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MORALITY BEFORE KNOWLEDGE

Biomass allocation and carbon partitioning in young teak trees: Implications for ecological modeling and sustainable resource management

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ABSTRACT
Background: Climate change, that is marked by improvement of earth's surface temperature (global warming), is caused by human activities that increase the emission of greenhouse gasses to the atmosphere. These gases include CO_2, N_20, CH_4, SF_6, PFC, and HFC. Ignition of hydrocarbonic compounds such as fossil fuels (coal, petrol fuel, and natural gas) or biomass (wood) are human activity that could cause emission of greenhouse gases to the atmosphere and, further, global climate change. **Methods:** This study involved field-based observations with laboratory-based sample analysis. Materials used for this study consisted of 30 teak *(Tectona grandis* L. f.) consisting of 6 tree samples in each age group of 1 to 5 year old tree located within the KPH Balapulang area. **Findings:** Biomass root to shoot ratio based on main stem is about 0.1155-0.5048 (Average 0.2296), while based to surface biomass is about 0.1090-0.4317 (Average 0.1983). Carbon mass root to shoot ratio based on main stem is about 0.1159-0.5068 (Average 0.2320), while based to surface carbon mass is about 0.1111-0.4381 (Average 0.2030). Average expansion factor of biomass for age level I-V is 1.15, while average expansion factor of carbon mass for age level I-V is 1.13. **Conclusion:** The result of this study indicating that those ratios and factors quantify the proportion of root versus aboveground biomass or carbon and the multiplication of stem biomass or carbon to estimate total tree values. **Novelty/Originality of this article:** This study provides the quantitative data on root-to-shoot ratios, biomass and carbon mass expansion factors for teak (*Tectona grandis* L. f.) across different age classes.

KEYWORDS: expansion factor; root to shoot ratio; teak.

1. Introduction

The phenomenon of climate change has attracted the attention of various groups, including academics and environmentalists. Climate change is a condition characterized by increasing Earth's surface temperature (global warming), which is triggered by excessive human activities in using fossil fuels, resulting in the accumulation of greenhouse gases (GHGs). These GHGs include carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), sulfur hexafluoride (SF_6), perfluorocarbons (PFC), and hydrofluorocarbons (HFC) in the atmosphere. One of the natural elements capable of absorbing large amounts of CO_2 is forest. This is because the vegetation within forests binds CO_2 during the photosynthesis process and stores it in the form of biomass. Therefore, the existence of forests plays a significant

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role in preventing and addressing global warming. 50% of the biomass found in forests consists of carbon (Brown, 1997).

Perum Perhutani is one of Indonesia's state-owned enterprises/*Badan Usaha Milik Negara* (BUMN) that consistently manages plantation forests located in Java, producing various types of commercial timber, including hardwood and teak wood. In addition to the tangible benefits of timber, intangible benefits such as stored carbon mass are also obtained as part of efforts to mitigate GHG emissions in the atmosphere. Therefore, it is necessary to conduct research on the calculation of biomass and carbon mass in forest stands within Perum Perhutani areas, particularly in teak stands. One method to calculate tree biomass and carbon mass is by using the root-to-shoot ratio The root-to-shoot ratio is the value representing the proportion or comparison between the biomass or carbon mass in the roots of teak trees and the biomass or carbon mass above ground (stem, branches, twigs, and leaves) (Dewi, 2011). The objective of this study is to calculate the root-to-shoot ratio of biomass and carbon mass in the teak trees *(Tectona grandis L. f.).*

