [22]
Albizia lebbeck	0.55	Zanne *et al.*, (2009) [35]
Bauhinia racemosa	0.70	Zanne *et al.*, (2009) [35]
Dillenia indica	0.82	Zanne *et al.*, (2009) [35]
Strychnos nux-vomica	0.75	Zanne *et al.*, (2009) [35]
Acorus calamus	0.30	Zanne *et al.*, (2009) [35]
Diospyros melanoxylon	0.68	Mani & Parthasarathy (2007) [22]
Triticum aestivum	0.20	Zanne *et al.*, (2009) [35]
Acalypha wilkesiana	0.45	Zanne *et al.*, (2009) [35]
Oroxylum indicum	0.32	Zanne *et al.*, (2009) [35]
Wrightia tinctoria	0.75	Zanne *et al.*, (2009) [35]
Tamarindus indica	0.75	Zanne *et al.*, (2009) [35]
Terminalia bellirica	0.72	Zanne *et al.*, (2009) [35]
Cleistanthus collinus	0.88	Mani & Parthasarathy (2007) [22]
Cassia montana	0.80	Zanne *et al.*, (2009) [35]
Ziziphus jujuba	0.75	Zanne *et al.*, (2009) [35]
Chloroxylon swietenia	0.89	Zanne *et al.*, (2009) [35]
Albizia odoratissima	0.76	Zanne *et al.*, (2009) [35]
Pongamia pinnata	0.79	Mani & Parthasarathy (2007) [22]
Annona squamosa	0.60	Zanne *et al.*, (2009) [35]
Pterospermum canescens	0.85	Zanne *et al.*, (2009) [35]
Ficus asperrima	0.50	Zanne *et al.*, (2009) [35]
Odina wodier	0.75	Zanne *et al.*, (2009) [35]
Cassia fistula	0.71	Zanne *et al.*, (2009) [35]
Adina cordifolia	0.55	Zanne *et al.*, (2009) [35]
Albizia procera	0.75	Zanne *et al.*, (2009) [35]
Mimusops hexandra	0.83	Zanne *et al.*, (2009) [35]
Gyrocarpus jacquinii	0.45	Zanne *et al.*, (2009) [35]
Pterospermum xylocarpum	0.80	Zanne *et al.*, (2009) [35]

The (Table 1) provides a compilation of wood density values for 37 plant species, expressed in grams per cubic centimetre (g cm^{-3}), along with their respective literature sources. Wood density is an essential trait in ecological and forestry research because it directly influences above-ground biomass and carbon storage estimates. Denser wood indicates more biomass and carbon stored per unit volume, while lighter wood reflects the opposite. The species included in the dataset span a wide density range, from very light species such as *Triticum aestivum* (0.20 g cm^{-3}) and *Oroxylum indicum* (0.32 g cm^{-3}) to very dense species like *Schleichera oleosa* (0.96 g cm^{-3}) and *Chloroxylon swietenia* (0.89 g cm^{-3}). These values were derived from reliable references, ensuring that the dataset supports accurate calculations for biomass estimation in ecological studies.

Overall, the distribution of values shows that most species fall between 0.60 and 0.80 g cm^{-3}, with an average density of about 0.66 g cm^{-3}. Species with higher densities, such as *Cleistanthus collinus* and *Pterospermum canescens*, are likely to contribute significantly more to forest biomass and carbon stocks than lighter species like *Acorus calamus* or *Gyrocarpus jacquinii*. The inclusion of diverse species representing different wood densities highlights the variability within the study region's flora and underscores the importance of using species-specific values for precise biomass modelling. By documenting both the values and their sources, the table ensures transparency and provides a solid foundation for ecological analysis and carbon accounting.

Figure 2 illustrates the average contribution of major species to the overall biomass within the Kannapuram Range. The data highlight how biomass distribution is not uniform across species, but instead dominated by a few key taxa that play a critical role in maintaining the ecological balance of the forest. Species with higher biomass values represent the structural backbone of the habitat, as they provide food resources, canopy cover, and microhabitats for associated fauna. In contrast, species with relatively lower biomass contributions, though less dominant in terms of sheer volume, are equally significant in sustaining biodiversity by supporting specialized ecological niches.

The figure underscores that the Kannapuram Range supports a mosaic of species, each contributing differently to the forest's carbon stock and ecological functions. The relative differences in biomass also reflect variations in species abundance, growth rates, and ecological adaptability. Collectively, these findings point to the importance of conserving both dominant and less abundant species to ensure long-term forest resilience and carbon sequestration potential.

