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# Estimating Biomass and Carbon Sequestration of Stem and Branches of *Pinus brutia* Ten. Trees in Duhok Governorate, Iraq

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## ABSTRACT
This study aims to estimate the biomass and carbon sequestration potential of naturally occurring Calabrian pine (*Pinus brutia* Ten.) in the trunk and branches across three distinct sites in the Duhok Governorate, Kurdistan Region of Iraq. At each site, a total of 43–60 trees were measured to develop robust allometric models for estimating tree biomass and carbon storage, using diameter at breast height (DBH) and total tree height as key predictors. Site-specific variables such as elevation, slope, and soil characteristics, which can significantly influence biomass accumulation and carbon dynamics, were also taken into account. Tree selection encompassed a range of size classes and age groups to ensure a representative sampling of the natural forest structure and growth variability. Carbon content was estimated by applying a widely accepted carbon conversion factor of 0.5 to the calculated dry biomass. The findings reveal that trees in Zawita store substantially more carbon, with an average of 326.7 kg for a tree with a 40 cm DBH, compared to 123.6 kg in Atrosh and 157.9 kg in Belkef. The highest overall carbon stock in trunk and branches was recorded in Zawita, reaching up to 577.6 kg for a tree with 50 cm DBH, indicating superior sequestration capacity and higher biomass productivity relative to the other sites. These results carry important implications for forest management, carbon accounting, and climate change mitigation strategies in the region. Moreover, the study provides a valuable baseline for long-term ecological monitoring, sustainable forestry planning, and carbon stock assessments. By emphasizing the ecological and climate-related importance of natural pine forests in semi-arid mountainous environments, the research supports conservation initiatives and underscores the role of *Pinus brutia* as a vital carbon sink contributing to both regional sustainability and global climate goals.

***Keywords*****:** *Pinus brutia* Ten, carbon storage, height-diameter relationship. allometric equation. Biomass estimation.



## INTRODUCTION
The increase in atmospheric carbon dioxide ($CO_2$), due to anthropogenic activities, has been among the primary causes of climate change, with disastrous consequences for diversity and planetary ecosystem balance [1,2]. Forest ecosystems are primary climate stabilizers because of their ability to sequester atmospheric $CO_2$ through photosynthesis and trap it as biomass within the wood, branches, and roots of trees [3,4]. The capacity of forests to sequester and store carbon renders them indispensable for long-term sustainability and achieving carbon equilibrium. However, measuring the forests that serve to sequester and store carbon and are hence particularly important for long-term sustenance and carbon balance. It is important to measure the capacity of different tree species and forest types for carbon storage, because carbon accounting is linked to the success of climate policy. As the global community intensifies its efforts to mitigate climate change, the tree biomass and carbon sequestration dynamics are becoming increasingly worthy of attention in developing adaptation and mitigation strategies. Forestry biomass usually means the weight of a tree, including its trunk, branches, leaves, and roots [6]. Carbon sequestration is one of the major ways in which trees regulate the climate by taking in $CO_2$ from the air through the process of photosynthesis and locking it in plant biomass. It is a straightforward biological process that occurs through the reaction: photosynthesis.

$$6CO2 + 6H2O + light\ energy \rightarrow C6H12O6 + 6O2$$

**Where:**
CO2 = carbon dioxide from the air
C6H2O water from the soil
Light energy = usually from the sun
C6H12= glucose (sugar used for energy and growth)

O2 = oxygen released into the atmosphere

Through this process, forests act as sinks for carbon, reducing $CO_2$ levels in the atmosphere, an essential factor in averting global warming [1,2]. Trees capture and accumulate carbon as they mature, with some of the organic matter being respired back to the atmosphere as $CO_2$ and the rest accumulating in the tree and contributing to biomass accumulation and forest carbon stock [7,4]. The carbon sequestration and release balance highlights the function of forests in ensuring ecosystem stability and allowing climate resilience.