Biomass is defined as the total mass or dry weight of all living organisms supported at each trophic level, encompassing all material derived from living organisms, including both living and dead organic matter, whether aboveground or belowground, such as trees, crop residues, grasses, litter, roots, animals, and animal waste (Penman, 2003). According to Chapman (1976), biomass refers to the weight of organic material of an organism per unit area at a given time, typically expressed as dry weight or, in some cases, ash-free dry weight. Forests play a crucial role in enhancing CO_2 absorption (Chen et al., 2021; Guo et al., 2024; Psistaki et al., 2024). With the aid of sunlight and soil water, chlorophyll-containing vegetation can absorb CO_2 from the atmosphere through the process of photosynthesis. The products of photosynthesis are stored in the form of biomass, allowing vegetation to grow larger or taller (Ding et al., 2025; Hiltbrunner et al., 2021; Weng et al., 2025). This growth continues until the vegetation physiologically ceases to grow or is harvested. In general, forests with high net growth—particularly those dominated by trees in their active growth phase—are capable of absorbing greater amounts of CO_2, whereas mature forests with minimal growth primarily store carbon stocks but are unable to absorb additional or surplus CO_2 (Kyrklund, 1990). The objective of this study is to calculate the root-to-shoot biomass and carbon mass ratios of teak (Tectona grandis L. f.). The findings of this research are expected to provide accurate information for forest managers regarding the potential biomass and carbon mass stored in the roots and aboveground components of teak trees.

2. Methods

This study involved field-based observations with laboratory-based sample analysis. Materials used for this study consisted of 30 teak *(Tectona grandis L. f.)* trees located within the KPH Balapulang area. This research uses two data, namely primary and secondary data. Primary data were collected directly in the field, encompassing measurements of the diameter and length of each main stem and branch, as well as the fresh weight of leaves, twigs, and roots. In addition, secondary data were collected from the Forest Management Unit/*Kesatuan Pengelolaan Hutan* (KPH) Balapulang office, which provided research location maps and detailed descriptions of site conditions such as topography, soil, geology, and climate.

2.1 Tree sampling and selection methodology

The selection of sample trees followed specific criteria, namely six trees were selected from each age class to represent the diameter distribution of teak stands in the study area, the selected trees were required to be healthy and exhibit normal morphological form, each sample tree was chosen to represent the average condition of teak trees within its respective diameter class (Elias, 2010). In this study, 30 teak (*Tectona grandis* L. f.) trees were selected as samples, representing different age classes within the Forest Management Unit of Balapulang area.

Table 1. Age class range of teak trees used as research material

No	Age Class	Number of Sample Trees
1	I	6
2	II	6
3	III	6
4	IV	6
5	V	6
Total number of sample trees	30 trees	

The diameter of each sample tree was measured at 1.30 m above ground level (diameter at breast height, DBH) and each tree was assigned a sequential identification number. Subsequently, the trees were felled, and measurements were taken for the volume of the main trunk and branches, as well as the fresh weight of the twigs, leaves, and roots. Upon completion of these measurements, three subsamples were collected from each tree component—namely the main trunk, branches, twigs, leaves, and roots—for further laboratory analysis.

2.2 Sample collection and field measurements

The sample tree data collection method involved the following stages (Elias, 2010). There are measurements of sample tree diameter, preparation prior to tree felling, branch pruning, felling of the main trunk, root excavation, separation of tree components, measurement of trunk and branch volume, measurement of fresh weight of twigs, leaves, and roots. Laboratory test samples were taken from each tree: the main stem, branches, twigs, leaves, and roots and stumps. Three replicates were taken from each tree, resulting in a total of 30 x 5 x 3 samples, or 450 samples. These samples consisted of 90 main stem samples, 90 branch stem samples, 90 twig samples, 90 leaf samples, and 90 root samples.

2.3 Laboratory testing material testing methods

Wood density samples were prepared with dimensions of 2 cm × 2 cm × 2 cm. Sample were processed with weighing the sample in its wet state to obtain the initial (fresh) weight. Then, determining the sample volume: the sample was coated in paraffin and submerged in an Erlenmeyer flask filled with water until fully submerged. According to Archimedes' principle, the volume of the sample corresponds to the volume of water displaced by the sample. Last, drying the sample in an oven at 103 ± 2°C for 24 hours and weighing it to obtain the oven-dry weight. Moisture content samples from the main trunk, branches, and roots with diameters greater than 5 cm were prepared in dimensions of 2 cm × 2 cm × 2 cm. Samples from leaves, twigs, and small roots (diameter < 5 cm) were prepared with a mass of approximately 300 g each. Sample were processed with weighing the sample in its wet state, drying the sample in an oven at 103 ± 2°C until a constant weight was achieved and placing it in a desiccator and weighing the oven-dry weight, and expressed as a percentage of the oven-dry weight, was recorded as the moisture content of the sample.

