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Original Research

Allometric models for estimation of aboveground biomass of *Combretum molle* R.Br. ex G.Don. and *Terminalia schimperiana* Hochst. in Tulu Lafto Forest, Horo Guduru Wollega zone, Ethiopia

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Abstract

Forests play a key role in the global carbon cycle. Hence, accurate forest biomass estimation is crucial in climate change mitigation efforts and for monitoring carbon stock dynamics. This study developed allometric models used to estimate AGB of two indigenous tree species, namely, Combretum molle and Terminalia schimperiana, using a semi-destructive method. Diameter at breast height (DBH) and total height were measured for 40 selected trees per species across 10 plots (each 0.1 ha). Selected branches with leaves were trimmed for fresh and dry weight analysis. Samples were taken to the laboratory for dry-to-fresh weight ratio determination and further analysis. Wood density was calculated for both species. The results showed that C. molle had a significantly higher mean wood density (0.573 g/cm³) than T. schimperiana (0.476 g/cm³, p = 0.000), a significantly lower mean biomass (34.57) compared to T. schimperiana (266.13, p = 0.000). Linear regression analysis revealed that DBH was the most reliable predictor for AGB for both species. The study recommends using Model 2 for C. molle (DBH- 5-43cm) and Model 5 for T. schimperiana (DBH-5-60cm) for AGB estimation. It also emphasizes conserving and incorporating C. molle and T. schimperiana in national afforestation programs for carbon sequestration projects.

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INTRODUCTION

Depending on the degree of disturbance, forests and woodlands can act as both sources and sinks of carbon, making them essential parts of the global carbon cycle (Shirima et al., 2011). Therefore, accurate estimation of forest biomass is essential for carbon stock assessment, understanding ecosystem productivity, and formulating strategies of climate change mitigation and sustainable forest management (Kershaw et al., 2016; Freer et al., 2007). As direct biomass measurement is labor-intensive, costly, and often destructive biomass models are widely applied to determine the biomass of trees from easily measurable dendrometric variables, namely DBH and height (Brown, 1997; Kershaw et al., 2016). Allometric models are mathematical equations that estimate tree biomass from DBH, height, wood density, crown cover, or a combination of these. This offers a cost-effective and non-destructive method of quantifying aboveground biomass (AGB) across various forest types and species. Despite this, allometric models can yield biased results when used outside the ecological context in which they were developed (Clark et al., 2001; Cairns et al., 2003; Ngomanda et al., 2013; Mwakalukwa et al., 2014), prompting the need for locally developed equations that account for tree size variability (Brown, 2002).

In Ethiopia, woodlands and bushlands cover about 55% of the landmass and are crucial for livelihoods and ecosystem services like biodiversity conservation and carbon sequestration (WBISPP, 2004). *Combretum-Terminalia* woodlands form a significant component of the dryland forest ecosystems, particularly in the lowland and mid-altitude areas of the country. *Combretum molle* and *Terminalia schimperiana* are among the dominant native woody species in these woodlands, playing vital ecological, socio-economic, and environmental roles (IBC, 2014; Gurmessa et al., 2022). *Combretum molle* is a small to medium deciduous tree up to 15 m high and 50 cm DBH. It is generally used to produce high-quality charcoal. *Terminalia schimperiana,* on the other hand, is a broad-leaved tree that reaches a height of 10–20 m, and its wood is used for all types of construction and is suitable for household utensils. Both species are strong, durable, and termite-resistant. They are also important carbon reserves in the woodland vegetation.

Despite their ecological importance and potential contribution to carbon sequestration, there are no site- and species-specific models formulated for these species in western Ethiopia, including those in the Tulu Lafto Forest. While Abich et al. (2022) developed biomass models for northern Ethiopian woodlands, these relied on destructive sampling of a few individuals and did not include trees from western Ethiopia.

