Allometric models to estimate the aboveground biomass of forest: A literature review

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Abstract. Forests are important carbon sinks throughout the world, and therefore, the key to reducing the impact of climate change. Allometric models are essential for measuring biomass and carbon storage in forest ecosystems. Expected allometry exists for tropical trees, but species-specific models and locations are more accurate. The more reasonable methods for estimating tree biomass and carbon storage in forests, are very critical given, concerns to be global climate change. This study aimed to clarify the model formation in estimating aboveground biomass. The stages of this research include several steps, namely in the initial stages, gathering articles, and journals, then making a resume and classifying the independent variables used in allometric models. The most common independent variables are diameter at breast height (DBH) and height data.

1. Introduction
Forests have a significant role to play in mitigating climate change by absorbing carbon from the atmosphere and absorb it through the process of photosynthesis in roots, branches the leaves, stems, and roots [1]. According [2] states that live tree biomass estimates are very important for carbon accounting, bioenergy feasibility studies, and other analyzies. Aboveground biomass - the number of organic producers in living and dead plant material - is an essential component of the carbon cycle in forest ecosystems, which provides short-term and long-term carbon sequestration [3]. According to [4], in the tropical forest, 90% of the total aboveground biomass precise tree biomass estimation models are important for conservation and management. Predicting ABG on a large spatial scale in central Amazon is a challenging task due to inherent variations in tree allometry and architecture, heterogeneity of succession stages, and high diversity of tree species. Accurate assessment of estimated forest biomass is vital for applications such as wood extraction, tracking changes in forest carbon stocks, and the global carbon cycle. Forest biomass values can be estimated through field measurements and Geographic Information Systems, and remote sensing [5]. According to [6] states that allometric regression models are often used to estimate tree biomass in the forests. These models are mathematical functions that connect the dry mass of a tree with one or more tree dimensions, such as height, diameter, and wood density. The allometric equation model was often used to estimate forest biomass. Allometric suitability equations usually have good match performance and high $R^2$ values, and variables for prediction
biomass, such as the diameter and height of trees [7]. Accurate estimation of forest carbon storage and changes in storage capacity is essential to assess the impact of forest management on the role of forests in carbon sequestration. This study aims to clarify the model formation in estimating aboveground biomass.

2. Research Methods
To clarify the aboveground biomass estimation model, the following steps are carried out: First, collect articles, e-books, and International Journals. These articles were collected from Proquest, YouTube, Pdfdrive, the Google Scholar Database, Google Playbook, and the web, which contained a collection of journals. Second, review some literature studies on journals, textbooks, e-books, and articles about biomass estimates. Third, look for various websites that produce many articles that discuss using models to estimate biomass. Then this article is grouped, examined, and selected according to the purpose of this study. Furthermore, the selected article will be recorded as data and information presented and discussed. Fourth, conduct discussions and continue the papers that will be presented [8].

3. Literature Review
Forest biomass is an organic material produced from primary production through photosynthesis is reduced through consumption respiration and harvest. Estimates of biomass give information about fictional structures and attribute a forest. Nearly 50% of the forest vegetation biomass is composed of the element carbon [8]. Biomass can be grouped into two categories, namely belowground and aboveground biomass. Biomass can be measured based on dry weight due to the variability of the water content prevailing in each plant. The unit of measurement of biomass is grams per m² or kg per ha [9].

Forest ecosystems contain more than 45% of terrestrial biosphere carbon and play a major role in the world carbon cycle (Beer et al. 2010). Estimation of ecosystem carbon storage in forests is very essential to predict national climate-carbon feedback and guide implementation of mitigation policies [10][11]. According to Lisboa [12], to estimate biomass was used as a destructive method by cutting 39 trees and measuring diameter at breast height, total height, and commercial height. The variables of basic wood density, total dry weight, and volume of timber traded were determined using the Somali formula. The least squares non-linear regression equation was used to construct six biomass allometric models. The destructive method is a typical method for measuring biomass. This method is carried out by harvesting all parts of the plant including the roots, dry it and weigh the biomass. Measurement by this method to measure forest biomass can be done by repeating several areas snippets or extrapolate for a larger area using allometric equations. Although this method is considered accurate for calculating biomass in a small area, this method is expensive and very time consuming. Here, a non-destructive method is carried out in Suren tree biomass research and then analyzes it using allometric equations. This method is a method of sampling by measuring without doing harvesting. This method, among others, is done by measuring the height or diameter trees and uses allometric equations to extrapolate biomass. [13].