The determination of volatile matter content followed the American Society for Testing and Materials (1990) D 5832-98 standard. Sample were processed with cutting the wood samples from each tree component into small pieces the size of matchsticks, oven-drying the samples at 80°C for 48 hours, grinding the dried samples into powder using a Willey mill, sieving the powder through a 40–60 mesh screen, weighing approximately 2 g of the sieved powder in a porcelain crucible, covering it, and recording the initial weight, placing the crucible in an electric furnace at 950°C for 2 minutes, then cooling in a desiccator and reweighing, the difference between the initial and final weight, expressed as a percentage of the oven-dry sample weight, was recorded as the volatile matter content. Samples were processed according to ASTM D 2866-94 standard. Sample were processed with placing the residual sample from the volatile matter determination into an electric furnace at 900°C for 6 hours, cooling the sample in a desiccator and weighing it to obtain the final weight, and the final weight (ash), expressed as a percentage of the oven-dry sample weight, represented the ash content of the sample. The carbon content of each tree component was determined according to the Indonesian National Standard/*Standar Nasional Indonesia* (SNI) 06-3730-1995. The carbon content of the sample was calculated by subtracting the percentages of volatile matter and ash from 100%.

2.4 Data processing methods

The symbols used in the formulas are defined as follows, V denotes the volume (m^3); π\piπ is the mathematical constant 3.14; Dp represents the diameter at the base (m); Du refers to the diameter at the tip (m); and L indicates the length (m).

$$V = \frac{1}{4}\pi\left\{\frac{Dp + Du}{2}\right\}^2 x\ L \quad \text{(Eq. 1)}$$

The symbols used in the formulas are defined as follows, BJ denotes specific gravity refers to the oven-dry mass; VVV represents the volume in the green condition; and ρ indicates the moisture coefficient ($g/cm^3 = 1$).

$$BJ = \frac{Berat\ Kering\ Tanur}{Volume/\rho} \quad \text{(Eq. 2)}$$

The symbols used in the formulas are defined as follows, BBc denotes wet weight of sample (gr). BKc denotes oven-dry weight of sample (gr). % KA represents moisture content (%).

$$\%\ \text{KA} = \frac{BBc - BKc}{BKc}\ x\ 100\% \quad \text{(Eq. 3)}$$

The symbols used in the formulas are defined as follows, BK denotes oven-dry weight (gr). BB denotes wet weight (gr). %KA represents moisture content (%).

$$BK = \frac{BB}{1 + [\frac{\%KA}{100}]} \quad \text{(Eq. 4)}$$

The calculation of volatile matter content, is based on the proportion of the sample's weight loss relative to its oven-dry weight. In this context, the weight loss experienced by the sample, while the oven-dry sample weight. Volatile matter content is therefore obtained by dividing the sample's weight loss by its oven-dry weight and multiplying the result by 100 percent. Similarly, the determination of ash content, is conducted by comparing the residual sample weight with the oven-dry sample weight. Here, the remaining weight of the sample after ignition, and this value is divided by the oven-dry sample weight to calculate the ash content, which is then expressed as a percentage.

The carbon content, is derived from the relationship between volatile matter and ash content. Specifically, carbon content is calculated by subtracting both the volatile matter content and the ash content from 100 percent, reflecting the proportion of carbon remaining in the sample. In addition, the biomass ratio (Rb) is defined as the ratio between root biomass (Ba) and aboveground biomass (Bat). This ratio provides an indication of biomass distribution within the plant structure. Likewise, the carbon mass ratio (Rc) is determined by comparing the carbon mass in the roots (Ca) with the carbon mass in the aboveground components (Cat). This ratio illustrates the allocation of carbon within different parts of the plant.

3. Results and Discussion

3.1 Moisture content

Moisture content refers to the amount of water contained in wood relative to its oven-dry weight, expressed as a percentage. The results of the study on the moisture content of teak trees across different age classes are presented in Table 2.