Statement of the problem

The lack of reliable, site-specific allometric models causes significant uncertainty in biomass and carbon stock estimation and impairs effective implementation of climate-related policies. Existing models are often generalized or developed for different species or regions, limiting their applicability to native dryland species like *Combretum molle* and *Terminalia schimperiana*. Hence, it is critically vital to develop reliable and species-specific biomass estimation models for precise biomass estimation, which is specific to the trees in Tulu Lafto Forest. This study addressed this knowledge gap by developing allometric models using a semi-destructive method for the accurate estimation of AGB of *C. molle* and *T. schimperiana*.

Research questions

This study has been conducted to answer the following research questions.

i) Which allometric models are suitable for accurate estimation of AGB of *Combretum molle* and *Terminalia schimperiana* in Tulu Lafto Forest?
ii) Does diameter at breast height perform better than total height in explaining variations in AGB of the target species?
iii) Do the newly developed species-specific models perform better than the existing general or regional allometric models?

MATERIALS AND METHODS

Study area

Geographically, Tulu Lafto Forest is found in the Angar Didessa watershed, western Ethiopia (Figure 1) (9°27′–9°37′ N, 36°47′–37°00′ E). The area receives over 1500 mm of annual rainfall and has an average temperature above 17°C. Numerous rivers and streams from the forest feed into the Anger River, making it a key headwater source for the Blue Nile River (Gurmessa et al., 2022).

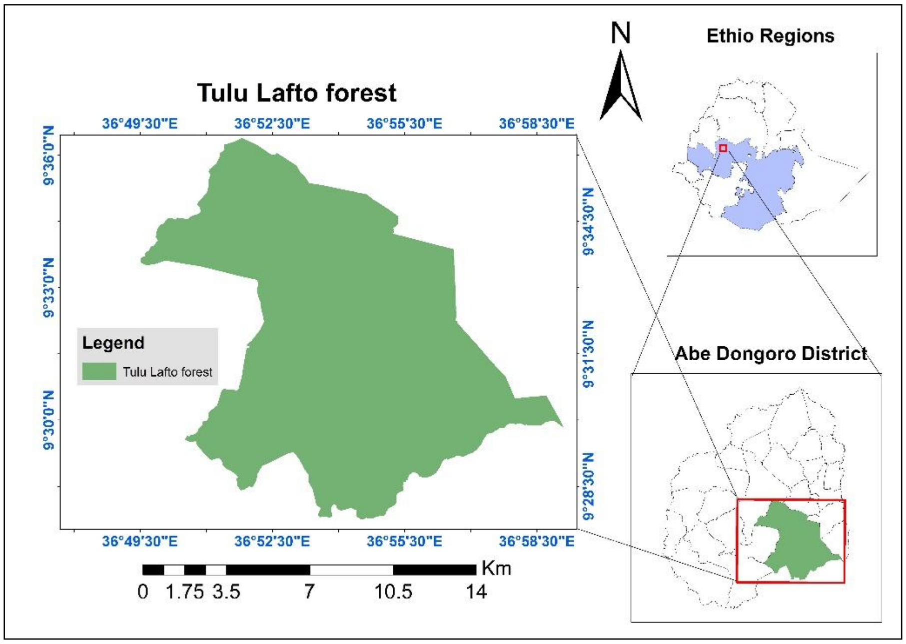

Figure 1. *Map of the study area (Tulu Lafto Forest)*

Data collection

Following a preliminary survey in the area, appropriate sample sites were identified. Ten sample plots, each measuring 0.1 ha (20 m × 50 m), were purposively established in the forest. Two tree species, *Combretum molle* and *Terminalia schimperiana*, were selected, and 80 trees (40 per species) were sampled using preferential sampling to ensure representation across size classes while excluding damaged or hollow trees following Abich et al. (2022). Tree parameter data collection was made following the FAO's manual (Picard et al., 2012). For each tree with DBH ≥ 5 cm, total height and DBH were measured. Semi-destructive methods, involving trimming some branches, separating leaves, and weighing fresh leaf and wood biomass, were used. Random samples of these components were collected to determine dry weight, volume, and wood density. Nondestructive methods were used for untrimmed parts. Allometric equations formulated from basal diameter and biomass were used to determine the biomass of small branches that remained on the tree, while large branches and trunks were segmented into sections of less than a meter in length, and their volumes were calculated based on diameter and length measurements. As per the methods indicated by Picard et al. (2012), volumes and wood density were used to determine the biomass of large branches and the stem.