The biomass estimation equation, also known as the allometric equation or regression model, can be used to estimate the biomass or volume of tree components above the ground based on diameter data at breast height and tree height. This equation is derived based on tree weight measurements related to DBH and sample tree height. [12][5] [6].

The use of allometric equations for estimating the biomass of tree species that exist in forests or plantations is everyday and cost effective [5]. According to [4] the parameter for estimation models applicable across species and a wide range of compositional and structural variation related to species sorting into height layers and frequent natural disturbances.

Individual tree biomass and stem volume models use the following general equation:

\[ Y = \beta_0 X_1^{\beta_1} X_2^{\beta_2} \ldots X_l^{\beta_l} + \epsilon \]

Where \( y \): biomass (kg); \( x_j \) are predictive biometric variables, such as tree height \( H (m) \) and diameter at breast height (cm), \( \beta_j \) are parameter and \( E \) is error term.
Then, the biomass of tree can be estimated with allometric equations which include both diameter and height as follow: [14].

\[ W = w a D^b H \text{ or } \log w = a' + b \log D + c \log H \]

\[ W = a (D^2 H)^b \text{ or } \log w = a' + b \log (D^2 H) \]

where \(D\) and \(H\) represent tree diameter at breast height (cm) and height (m) and \(a, b, a',\) and \(c\) are regression coefficients.

To determine the best model in estimating the biomass allometric model, a model reliability test with several criteria is needed. The following statistical indices to evaluate tree biomass model are comprise consideration on the largest determination coefficient \((R^2)\) and correlation coefficient \((r)\), aggregative deviation percentage \((AgD) < 1\%\), and average deviation percentage \((AvD) > -1\% \text{ and } < 10\%\). Standard error of estimate \((SEE)\), mean prediction error \((MPE)\), total relative error \((TRE)\), average systematic error \((ASE)\) and mean percent standard error \((MPSE)\).

Previous researchers use scatter plots to explore data trends in the distribution of biomass DBH by species. This activity is carried out to decide whether linear or non-linear models will be more suitable to fit the data [17]. Total tree above ground biomass sample trees are calculated by summing the total dry weight of each of the three structural components [6].

### 4. Results and discussion

Factors that influence the estimation of forest biomass are variables that have a measured value, and the results are influenced by the variables that affect it. The study discusses the estimation of biomass and the independent variables shown in table 1, as follows:

| No | References | Title                                                                 | Approaches & Independent Variables                                                                 | Fit Model                                                                 |
|----|------------|----------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| 1  | [18]       | Chaturvedi, et al. (2010) Non-destructive estimation of tree biomass by using wood specific gravity in the estimator | Stem, root, branch leaf, diameter at breast height, volume, height (H; m)                          | \(Y = a + b \log X,\) \(y = \text{biomass (k/g tree}^{-1}),\) \(x = \text{diameter at breast height, V volume (V}; \text{m}^3), \text{ Diameter at Breast Height (D}; \text{m), height (H}; \text{m})\) |
| 2  | [15]       | Latifah S (2013) Carbon Sequestration Potential in Aboveground Biomass of Hybrid Eucalyptus Plantation Forest | data of stem dry weight, branch, twig, leaf dry weight, percentage of water content density of wood, DBH) | \(Y = 1,351.09x^{0.876} e^{(0.094x)}\) \(X = \text{DBH}\) |
| 3  | [19]       | Chave (2014) Improved allometric models to estimate the aboveground biomass of tropical trees | trunk diameter D (cm), total tree height H (m), wood specific gravity q (g cm), and total oven-dry AGB (kg). | \(AGB = 0.0673 x (\rho D 2 H)^{0.976}\) \(AGB= \text{aboveground biomass}\) |
| Page | Reference | Topic | Estimation Method | Formula |
|------|-----------|-------|-------------------|---------|
| 4    | [13] Latifah, S. et al. (2018) | Estimation of aboveground tree biomass Toona sureni and Coffea arabica in agroforestry system of Simalungun, North Sumatra, Indonesia | DBH, volume (m3) (wood density) | (AGB)est. = 0.281 D^{2.06} |
| 5    | [2] Nath, A.J. (2019) | Allometric Models for Estimation of Forest Biomass in North East India | (DBH), height (H; m) | AGB = 0.0673D^{2}H^{0.976} |
| 6    | [1] Baishya, R.; (2011) | Estimation of tree biomass, carbon pool, and net primary production of an old-growth Pinus Kesiya Royle ex. Gordon forest in north-eastern India | Estimation of NPP, Density of trees, shrubs and stem, branch, twig, needle, root, dependent variables | The DBH and dry weight |
| 7    | [5] Kebede.B & Teshome Soromessa (2018) | Allometric equations for aboveground biomass estimation of Olea europaea L. subsp. cuspidata in Mana Angetu Forest | (DBH), height (H; m) | Tree Volume |
| 8    | [4] Marra, D.M, (2015) | Predicting biomass of hyper diverse and structurally complex Central Amazon forests—A virtual approach using extensive field data | DBH, H Height, volume (m3) wood density | Log AGB= -1.803-0.976 E + 0.976 (log WD) + 2.673 (log DBH) -0.0299 (log DBH 2) |
| 9    | [4] Chen (2015) | Biomass modeling of larch (Larix spp.) plantations in China based on the mixed model, dummy variable model, and Bayesian hierarchical model | Dbh, height, dummy variable model, linear mixed model, and Bayesian hierarchical model | Y = aDBHb δ |
Allometric equations to estimate aboveground biomass of small-diameter mixed tree species in secondary tropical forests