Table 2. Water content of teak trees in each age class

Age Class	Water Content (%)				
	Stem	Branches	Twigs	Roots	Leaves
I	113.72	114.28	72.17	113.47	50.98
II	78.89	56.97	66.72	81.90	103.83
III	76.70	62.40	50.89	69.56	131.84
IV	82.16	85.16	85.68	83.87	44.62
V	39.16	37.83	19.15	62.38	-
Average	78.13	71.33	58.92	82.24	82.82

Table 2 shows the average moisture content of teak trees. The leaf part exhibited the highest average moisture content compared to other parts of the tree, amounting to 82.82%, while the lowest average moisture content was found in the twig part, at 58.92%. Leaves have the highest moisture content, presumably because they serve as the main site of photosynthesis and contain cell cavities filled with absorbed water and nutrients from the environment. In addition, the presence of stomata allows for greater water absorption within the leaves. Roots have the second-highest moisture content after leaves, as they function to absorb water and nutrients from the soil, thereby allowing roots to retain a considerable amount of water. Twigs, on the other hand, exhibit lower moisture content because they are composed of smaller cellular cavities compared to the stem, branches, and roots.

3.2 Specific gravity

The specific gravity of wood is the ratio between the density of the wood and the density of a standard substance at a certain temperature (Brown, 1997). Distilled water at 4°C is commonly used as the standard substance, with a density of 1 g/cm^3. The results of the study on the specific gravity of teak wood are presented in Table 3. Table 3 shows that the specific gravity of teak trees ranges from 0.5150 to 0.5654. The variation in specific gravity values is influenced by environmental factors such as soil fertility and soil type.

Table 3. Specific gravity of teak trees in each age class

Age Class	Specific Gravity				
	Stem	Branches	Twigs	Roots	Leaves
I	0.3970	0.4740	0.3870	0.4700	0.1680
II	0.5930	0.5590	0.5770	0.5870	0.1040
III	0.5510	0.6110	0.6070	0.6280	0.0900
IV	0.5630	0.4950	0.4690	0.5760	0.1120
V	0.5610	0.6150	0.5350	0.5660	-
Average	0.5330	0.5508	0,5150	0,5654	0.1185

3.3 Volatile matter content

Volatile matter content refers to the substances in charcoal that vaporize easily when heated to a temperature of 950°C. Based on the results of laboratory analysis, the highest average volatile matter content was found in the leaf portion (45.72%), followed by twigs (39.48%), branches (36.65%), and roots (35.66%), while the lowest average volatile matter content was observed in the stem (33.14%). These findings are consistent with the study by

Dewi on Acacia mangium, which reported the highest volatile matter content in the leaves and the lowest in the stem (Dewi, 2011). The high volatile matter content in leaves is attributed to their higher concentrations of aliphatic, terpenoid, and phenolic compounds, which are easily volatilized at 950°C. Approximately 30% of aliphatic, terpenoid, and phenolic compounds are found in the woody parts of the tree, while 70% are present in the leaves (Haygreen & Bowyer, 1982). The complete results of the study on the volatile matter content of teak *(Tectona grandis L. f.)* are presented in Table 4.

Table 4. Teak tree volatile matter content in each age class

Age Class	Volatile Matter (%)				
	Stem	Branches	Twigs	Roots	Leaves
I	33.65	37.67	42.65	36.07	48.94
II	28.80	32.81	34.79	31.05	40.41
III	33.73	38.15	38.72	35.57	43.49
IV	35.69	39.40	41.42	38.71	50.06
V	33.86	35.21	39.82	36.89	-
Average	33.14	36.65	39.48	35.66	45.72

3.4 Ash content

Ash represents the inorganic components that remain after the combustion of organic matter. Based on the results of laboratory analysis, the highest percentage of ash content was found in the leaf portion, with a value of 2.90%, while the lowest was observed in the stem, at 0.69%. These findings are consistent with the study by Dewi, which reported that Acacia mangium exhibited the highest ash content in the leaves (3.61%) and the lowest in the stem (1.46%) (Dewi, 2011). The high ash content in leaves is attributed to their relatively high concentrations of inorganic compounds and water, which result from photosynthetic processes and are transported to the leaves via the xylem. The complete results of the analysis of ash content in teak *(Tectona grandis L. f.)* are presented in Table 5.