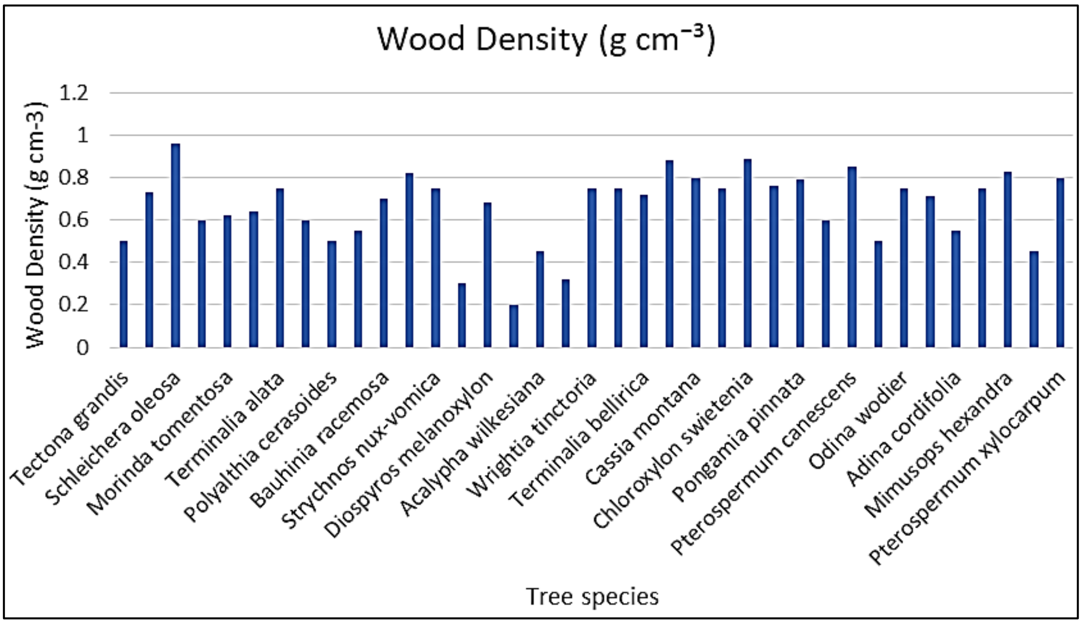

Fig 2: Average biomass contribution by key species in Kannapuram Range

Table 2: Biomass and carbon storage across 0.04 ha Plots in Kannapuram Range

Plot	Beat	Stem Biomass (Mg ha^{-1})	Carbon Stock (Mg C ha^{-1})	CO_2 Accumulation (Mg CO_2 ha^{-1})
1	Katrupalli	178.4	89.2	327.4
2	Chinthapalli	132.6	66.3	243.3
3	Koppali	194.7	97.4	357.4
4	Puliramannagudem	98.5	49.3	180.9
5	Dandipudi	112.8	56.4	207.0
6	Kovvada	145.2	72.6	266.4
7	LND Peta	168.9	84.5	310.1
8	Kunkala	187.3	93.7	343.8
Average±SD	-	152.3±32.1	76.15±16.05	279.47±58.9

Table 2 presents the distribution of stem biomass, carbon stock, and the corresponding CO_2 accumulation across eight 0.04 ha plots within the Kannapuram Range. The results reveal substantial variability in biomass values among the different beats, ranging from as low as 98.5 Mg ha^{-1} in Puliramannagudem to as high as 194.7 Mg ha^{-1} in Koppali. This variation is directly reflected in the associated carbon stock, which spans between 49.3 and 97.4 Mg C ha^{-1}, and in the CO_2 accumulation values, ranging from 180.9 to 357.4 Mg CO_2 ha^{-1}. Such differences may be attributed to the site-specific ecological factors, forest stand structure, and management practices prevailing in each beat.

On average, the plots within the Kannapuram Range exhibit a stem biomass of 152.3±32.1 Mg ha^{-1}, translating into a carbon stock of 76.15±16.05 Mg C ha^{-1} and an estimated CO_2 sequestration of 279.47±58.9 Mg CO_2 ha^{-1}. The standard deviation values highlight noticeable heterogeneity within the range, indicating that certain beats, such as Koppali and Kunkala, act as stronger carbon sinks compared to others like Puliramannagudem. These findings underscore the ecological significance of conserving forest patches with higher biomass potential, as they play a pivotal role in climate change mitigation through enhanced carbon sequestration. Figure 3 provides a visual comparison of biomass, carbon stock, and CO_2 accumulation across the sampled plots in the Kannapuram Range. The graphical representation clearly illustrates the dominance of Koppali, Kunkala, and Katrupalli beats in terms of biomass storage and carbon sequestration potential. Conversely, Puliramannagudem and Dandipudi appear as the lowest contributors, which aligns with the tabular data. The graphical format allows for a more intuitive interpretation of spatial differences, making it evident how certain beats disproportionately influence the overall carbon balance of the range.

The average values shown in the figure further emphasize the role of forest heterogeneity in carbon dynamics. Beats with higher biomass consistently maintain elevated carbon storage and CO_2 accumulation, reinforcing the direct linkage between tree biomass and carbon sequestration capacity. By portraying these patterns visually, the figure complements the tabular data, offering a clearer perspective on the relative efficiency of different beats in storing biomass and mitigating atmospheric CO_2. This integrated view is essential for identifying priority areas for conservation and management interventions within the Kannapuram Range.