Data Analysis

Descriptive statistics were computed for key tree parameters, including DBH, total height, wood specific gravity, and aboveground biomass. Normality and homogeneity of variance were tested using the Shapiro-Wilk test ($p > 0.05$) and Fisher's F test ($p < 0.05$), respectively. Since DBH, height, and biomass did not meet parametric assumptions, the Wilcoxon rank-sum test was employed to assess differences in mean height and DBH between *Combretum molle* and *Terminalia schimperiana*. Trees were also categorized into size classes, and biomass was computed for each class. Data analysis was conducted using Excel, SPSS v20, and R software v3.4.2 (R Development Core Team, 2018).

Aboveground biomass estimation

The trimmed and untrimmed biomass were summed to obtain the total aboveground biomass of trees.

$$B_{tAGB} = B_{trimmed\ dry} + B_{untrimmed\ dry} \quad (1)$$

Trimmed biomass

To determine the moisture content of the wood (χ_{wood}) and the leaves, equations 2 and 3 were used.

$$\chi_{wood} = \frac{B_{aliquot\ dry\ wood}}{B_{aliquot\ fresh\ wood}} \quad (2)$$

$$\chi_{leaf} = \frac{B_{aliquot\ dry\ leaf}}{B_{aliquot\ fresh\ leaf}} \quad (3)$$

Then, total trimmed biomass was computed as follows:

$$Y = B_{trimmed\ wood} \times \chi_{wood} + B_{trimmed\ leaf} \times \chi_{leaf} \quad (4)$$

Where: ***Y:*** is total trimmed biomass; $B_{trimmed\ leaf}$ is the fresh mass of the leaves, and $B_{trimmed\ wood}$ is the fresh mass of the wood.

Untrimmed biomass

Two separate computations were conducted to determine the biomass of the untrimmed (standing) parts of the trees. One is for small branches, and the other is for the large branches and the trunk. The two biomasses were summed to obtain the total untrimmed biomass (Picard et al., 2012).

$$B_{untrimmed\ total} = B_{untrimmed\ small\ branch} + B_{untrimmed\ trunk\ and\ large\ branch} \quad (5)$$

For sections of the trunk that were considered to be cylindrical in shape, volume, density, and dry biomass were calculated using Smalian's formula (equations 6 - 8), respectively (Picard et al., 2012).

$$V_i = \frac{\pi}{8} L_i (D_{1i}^2 + D_{2i}^2) \quad (6)$$

Where V_i is the volume of section i, L_i is its length, and D_{1i} and D_{2i} are the diameters of the two extremities of section *I*.

$$\bar{\rho} = \frac{B_{aliquot\ dry\ wood}}{V_{aliquot\ fresh\ wood}} \quad (7)$$

$$B_{dry\ section} = \bar{\rho} \times \sum_i Vi \quad (8)$$

The biomass of untrimmed small branches was computed using allometric models developed from the relationship between dry biomass and basal diameter of trimmed branches, following standard procedures for allometric equation development (Picard et al., 2012). Linear regression analysis, using basal diameter (D) as the predictor, was applied to estimate biomass (Table 1).

$$B_{dry\ branch} = a + bD \quad (9)$$

Where *a* and *b* are model parameters and *D* is the basal diameter of the branch.