Table 5. Teak tree ash content in each age class

Age Class	Ash Content (%)				
	Stem	Branches	Twigs	Roots	Leaves
I	0.73	0.79	0.99	0.70	3.32
II	0.79	0.76	0.70	0.83	2.82
III	0.61	0.77	0.69	0.77	2.77
IV	0.88	0.65	0.73	0.68	2.68
V	0.43	0.65	0.88	0.71	-
Average	0.69	0.72	0.80	0.74	2.90

3.5 Carbon content

Carbon content represents the final value obtained by subtracting the total ash and volatile matter contents. Tree parts with higher ash and volatile matter contents generally exhibit lower carbon content. Based on laboratory analysis, the highest average carbon content was found in the stem and root portions of teak (*Tectona grandis* L. f.), with values of 66.17% and 63.60%, respectively. These results are consistent with the findings of Dewi on *Acacia mangium*, which reported that the highest carbon content was found in the stem and root parts of the tree (Dewi, 2011). The complete results of the analysis of teak carbon content are presented in Table 6.

Table 6. Teak tree carbon content in each age class

Age Class	Carbon Content (%)				
	Stem	Branches	Twigs	Roots	Leaves
I	65.63	61.55	56.36	63.23	47.69
II	70.41	66.43	64.51	68.13	56.78
III	65.66	61.08	60.59	63.66	53.74

IV	63.43	59.95	57.84	60.60	47.27
V	65.71	64.15	59.30	62.40	-
Average	66.17	62.63	59.72	63.60	41.10

3.6 Biomass

Biomass refers to the amount of organic material per unit area contained within an ecosystem component (in this case, the tree), generally expressed in terms of dry weight. The complete results of the biomass analysis of teak *(Tectona grandis L. f.)* are presented in Table 7. Based on the analysis, the highest average biomass value was found in the stem portion of the tree, amounting to 366.1223 kg. This is because the products of photosynthesis in the leaves—mainly polysaccharide compounds consisting of carbon, hydrogen, and oxygen, which are the principal constituents of biomass—are predominantly distributed to the stem.

Table 7. Teak tree biomass in each age class

Age Class	Biomass (Kg)				
	Stem	Branches	Twigs	Roots	Leaves
I	15.4027	1.1857	2.8303	2.8357	1.4801
II	89.6162	2.2740	9.2005	45.2379	3.7012
III	383.9103	4.3003	16.9960	70.1164	6.0506
IV	688.6510	11.9559	51.3586	110.9633	15.6564
V	653.0312	13.0125	26.0632	75.4542	-
Average	366.1223	6.5457	21.2897	60.9215	5.3777

3.7 Carbon Mass

Based on the results of laboratory analysis of teak *(Tectona grandis L. f.)* carbon mass, the stem portion exhibited the highest average carbon mass compared to other parts of the tree. The branches showed the lowest carbon mass value, likely due to the relatively small number of branches present in the teak trees used as samples. Carbon mass is influenced by biomass, with a directly proportional relationship—meaning that the higher the biomass, the greater the carbon mass of the teak tree. The detailed results of the carbon mass analysis in this study are presented in Table 8.

Table 8. Carbon mass of teak trees in each age class

Age Class	Carbon Mass (Kg)				
	Stem	Branches	Twigs	Roots	Leaves
I	8.9066	0.1289	1.7152	1.7309	0.8716
II	61.5178	0.7869	6.3183	31.1756	2.5406
III	250.5027	0.9468	11.0209	45.5761	3.9053
IV	429.5962	2.4842	32.0189	69.1667	9.7229
V	423.9428	1.5271	16.8926	49.1256	-
Average	234.8932	1.1748	13.5932	39.3549	3.4081

3.8 Root-to-Shoot ratio of tree biomass

The root-to-shoot ratio of tree biomass is the comparison between below-ground biomass (roots) and above-ground biomass (main stem, branches, twigs, and leaves). The ratio of root biomass to main stem biomass is obtained by dividing the biomass value of the roots by that of the main stem of the teak *(Tectona grandis L. f.)* tree. The aboveground biomass ratio is calculated by dividing the root biomass by the total sum of biomass values from all above-ground tree components (main stem, branches, twigs, and leaves).