\[ \ln(AGB) = \beta_0 + \beta_1 \ln(DBH \cdot H) + \varepsilon \]

Allometric Models for Tree Biomass Estimation on Different Types of Forest Ecosystems in Indonesia.

\[ (AGB) = 0.281 \cdot D^{2.06} \]

Allometric Equations for aboveground and belowground biomass estimations in an evergreen Forest in Vietnam

\[ \text{AGB} = \exp (-3.051 + 0.966 \ln(DBH^2 \cdot H) + 3.05 \ln(WD)) \]

\[ WD = \text{wood density} \]

The results of tree biomass estimation are used, among others, in assessing the condition and structure of the forest; it is essential for forecasts of carbon fluxes based on forest productivity. Biomass provides a means of determining sequestration of carbon in wood, leaves, and roots and it can be used as an indicator of site productivity, both economic and biological [21].

Some general equations are tested for estimating aboveground biomass by developing allometric models that relate independent variable (DBH, H, and WD) with aboveground biomass [21]. However, H is a strong predictor of AGB, because together with DBH it defines the slenderness of tree and also shows the availability of the lifetime light. Obtaining this data is still expensive and challenging in the canopy of tall and complex tropical forests [4]. The tree height variable (H) in a possible regression model increases the potential application of the equation to Different sites because height is often used as an index for the site growth condition [22].

Forest inventory is an activity and preparation of data and information regarding forest resources and forest resources of an area to see the potential of forest resources and carry out a forest resource management plan. They usually gather information, including only tree diameter at breast height and commercial height. In many cases, it is difficult to measure the height of commercial trees accurately. When compiling a biomass estimation model, the tree height is included as the independent variable in the model, it is possible to have an estimation bias. Therefore, it is essential to develop a model of estimating volume and total aboveground biomass using variables, which can be accurately measured in the field, such as diameter at breast height.

For aboveground biomass, several standard equations were tested to develop allometric models that relate the geometric measures (DBH, H and WD) given to aboveground biomass. Estimation of the aboveground biomass in the study site can used the biomass allometric equations and biomass expansion factor given. In many cases, if the information of diameter at breast height is available then the use of biomass allometric models usually uses the DBH variable [12] [23]. Biomass estimation models and allometric relationship can differ substantially between different tree species, specifically on species-rich areas with high tree diversity size and architecture like in a tropical rain forest [23] [24]. The results showed that the density of trees, width of the base area, and biomass vary by forest type. Regression
analysis between the basal area and biomass shows a positive relationship, which is means that as the basal area increases, biomass will also increase [26].

In this case, allometric equations are an essential step Estimating AGB [25]. Allometric equations using specific species and locations are preferred over general equations, because available equations sometimes make biases biomass estimation. One effective way to estimate biomass is to develop an allometric method using field inventory data on tree dimensions (diameter at breast height and height) which are thought to have a strong relationship with biomass measurements

In the case of model applications, the allometric equation is specific to particular species and locations differently, so allometric equations cannot be compared differently species and location. Various allometric equations can be compared to get the best model by considering the variable composition and equation form. Basically, a good model is to have very high accuracy, a simple estimate, easy to analyze and easy to apply [15].

5. Conclusion
Biomass calculation is one of the important steps that must be recognized and carried out in an activity or climate change mitigation project in the forestry sector. Independent variables commonly used to estimate aboveground biomass are diameter, the height of trees, and wood density. Tree height as a predictor variable is used in most biomass estimation models. Indeed, we expect the inclusion of H to substantially increase the level of our trees and landscaping prediction. Allometric models are the powerful tools widely applied to predict biomass and carbon storage of the forests.

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