Table 1

Allometric models used to estimate the biomass of untrimmed small branches:

Model No.	Allometric Equation	a	b	RSE	R^2	P-value	Species
1	$Y = a + b * D$	-1.1875	0.8051	0.22	0.94	0.000	*C. molle*
2	$lnY = a + b * lnD$	-1.215	1.389	0.07	0.95	0.000	
3	$Y = a + b * D$	-0.7714	0.513	0.17	0.88	0.000	*T. schimperiana*
4	$lnY = a + b * lnD$	-2.071	1.634	0.11	0.87	0.000	

Note: D: basal diameter of small branch; Y: biomass of untrimmed small branches

Log-transformed basal diameter (*lnD*) was the best predictor variable for biomass of untrimmed small branches of both species ($R^2 = 0.95$ for *C. molle* and *0.87* for *T. schimperiana*) and (RSE = 0.07 for *C. molle* and 0.11 for *T. schimperiana*). Untrimmed biomass of small branches for *C. molle* and *T. schimperiana* was, therefore, calculated using models 2 and 4, respectively (Table 1).

Finally, the total AGB of each tree was calculated by summing the biomass of the trunk -and large branches, the trimmed small branches, and the untrimmed small branches.

Allometric models

Allometric models were developed using DBH and total height (H) to estimate total aboveground biomass. Model performance was assessed using different statistical metrics, including adjusted R², residual standard error (RSE), p-values, and Akaike Information Criterion (AIC). Adjusted R² was preferred for multiple regressions to account for the number of predictors and avoid overestimating model fit (Zar, 2010). AIC was used to compare models by balancing model fit and complexity, with lower values indicating better performance and reduced risk of overfitting (Guthery et al., 2003). AIC is a widely used criterion for model selection, and it was calculated using the likelihood (L) of the fitted model and the total number of parameters (p).

$$AIC = -2\ln(L) + 2p$$

Additionally, residual standard error (RSE) was used as a complementary statistic, where a lower RSE signifies a better model fit (Chave et al., 2005). Although various goodness-of-fit metrics have been proposed, AIC and RSE together offer a sufficient and reliable assessment of model performance, especially for mixed-species regression models. Furthermore, *p-values* were reported to determine the statistical significance of model parameters, indicating the likelihood that the observed results occurred by chance.

RESULTS AND DISCUSSIONS

Results

Tree Parameters

Combretum molle and *Terminalia schimperiana* are among the most abundant tree species in Tulu Lafto Forest, with densities of 109 and 53 trees per hectare, respectively. *C. molle* exhibited a lower mean diameter at breast height (17.73±8.79 cm), height (8.11±3.1 m), and basal area (305.99±312.42 cm^2/tree) compared to *T. schimperiana,* which had a mean DBH of 23.38±13.13 cm, height of 10.90±4.39 m, and basal area of 564.87±658.49 cm^2/tree. However, *C.* molle had a higher mean wood specific density (0.573±0.029 g/cm^3) than *T. schimperiana* (0.476±0.026 g/cm^3) (Table 2).

Table 2

Tree parameters measured for T. schimperiana and C. molle in Tulu Lafto Forest (n=40 each)

Tree Species	Summary	DBH (cm)	Height (m)	Basal area (cm^2)	Density (g/cm^3)
Terminalia schimperiana	Min	6.69	4	35.15	0.443
	Max	60.19	20	2843.92	0.521
	Mean	23.38	10.89	564.87	0.476
	sd	13.33	4.39	658.49	0.026
C. molle	Min	6.37	2.5	31.85	0.505
	Max	42.99	17	1450.79	0.614
	Mean	17.73	8.11	305.99	0.573
	sd	8.795	3.10	312.42	0.029

The Wilcoxon rank-sum test showed that *Combretum molle* was significantly shorter (mean = 8.11 m) than *Terminalia schimperiana* (mean = 10.9 m; $W = 508.5$, $p = 0.005$). Although *T. schimperiana* had a higher mean DBH (23.38 cm) compared to *C. molle* (17.73 cm), the difference was not statistically significant at a 95% confidence interval ($W = 597.5$, $p = 0.052$). However, a student's t-test revealed that *C. molle* had a significantly higher wood specific density (mean = 0.57 g/cm^3) than *T. schimperiana* (mean = 0.47 g/cm^3; $t = 16.43$, $p = 0.000$).