The results of the study on the root-to-shoot ratio of teak tree biomass are presented in Table 9. The analysis showed that the root-to-shoot ratio for the main stem biomass ranged from 0.1155 to 0.5048, with an average of 0.2296. The root-to-shoot ratio for total above-ground biomass ranged from 0.1090 to 0.4317, with an average value of 0.1983.

These values are lower than those reported by Adinugroho for several typical secondary forest tree species—Macaranga, Mallotus, Trema, Melastoma, and Leea—which had a root-to-shoot ratio of 0.25 (Adinugroho et al., 2006). Based on these results, it can be concluded that root biomass accounts for approximately 20% of the total biomass of teak trees. This proportion is higher than that reported by Elias for Acacia mangium, which had a root biomass proportion of 15%, with a root-to-shoot ratio ranging from 0.0906 to 0.2071 and an average of 0.1443 (Elias, 2010). The root-to-shoot ratio is a variable commonly used to estimate below-ground biomass. Its application is based on the difficulty of obtaining root samples for direct biomass measurements. Similar to the Biomass Expansion Factor (BEF), the root-to-shoot ratio serves as an indirect estimation method for determining total tree biomass.

Table 9. Root to shoot ratio of teak tree biomass

Age Class	Ratio of Root Biomass and Aboveground Tree Biomass	
	Stem	Aboveground
I	0.1841	0.1357
II	0.5048	0.4317
III	0.1826	0.1705
IV	0.1611	0.1446
V	0.1155	0.1090
Average	0.2296	0.1983

3.9 Root-to-Shoot ratio of tree biomass

The root-to-shoot ratio of carbon mass represents the proportion between the carbon mass stored in the roots of teak *(Tectona grandis L. f.)* and the total carbon mass stored in above-ground components (stem, branches, twigs, and leaves). This value is calculated by dividing the carbon mass of the roots by the carbon mass of the main stem, and by comparing the carbon mass in the roots with the total above-ground carbon mass of the tree (main stem, branches, twigs, and leaves). The results of the root-to-shoot ratio analysis of teak tree carbon mass are presented in Table 10.

Table 10. Root to shoot ratio of teak tree carbon mass

Age Class	Ratio of Root Carbon Mass to Aboveground Tree Carbon Mass	
	Stem	Aboveground
I	0.1943	0.1489
II	0.5068	0.4381
III	0.1819	0.1711
IV	0.1610	0.1460
V	0.1159	0.1111
Average	0.2320	0.2030

Table 10 shows that the root-to-shoot ratio of root carbon mass to main stem ranged from 0.1159 to 0.5068, with an average value of 0.2320. The root-to-shoot ratio of root carbon mass to total above-ground carbon mass ranged from 0.1111 to 0.4381, with an average value of 0.2030. These values are lower than those reported by Adinugroho who found a root-to-shoot ratio of 0.25 in several typical secondary forest tree species—Macaranga, Mallotus, Trema, Melastoma, and Leea—but higher than those reported by Elias, who found that Acacia mangium had a root-to-shoot carbon mass ratio of 0.15, ranging from 0.0794 to 0.2132, with an average of 0.1442 (Adinugroho et al., 2006; Elias et al., 2010).

The root-to-shoot ratio of carbon mass is used to estimate the total carbon stock in forest stands, supported by data such as stand volume, Biomass Expansion Factor (BEF), wood density, and carbon content in biomass. As stated by Penman et al. (2003), total carbon stock in forest stands can be estimated using the formula: $C = (V \times WD \times BEF) \times (1 + R/S) \times CF$ where C is the total carbon stock (tons/ha), V is the stand volume

(m^3/ha), WD is the wood density (tons/m^3), BEF is the ratio of above-ground biomass to stem biomass, R/S is the ratio of root biomass to shoot biomass, and CF is the carbon fraction in biomass (Penman, 2003).