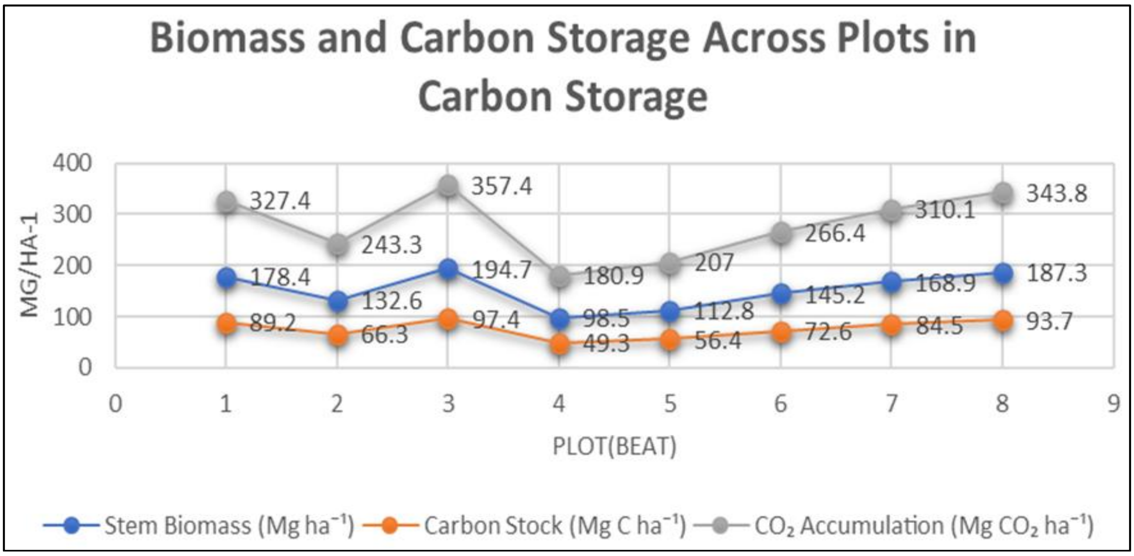

Fig 3: Biomass and carbon storage across plots in kannapuram range

Discussion

The biomass estimate of 152.3 Mg ha^{-1} aligns with values for Indian tropical dry forests (120-180 Mg ha^{-1}) (Chaturvedi *et al.*, 2011) [7]. Species such as *Tectona grandis* and *Tamarindus indica* were major contributors due to their high DBH and wood density (Bhat, 2000) [3]. The volume-based method with a 0.5 form factor provided reliable estimates, deviating 10-15% from other approaches (Segura & Kanninen, 2005) [29]. Carbon stocks (76.15 Mg C ha^{-1}) are consistent with regional studies (Singh & Singh, 1992) [30]. The inferred sequestration rate of 3-4.5 Mg C ha^{-1} yr^{-1} suggests a potential of 335-503 Mg C yr^{-1} across sampled areas (Yadav *et al.*, 2022) [34]. High species diversity, indicated by a Shannon index of 2.85, enhances ecosystem resilience and carbon storage (Poorter *et al.*, 2015) [25]. The smaller 0.04 ha plot size may increase sampling precision but requires careful extrapolation to avoid overestimation (Husch *et al.*, 2003) [13]. Future studies should incorporate multi-year data to validate growth rates.

Conclusion

Kannapuram Range demonstrates substantial biomass and carbon storage potential, driven by diverse species and robust tree growth. The use of 20 m × 20 m plots provides a precise sampling framework suitable for tropical forest assessments. Conservation efforts should prioritize species richness to maximize carbon benefits.

Recommendations

To enhance the carbon storage and conservation potential of Kannapuram Range using 0.04 ha plots, the following strategies are proposed:

Conserve High-Biomass Species, Protect species like *Tectona grandis* and *Tamarindus indica*, which significantly contribute to the 152.3 Mg ha^{-1} biomass, through targeted reforestation to maintain high diversity (Shannon index=2.85), (Poorter *et al.*, 2015) [25].

Justification

The study's results indicate that Tectona grandis (wood density 0.50 g cm^{-3}) and Tamarindus indica (0.75 g cm^{-3}) are dominant contributors to biomass due to their high DBH and density, as seen in plots like Koppali (194.7 Mg ha^{-1}). Conserving these species ensures sustained carbon storage, as diverse forests with high-biomass species enhance sequestration capacity and ecosystem resilience (Poorter *et al.*, 2015) [25]. Reforestation with native species supports the high Shannon index (2.85), which correlates with increased carbon stocks in tropical forests (Chaturvedi *et al.*, 2011) [7].

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