Aboveground Biomass

Trimmed small branches of *T. schimperiana* had a mean biomass of 1.91 kg per tree (range: 0.87-2.49 kg), while *C. molle* had a biomass of 2.53 kg per tree (range: 1.44-5.12 kg) (Table 3). In both species, wood biomass was greater than leaf biomass, accounting for 62.11% of the total biomass in *C. molle* and 65.84% in *T. schimperiana*.

Table 3

Summary of Trimmed Biomass (kg) of T. schimperiana and C. molle D: Basal diameter (cm), n = 40.

Tree Species	Summary	D (cm)	Wood (Kg)	Leaf (Kg)	Total (Kg)
T. schimperiana	Min	3.52	0.23	0.2	0.87
	Max	6.51	1.75	1.01	2.49
	Mean	5.23	1.26	0.63	1.91
C. molle	Min	3.08	0.91	0.44	1.44
	Max	7.3	3.15	1.97	5.12
	Mean	4.62	1.57	0.96	2.53

The untrimmed biomass of small branches for *T. schimperiana* was 261.32 kg, with a mean of 6.53 kg (range: 1.05 to 22.51 kg), while for *C. molle*, it was 270.06 kg, with a mean of 6.75 kg (range: 1.42 to 23.28 kg) (Table 4).

Table 4

Untrimmed biomass (kg) of small branches of *C. molle* and *T. schimperiana* (n=40) (where D=basal *diameter (cm) of untrimmed small branch*)

Tree Species	Summary	D (cm)	Biomass (Kg)
T. schimperiana	Minimum	3.66	1.05
	Maximum	23.88	22.51
	Mean	10.39	6.53
	Total		261.32
C. molle	Minimum	3.08	1.42
	Maximum	23.12	23.28
	Mean	8.86	6.75
	Total		270.06

T. schimperiana had significantly more biomass in its trunk and large branches (257.69 kg, range: 26.21-1097.74 kg) compared to *C. molle* (25.29 kg, range: 1.11-82.84 kg). The total aboveground biomass was calculated by adding both trimmed and untrimmed biomass. The results showed higher biomass in *T. schimperiana* (mean = 266.13 ± 209.86 kg) than *C. molle* (mean = 34.57 ± 25.29 kg; $W = 34, p = 0.000$) (Figure 2). In the study area, all trees of *T. schimperiana* and *C. molle* were divided into 8 and 6 DBH classes, respectively, with 5 cm intervals. As the size class increased, the number of individuals decreased, while biomass stock increased for both species. Smaller DBH classes were more abundant but stored less biomass, while larger trees, though fewer in number, accumulated more biomass (Figure 3).