3.10 Expansion factor

According to Sutaryo, the expansion factor is used to multiply a certain nominal quantity (volume or biomass) of one or more tree components to obtain the corresponding nominal quantity for the entire tree (Sutaryo, 2009). The biomass or carbon mass expansion factor multiplies the biomass or carbon mass of the stem to estimate the total biomass or carbon mass of the whole tree. In simple terms, the biomass expansion factor or carbon mass expansion factor is the ratio of the total biomass or carbon mass of all tree components to the biomass or carbon mass present in the stem. Table 11 presents the values of biomass and carbon mass expansion factors for teak (*Tectona grandis* L. f.) trees.

Based on the data in Table 11, the values of the biomass and carbon mass expansion factors vary across different age classes of the trees. The calculated biomass expansion factor for age class I is higher than that of the other age classes. Expansion factors are commonly used as an approach to estimate aboveground biomass or carbon mass, supported by data such as stem volume and wood density. Therefore, the application of biomass or carbon mass expansion factors must consider the age of the forest stand, as using a constant expansion factor for trees of any age can lead to biased estimates.

Table 11. Biomass expansion factor and carbon mass of teak trees

Age Class	Expansion Factor	
	Biomass	Carbon Mass
I	1.3568	1.3049
II	1.1693	1.1568
III	1.0712	1.0634
IV	1.1147	1.1029
V	1.0598	1.0434
Average	1.1544	1.1343

3.11 Discusion

The teak tree (*Tectona grandis* L. f.), a member of the Verbenaceae family, is a deciduous species that sheds its leaves during the dry season (Setiawan et al., 2024; Sreekumar & Sanil, 2021). In Indonesia, teak wood is known by various local names, including *deleg*, *dodokan*, *jate*, *jatih*, *jatos*, *kiati*, and *kuludawa*, while in other countries it is referred to as *giati* (Venezuela), *teak* (Myanmar, India, Thailand, the United States, Germany), *teck* (France), and *tea* (Brazil). Teak trees can grow to substantial sizes over several centuries, reaching heights of 40–45 meters with diameters of 1.8–2.4 meters (Arunkumar et al., 2024). On average, teak trees may reach heights of 9–11 meters with diameters of 0.9–1.5 meters. High-quality teak trees are characterized by large girth, straight boles, and minimal branching. The finest teak typically comes from trees over 80 years old (Martawijaya, 1981).

According to Martawijaya (1981), teak grows well in regions with a distinct dry season, rainfall types C to F, an average annual precipitation of 1,200–2,000 mm, and elevations up to 700 meters above sea level. Teak trees can grow on various geological formations and are not restricted to a specific soil type, but they require well-drained soils with adequate aeration. Teak has an average specific gravity of 0.67 (ranging from 0.62 to 0.75), with durability classes I–II and strength class II. Its heartwood ranges in color from golden brown to reddish brown, making it easily distinguishable from the sapwood, which is whitish to slightly grayish. Teak is widely used for construction materials, door and window frames, door panels, railway sleepers, household furniture, and decorative veneers (Mandang & Pandit, 1997).

Sutaryo (2009) states that biomass is classified into four categories, (1) sboveground biomass, which includes all living materials above the soil surface, consisting of stems, stumps, branches, bark, seeds, and leaves of vegetation from both tree strata and understory plants in the forest floor, (2) belowground biomass, which comprises all biomass from the living roots of plants. The definition of roots applies up to a specified diameter threshold, as roots smaller than this limit are often difficult to distinguish from soil organic matter and litter, (3) dead organic matter, which includes dead wood and litter. Litter refers to all dead organic materials with diameters smaller than the specified limit and exhibiting various levels of decomposition on the soil surface. Dead wood includes all dead organic materials not categorized as litter, whether still standing or lying on the ground, as well as dead roots and stumps with diameters exceeding the specified limit, (4) soil organic carbon, which encompasses carbon in both mineral soils and organic soils, including peat.

Carbon is the fundamental building block of all organic compounds. Its movement within an ecosystem parallels the flow of energy through other chemical substances; for instance, carbohydrates are produced during photosynthesis, and CO_2 is released along with energy during respiration. The reciprocal processes of photosynthesis and cellular respiration form a connection between the atmospheric and terrestrial environments within the carbon cycle. Plants obtain carbon in the form of CO_2 from the atmosphere through leaf stomata and incorporate it into organic biomass through photosynthesis. A portion of this organic material then becomes a carbon source (Campbell et al., 2004, as cited in Agnita, 2010).