The Calabrian Pine (*Pinus brutia* Ten.) is native to the eastern Mediterranean region and is known for its adaptability to diverse climatic conditions and poor, rocky soils [8]. Covering approximately 50,000 hectares in the Kurdistan Region of Iraq, the species is predominant in Duhok, wherein its importance lies in providing a habitat for afforestation and ecological rehabilitation [16]. Additionally, away from being economically and environmentally significant, the species Pinus brutia also contributes to biomass production and carbon sequestration [9]. The trunk and branches hold most of the tree's biomass, and therefore, these are important factors to calculate the potential for carbon sequestration [10]. Although *Pinus brutia* is a significant part of forest stands, few studies have investigated its assumed biomass and carbon storage in Iraq. Most available studies on biomass estimation and carbon sequestration focus on other regions or tree species, leaving a research gap in understanding the allometric relationships specific to naturally growing *Pinus brutia* stands in Duhok. Allometric relationships are usually used to estimate tree biomass based on measurable characteristics like breast height diameter (DBH) and overall tree height [11, 12]. General models, however, yield biases when applied specifically to individual tree populations owing to variations in species traits, site conditions, and stand structure [13,14]. As deforestation and climate change threaten forest ecosystems even more, accurate biomass estimation techniques are at the heart of forest stability, carbon computation, and reforestation policy formulation. This study attempts to bridge these gaps by creating localized allometric models for the estimation of naturally occurring *Pinus brutia* trees' biomass and carbon sequestration capacity at three locations in Duhok province. Specifically, the research seeks to:

1- Determine the relationship between dry weight and green weight for both stems and branches.

2- Estimate the amount of stored carbon in *Pinus brutia* using DBH and total tree height as predictor variables;

3- Compare the carbon storage capacity of trees across the three study locations to assess the impact of environmental conditions on biomass accumulation.

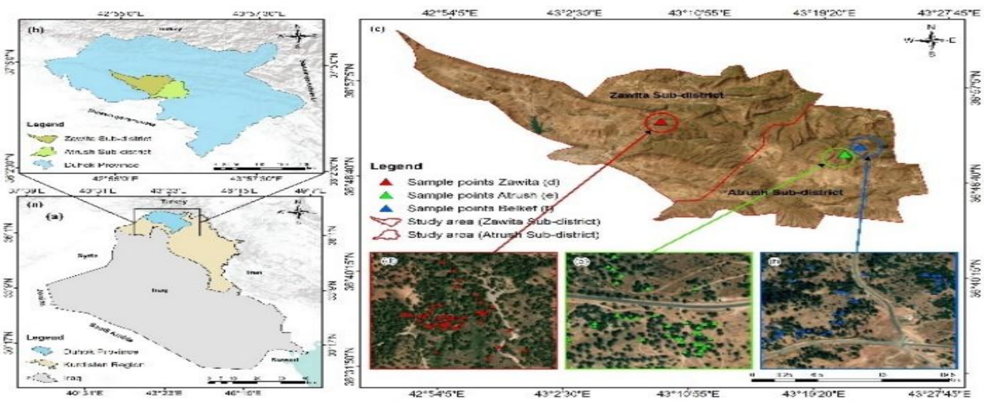
Through developing species-specific allometric equations, this study will offer a more accurate and scientifically proven method of tree biomass and carbon content estimation. The results will have applications in forest resource management, afforestation, and carbon offsetting, particularly in areas where forest protection is crucial in the fight against land degradation.

**Materials and methods**

**2.1 Study Area Description**

The study was conducted at three natural *Pinus brutia* sites in Duhok province, Kurdistan Region, Iraq: Zawita, Atrosh, and Belkef (Figure 1). These sites represent different environmental conditions influencing biomass and carbon sequestration. The region has a Mediterranean climate with (500–1000) mm of annual rainfall, mainly from November to April, and elevations ranging from( 600 -1,200) m a.s.l. According to [15], Soils are generally shallow, rocky, and well-drained, classified mainly as Mollisols (Xerolls, Calcixerolls).

Zawita, at the highest elevation, has dense tree cover, cooler temperatures, and higher rainfall—ideal for tree growth. Atrosh, at mid-elevation, has moderate tree cover and warmer conditions. Belkef, at the lowest elevation, experiences higher temperatures, lower moisture, and sparse tree cover. These environmental differences affect *Pinus brutia* growth and carbon sequestration across the sites.




(Figure. 1) Study Area Map. (a) Iraq, (b) Duhok Governorate, (c) Study area (Zawita, Atrosh, and Belkef) with sample locations.

**2.2 Field work**

This section outlines the methods applied in data collection on *Pinus brutia* trees within the research area. During fieldwork, representative trees were sampled, biometric measurements taken, and samples were prepared to approximate biomass and carbon.