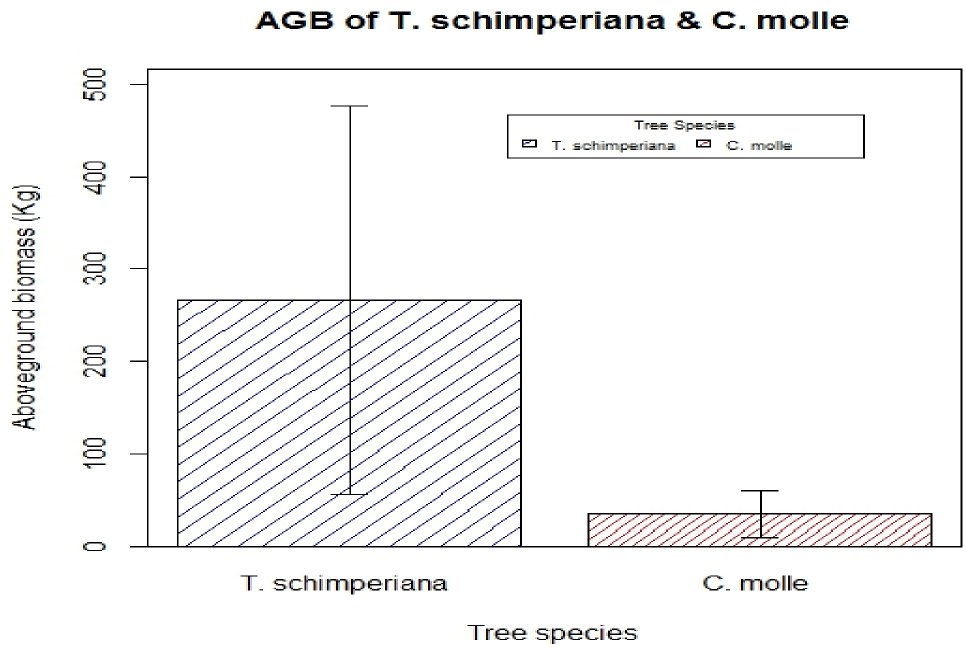

Figure 2. *Aboveground biomass of C. molle and T. schimperiana in Tulu Lafto Forest*

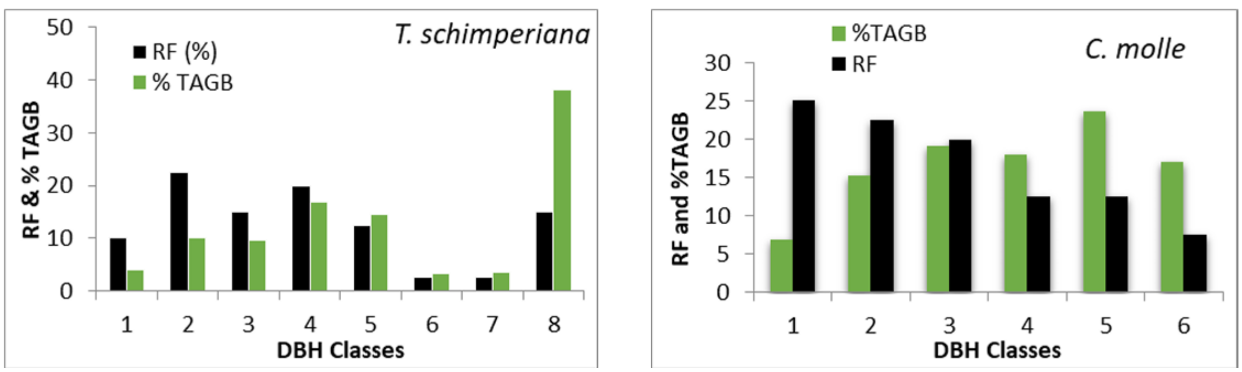

Figure 3. *Relative frequency and percent biomass of C. molle and T. schimperiana in different DBH classes.*

Note: DBH Classes: 1=5.00-10.00 cm; 2=10.01-15.00 cm; 3=15.01-20.00 cm; 4=20.01-25.00 cm; 5=25.01-30.00 cm; 6=30.01-35.00 cm; 7=35.01-40.00 cm; 8=>40 cm

Allometric Equations

In this study, DBH showed a significant positive correlation, accounting for over 94% ($p < 0.05$) of the variation in aboveground biomass of *C. molle*. Similarly, a strong positive correlation was observed between total aboveground biomass (Y_t) and DBH for *T. schimperiana* ($r = 0.92$ ($P < 0.05$)). Aboveground biomass was also positively correlated to tree height, but with greater variance. Regression was made between the dependent variable, aboveground biomass (AGB), and the explanatory variables (DBH and total height) individually and in combination. Three allometric biomass equations were developed and tested for each species. In these regression equations, AGB was related to DBH and height (H) individually to estimate the total biomass of each of the two species (*C. molle* and *T. schimperiana*). The coefficient of determination (R^2) ranged from 0.61 to 0.94 (Table 5). Results indicated that the model with DBH alone (models 2 and 5) performed better in estimating aboveground biomass of *C. molle* (*Adj. R^2=0.77, RSE=8.82, and AIC=291.59*) and *T. schimperiana* (*Adj. R^2=0.94, RSE=43.75, and AIC=419.75*) than the model with height alone (*Adj. R^2=0.61, RSE=11.56, and AIC=313.26 for C. molle and Adj. R^2=0.83, RSE=72.18, and AIC=459.79 for T. schimperiana*). Inclusion of total height in addition to DBH did not show significant variation in model parameters, suggesting the weak relation between height and AGB of both *C. molle* and *T. schimperiana* (models 3 & 6).