Sutaryo (2009) states that forests, soils, oceans, and the atmosphere all store carbon that moves dynamically among these storage components over time. These storage components are referred to as active carbon pools. Deforestation alters the carbon balance by increasing the amount of carbon in the atmosphere and reducing the carbon stored in forests; however, it does not increase the total amount of carbon interacting with the atmosphere. Another important carbon reservoir is fossil fuel deposits. Carbon pools are categorized into three main groups: living biomass, dead organic matter, and soil carbon (Penman, 2003). Living biomass consists of two components: Aboveground Biomass (AGB) and Belowground Biomass (BGB). Dead organic matter is grouped into two categories, namely dead wood and litter (Błońska et al., 2023; Shannon et al., 2022).

There are four main methods for estimating biomass: (1) destructive sampling through on-site harvesting, (2) non-destructive sampling using forest inventory data collected in situ, (3) remote sensing–based estimation, and (4) model development. Allometric equations are used to extrapolate sample data to larger areas. However, the use of standard allometric equations varies across locations and species, and applying generalized equations may lead to significant errors in biomass estimation (Heiskanen, 2006). Two general approaches are used to estimate the biomass potential of trees or forests; direct and indirect approaches. The direct approach involves the development of allometric equations, whereas the indirect approach uses biomass expansion factors. The latter cannot be used to estimate carbon at the individual tree level (Penman, 2003). Brown (1997) states that there are two approaches for estimating tree biomass. The first is based on estimating the volume of the bark to the branch-free bole, which is then converted into total biomass (tons/ha). The second involves directly using biomass regression equations.

The volatile matter content represents the easily evaporated substances contained in charcoal that are lost when heated to 950°C. Chemically, volatile matter is divided into three subgroups: aliphatic compounds, terpenes, and phenolic compounds. These volatile substances can coat and block the pores of charcoal (Haygreen & Bowyer, 1982). Ash content refers to the amount of metal oxides remaining after high-temperature combustion. Ash consists of minerals strongly bound within the charcoal, such as calcium, potassium, and magnesium. The main components of ash in tropical wood include potassium, calcium, magnesium, and silica. Errors in ash determination may occur due to the loss of alkali metal chlorides and ammonium salts, as well as incomplete oxidation of alkaline earth metal carbonates (Achmadi, 1990). Moisture content is defined as the amount of water contained in wood, expressed as a percentage of oven-dry weight (Kumar, 2025; Thybring &

Fredikssson, 2023). Moisture content estimation can be used to predict tree biomass. Moisture content is typically measured using two oven-drying methods: the low-temperature method at 103°C and the high-temperature method at 130°–133°C (Bonner, 1995). The root-to-shoot biomass ratio is the proportion between root biomass and the aboveground biomass of a tree. This ratio is calculated based on the total root biomass relative to the total aboveground biomass, which includes the stem, branches, twigs, and leaves.

4. Conclusions

The results of the study indicate that the root-to-shoot ratio of biomass in the main stem ranges from 0.1155 to 0.5048 with the average value of 0.2296. The root-to-shoot ratio of aboveground biomass ranges from 0.1090 to 0.4317, with an average value of 0.1983. The root-to-shoot ratio of root carbon mass to the main stem ranges from 0.1159 to 0.5068, with an average value of 0.2320. The root-to-shoot ratio of root carbon mass to aboveground components ranges from 0.1111 to 0.4381, with an average value of 0.2030. The average biomass expansion factor for teak trees in age classes I-V is 1.15. While the average carbon mass expansion factor for teak trees in age classes I-V is 1.13. The root-to-shoot ratio of biomass and carbon mass represents the proportion between the biomass or carbon mass of the roots and the biomass or carbon mass of the aboveground components (stem, branches, shoots, and leaves). The biomass expansion factor or carbon mass expansion factor refers to the ratio of the total tree biomass or carbon mass to the biomass or carbon mass contained in the tree stem.

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Author Contribution

The author solely carried out all stages of the research, including conceptualization, data collection, analysis, and manuscript preparation. All responsibilities and decisions related to this article were completed independently by the author.

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