### 2.2.1 Tree Selection Criteria

The sampled trees were considered healthy; the selection involved five representative trees at each site. Concerning health parameters, the selected trees were considered healthy without any diseases or damage. The healthy trees with large crowns were chosen so that they could provide maximum photosynthesis and carbon capture, and also varied in their DBH and height for the development of allometric models. Before making the selection, health and structure observations were visually undertaken on the trees. Measurement and data collection involve both standing and felled trees. DBH and crown radius are measured using conventional forestry tools, while crown radius is taken in different directions to capture asymmetry. After taking measurements, felling was done using chainsaws to allow more accurate biomass measurements.

### 2.2.2. Measurement and Data Collection

The selected trees were representative of the studied sites, density, and the available ages. Data collection included measurements taken from both standing and felled trees. Standing tree DBH and crown radius were taken with diameter tape and suitable forestry measuring tools. The crown radius was taken in multiple directions to account for asymmetrical crown patterns. Following those measurements, the trees were then felled to collect more accurate data, such as biomass estimation. Chainsaws were employed to fell trees and cut logs.

#### 2.2.2.1-Main Stem Biomass Assessment

Standardized methods were used to measure the stem, which makes up nearly 60% of the above-ground biomass. After being felled, the trunk was debarked and divided into 50 cm logs. A platform scale weighed each of these logs. A 2-3 cm disc was removed from the top of each log, weighed fresh, and then oven-dried at 105°C for 48-72 hours [16]. weights were recorded to estimate dry biomass using regression models from green weight, using the most suitable allometric equation.

#### 2.2.2.2.- Branches Biomass Assessment

Branches, a key part of above-ground biomass, were cut, weighed, and sampled to estimate their contribution to carbon sequestration. From each tree, 10–15 small branch discs were labeled, weighed fresh, and oven-dried to determine dry weight. A green-to-dry weight conversion model was developed and used to estimate branch carbon content, following the same method as for stems.

#### 2.2.2.3- Height-Diameter Relationship Data Collection

To develop height-diameter regression models, total height and DBH were measured on 43–60 trees per site with a Haga altimeter and a diameter tape. The data were employed to derive an allometric equation where tree height was regressed against DBH. The resulting models provide a handy means of estimating tree height from DBH measurements alone. These height-diameter relationships were later employed in calculations of tree volume.

## 2.3 Data Processing and Analysis

### 2.3.1-Stem Biomass Estimation

Stem biomass and its carbon contribution were analyzed by first estimating wood density, using volume and green weight of samples taken from the upper end of logs [17] The formula used was:

$$Wood\ Density = \frac{Wood\ Samples\ Mass}{Wood\ Volume}$$

The average wood density from five trees per site was used as the representative value

### 2.3.2- Height, Diameter Relationship, and Volume Estimation

Tree volume was estimated using DBH, and height data were analyzed in Statgraphics Centurion. Allometric models were developed, and the best model per site was selected based on accuracy. Heights were estimated for DBH values from 5 to 55 cm, and volume was calculated using site-specific equations [18] .

For Zawita:

$$V = 0.00754 + 0.00003675\, D^2H - 0.000003638\, D\, H^2$$

For Atrosh and Belkef:

$$V = 0.00301 + 0.00002563\ D^2\, H + 0.00000283\, D\, H^2$$

### 2.3.3-Estimating Stem Biomass

The estimation of stem biomass consisted of the multiplication of the volume estimate by the mean woody density assessed at each site [10]. The governing formula applied was:

Biomass = Volume * Wood Density

Dry weight was also regressed against DBH and height using allometric models, with the best-fitting equations used for biomass prediction.

### 2.3.4-Carbon Estimation

Estimation of carbon biomass was done using an assumed conversion factor, where the dry biomass carbon percentage was taken to be 50% [19, 20].

$$carbon\ content = dry\ mass * 0.5$$

### 2.3.5- Data Processing for Branch Biomass

A similar procedure was applied to branch biomass, using a regression equation for dry and green weight. The formula for carbon content was then applied to estimate branch carbon. The data were analyzed to determine biomass and carbon sequestration potential at the three study sites.

## 2.4 Validation and Verification

Regression equation validation involves checking precision and accuracy, particularly homoscedasticity (constant variance of residuals). Residual plots are used to test this, where randomly dispersed residuals suggest the model meets the assumption. Statistically, this is expressed as Residual~NID(0, σ), meaning residuals are normally distributed with a mean of zero and constant standard deviation.

Statistical analysis

The statistical analysis was done in three successive steps:

1- Two-dimensional scatter plots were drawn to illustrate the relationship between response and explanatory variables

2-Differential allometric equations were formulated in Statgraphics Centurion for estimating regression coefficients.