Table 5

Allometric biomass equations for a single predictor variable (Yt: total AGB; D: diameter at breast height; H: total height) in Tulu Lafto Forest. n=40.

Model No.	Allometric Equation	a	b	c	RSE	Adj_R^2	AIC	df	P-value	Species
1	$Y_t = a + b * H$	-8.94	4.71	-	11.58	0.61	313.26	38	0.000	*C. molle*
2	$Y_t = a + b * D$	-3.73	1.86	-	8.66	0.78	291.07	38	0.000	
3	$Y_t = a + b(H) + c(D)$	-7.34	1.2	1.51	8.82	0.774	291.59	37	0.000	
4	$Y_t = a + b * H$	-107.18	36.63	-	72.18	0.84	459.79	38	0.000	*T. schimperiana*
5	$Y_t = a + b * D$	-7.26	12.80	-	43.75	0.94	419.75	38	0.000	
6	$Y_t = a + b(H) + c(D)$	-27.94	5.46	11.14	43.31	0.94	419.87	37	0.000	

DISCUSSIONS

Tree parameters

Ethiopia possesses approximately 55 million hectares of woodlands and bushlands (WBISPP, 2004), with the *Combretum–Terminalia* woodland and wooded grassland vegetation types dominating large areas, especially in the western lowlands and river valleys. Common tree species in these ecosystems, such as *Combretum molle* and *Terminalia schimperiana*, are notably present in areas like the Tulu Lafto Forest. Wood properties vary significantly within and between species due to factors like site conditions, genetics, silviculture, and tree age (Henry et al., 2010). For instance, *C. molle* exhibited lower mean diameter at breast height (DBH) and height but had higher wood specific density compared to *T. schimperiana*, highlighting interspecific differences (Muller, 2004; Bastin et al., 2015). The wood density of *C. molle* aligns with that of *C. kraussii* in South Africa (Mensah et al., 2016) and exceeds some earlier estimates (FDRE, 2017). Meanwhile, *T. schimperiana*'s wood density is comparable to that of *T. superba* (Reyes et al., 1992). These interspecific variations in wood density underscore the importance of species-specific data for accurate biomass modeling (Chave et al., 2006), despite the intensive effort required for such measurements.

Aboveground biomass and carbon Stocks

C. molle and *T. schimperiana* have demonstrated significant carbon storage potential in their aboveground biomass in the Tulu Lafto Forest. The average aboveground biomass per tree was 34.57 kg for *C. molle* and 266.13 kg for *T. schimperiana,* respectively. Assuming that approximately 50% of tree biomass is carbon (Brown, 1997), the corresponding carbon stock was 17.28 kg per tree for *C. molle* and 133.07 kg per tree for *T. schimperiana.* These values translate to an estimated carbon stock of around 1.78 tons C ha^{-1} for *C. molle* and 7.05 tons C ha^{-1} for *T. schimperiana,* indicating their important role in the overall carbon sequestration potential of Tulu Lafto Forest. Moreover, the difference in carbon storage potential among these tree species highlights the importance of selecting appropriate species in forestry practices aimed at carbon sequestration and climate change mitigation.

Species-specific Allometric equation

The use of statistical methods to estimate the aboveground biomass of trees, particularly using models that relate biomass to easily measurable dendrometric variables like diameter at breast height (DBH), total height, and wood specific density, has gained emphasis (Eggleston et al., 2006; Picard et al., 2015). Accordingly, allometric equations were employed to estimate the biomass of untrimmed small branches. Although DBH and total height are commonly used tree parameters to estimate aboveground biomass, their predictive accuracy varies across species, especially when there's a weak correlation between DBH, height, and other tree traits. In this study, DBH alone was proven to be a strong predictor of aboveground biomass (AGB) for both *C. molle* and *T. schimperiana*, while adding tree height did not significantly improve model performance.