3-While screening the regression equations, the most accurate models relevant to biology were selected for biomass and carbon sequestration.

## 2.5 Measures of Model Precision and Accuracy

The regression models were judged, to their accuracy and predictivity, by some pertinent statistical criteria that include

### 2.5.1-Coefficient of Determination ($R^2$)

The $R^2$ measures the proportion of variance accounted for by the independent variables, theoretically ranging from 0 to 1, with a higher value of $R^2$ indicating a better model. It is estimated as

$$R^2 = 1 - \frac{Residual\ Sum\ of\ Squares}{Total\ Sum\ of\ Squares}$$

### 2.5.2-Ohtomo's Unbiased Test

The methodology was proposed by [21] to assess the performance of regression models using simple linear regression between observed and estimated values of the dependent variable

$\hat{y} = k + m\,y$

In this technique, the best model has the y-intercept (k) close to zero and slope (m) near one, indicating maximum closure between the predictions ($\hat{y}$) and observations (y).

### 2.5.3- Salih's Proposed Index

A modified form of Ohtomo's test, known as the Salih Index, was put forth by [13] to make further improvements in model accuracy assessment. It is given by:

Proposed Index = |K − 0| + |1 − m| + |1 − R2|

The Salih Index measures the departures of k from zero, and m and $R^2$ from one; the model with the least index value is deemed the most accurate. This criterion has been applied by different researchers, including [22, 23, 24].

### 2.5.4-Furnival Index Test (FI)

Introduced by [25], the Furnival Index compares the predictions of regression models, particularly when the dependent variable is transformed.

$$FI = \frac{\sqrt{Mean\ Square\ Error}}{Geometric\ Mean\ of\ First\ Derivative\ of\ y}$$

The Furnival Index has been widely used in forest and biomass estimation studies [26,13,27] The most accurate model has the lowest FI value.

**2.5.5- The Mean Absolute Error (MAE*)***

Mean Absolute Error (MAE) is a common measure of prediction accuracy in regression models, with or without response variable transformation. It is calculated as:

$$MAE = \frac{\sum|y_i - \hat{y}_i|}{n}$$

MAE and model accuracy have an inverse relationship—lower MAE values indicate better predictive performance. This parameter is often found in studies [28].

**2.5.6 Bias Percentage Testing**

The bias percentage tests the predictability of a model concerning observed values. Bias is determined using the formula:

$$Bais = \frac{1}{n}\sum_{1}^{n}(\hat{y}_i - y_i)^2$$

A lower bias percentage indicates greater reliability of the model. This test is known to have applications in forestry and biomass estimation studies.

**Result And Discussion**

**3.1-Development of Dry Weight–Green Weight Regression Models**

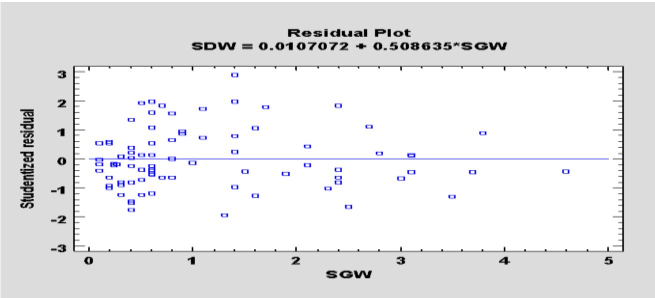
A uniform regression method was used to analyze the relationship between the dry weight and green weight at every study location. Eight models were generated per location. Detailed discussions examine main stem models exclusively to prevent redundant information while using a representative example from the Zawita location.

**3.1.1-Regression Analysis for the Zawita Location**

**Main stem and branches**

The dry weight was regressed on green weight in their different transform forms using Statgraphics Centurion software. Accordingly, eight allometric regression equations were developed. For each of them, the developed regression models were subjected to various criteria, and the most appropriate equation for each one was selected, as shown in (Table -1).

The homogeneity and validation of the selected equations were conducted by plotting the residuals $SDw_i - \widehat{SDw_i}$)against the explanatory variable. $SGw$. See (Fig. 2), which shows the mentioned test for the mean stem.




(Figure-2) Plotting of the residuals against the green weight of the dataset**.**

Residuals plotted against the explanatory variable showed random scatter, confirming that the model meets homoscedasticity and independence assumptions. This means the residuals are independently and identically distributed with a mean of zero and constant variance: Residuals ~ NID (0, $\sigma^2$).