Although incorporating tree height into biomass models was generally believed to improve prediction accuracy (Chave et al., 2005), this study found a weak correlation between tree height and biomass, likely due to a weak height-DBH correlation influenced by anthropogenic disturbances (e.g., logging, land cover conversion) that ultimately alter growth patterns and biomass accumulation. This supports the idea that the predictive utility of height varies depending on differences in tree architecture (Fayolle et al., 2013; Chave et al., 2005). Consequently, future research should focus on understanding the impacts of disturbance on tree characteristics to refine biomass prediction models. A similar weak relationship was also reported in Miombo woodlands in Malawi. Kuyah et al. (2016) reported a weak relationship between biomass and tree height in Malawi, where environmental/anthropogenic pressures have influenced tree growth.

The study recommends using DBH-based allometric models, specifically model 2 for *C. molle* and model 5 for *T. schimperiana*, as the most accurate. Model 2 for *C. molle* did not show significant prediction errors, closely matching with observed biomass (intercept = 0.0003; slope = 1.00) and outperforming the commonly used Chave et al. (2014) models, which overestimated biomass. Similarly, model 5 for *T. schimperiana* (intercept = –2.25; slope = 1.01) showed minimal error compared to pan-tropical models. The findings highlight the need for species- and site-specific models rather than relying on generalized equations.

Model uncertainties

Destructive sampling remains the most accurate method for estimating tree biomass (Lung et al., 2015; Seifert & Seifert, 2013; Kunneke et al., 2013), but its ecological and legal constraints have led to a preference for nondestructive or semi-destructive approaches. This study acknowledges potential model uncertainty due to the use of a uniform wood-specific density, which overlooks the known vertical variation in wood density within trees. Although the sample size (40 trees per species) is more than previous studies in Ethiopia (Tesfaye et al., 2015; Worku, 2015), it may still fall short in representing intraspecific variability. Nevertheless, the allometric models developed here contribute valuable tools for estimating aboveground biomass of *C. molle* and *T. schimperiana* in Ethiopia's *Combretum–Terminalia* woodlands.

CONCLUSIONS

Ethiopia's vegetation is highly diverse, ranging from moist Afromontane forests to arid desert scrubs. Despite this, only limited research has been conducted to assess the carbon sequestration potential of these ecosystems, partly due to a lack of appropriate biomass estimation models. To support Ethiopia's climate-resilient green economy initiatives and climate change mitigation efforts, an accurate assessment of forest carbon storage is essential. However, widely used generalized allometric models have shown poor predictive performance for tree species in Ethiopia, which is also true in this study area, where they overestimated the biomass of *C. molle* in Tulu Lafto

Forest. In contrast, locally developed, species-specific models provided more accurate estimates.

Recommendations

This study recommends Model 2 for *C. molle* (DBH range 5–43 cm) and Model 5 for *T. schimperiana* (DBH range 5–60 cm). Federal and regional research institutes and forestry departments should carry out field studies to test the validity of these models in various ecological regions across the country. Additionally, the study recommends that government agencies, including REDD+ offices, should include *C. molle* and *T. schimperiana* in afforestation programs for carbon sequestration projects. Finally, because belowground biomass represents a significant carbon pool, especially in dryland ecosystems, universities, government climate change units (e.g., REDD+ offices), and environmental researchers should work on root biomass assessments.

CRediT Authorship Contribution Statement

Fekadu Gurmessa: Conceptualization, Data Collection, Model Development and Analysis & Writing Original Draft. **Gora Alemayehu:** Data Analysis & Model Validation. **Mezgebu Senbeto:** Supervision, Review & Editing.

Declaration of Competing Interest

The authors declare that there is no conflict of interest.

Ethical approval

The authors explained the objectives of the study and obtained a support letter from Wallaga University and were granted permission by the government institution in the Abe Dongoro district and the local community.

Data Availability

The data used in this study are available upon request.

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