**3.1.2 Regression Analysis for the Atrosh Location**

At Atrosh, dry weight was regressed to a transformed green weight for stems and branches. The best models were selected from eight equations based on precision metrics (Table- 1). Validation checked residuals for homogeneity of variance and normality to confirm linear regression assumptions.

**3.1.3 Regression Analysis for the Belkef location**

**Main stem and branches**

The same methodology was applied to develop, evaluate, and select the most suitable regression models for both the main stem and branches, as summarized in (Table- 1).

(Table -1): Selected allometric equations for all locations.

| Location | Main stem(trunk) | Branches |
|---|---|---|
| Zawita | $SDw = 0.0107 + 0.5086\,SGw$ | $BDw = 0.0335 + 0.507\,BGW$ |
| Atrosh | $SDw = -0.02205 + 0.5003\,SGw$ | $BDw = 0.00540 + 0.5299\,BGw$ |
| Belkef | $SDw = -0.06202 + 0.5069SGw$ | $BDw = -0.00045 + 0.575\,BGw$ |

SDW=Stem Dry Weight, SGW= Stem Green Weight, BDW=Branch Dry Weight BGW=Branch Green Weight

### 3.2- Modelling the Height–Diameter Relationship

In this study, multiple regression models were developed to establish height-diameter (H-D) relationships for the three study regions. Tree height, the dependent variable, was transformed in various ways to create different H-D models, fitted using Statgraphics Centurion software (Table -2).

(Table -2): Developed the height–diameter regression models for all locations with their coefficient of determination

| Eq n.o | Eq. model | Zawita | | | Atrosh | | | Belkef | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $B_0$ | $B_1$ | $R^2$ | $B_0$ | $B_1$ | $R^2$ | $B_0$ | $B_1$ | $R^2$ |
| 1 | $H = b0 + b1D$ | 1.3 | 0.41 | 0.96 | 1.3 | 0.25 | 0.94 | 1.3 | 0.46 | 0.94 |
| 2 | $H = b0 + b1\sqrt{D}$ | 1.3 | 2.25 | 0.97 | 1.3 | 1.44 | 0.98 | 1.3 | 2.03 | 0.96 |
| 3 | $H = b0 + b1ln(D)$ | 1.3 | 3.58 | 0.96 | 1.3 | 2.33 | 0.98 | 1.3 | 2.99 | 0.96 |
| 4 | $H = b0 + b1D^2$ | 1.3 | 0.01 | 0.89 | 1.3 | 0.0067 | 0.81 | 1.3 | 0.06 | 0.70 |
| 5 | $\sqrt{H} = b0 + b1D$ | 1.14 | 0.09 | 0.97 | 1.4 | 0.06 | 0.94 | 1.16 | 0.10 | 0.93 |
| 6 | $\sqrt{H} = b0 + b1\sqrt{D}$ | 1.14 | 0.47 | 0.97 | 1.4 | 0.35 | 0.98 | 1.16 | 0.47 | 0.98 |
| 7 | $\sqrt{H} = b0 + b1ln(D)$ | 1.14 | 0.7418 | 0.969 | 1.4 | 0.5578 | 0.992 | 1.16 | 0.6941 | 0.992 |
| 8 | $H^2 = b0 + b1D$ | 1.69 | 6.412 | 0.927 | 1.69 | 2.695 | 0.934 | 1.69 | 5.4917 | 0.90 |
| 9 | $H^2 = b0 + b1\sqrt{D}$ | 1.69 | 34.39 | 0.964 | 1.69 | 15.278 | 0.954 | 1.69 | 23.88 | 0.875 |
| 10 | $H^2 = b0 + b1ln(D)$ | 1.69 | 54.39 | 0.887 | 1.69 | 24t 60 | 0.951 | 1.69 | 34.94 | 0.856 |
| 11 | $ln\,ln\,(H) = b0 + b1\,D$ | 0.26 | 0.0784 | 0.964 | 0.2623 | 0.0619 | 0.932 | 0.2623 | 0.1037 | 0.912 |
| 12 | $ln\,ln\,(H) = b0 + b1\sqrt{D}$ | 0.26 | 0.4316 | 0.991 | 0.2623 | 0.3573 | 0.984 | 0.2623 | 0.4754 | 0.985 |
| 13 | $ln\,(H) = b0 + b1ln(D)$ | 0.26 | 0.6891 | 0.993 | 0.2623 | 0.5794 | 0.994 | 0.2623 | 0.7054 | 0.992 |

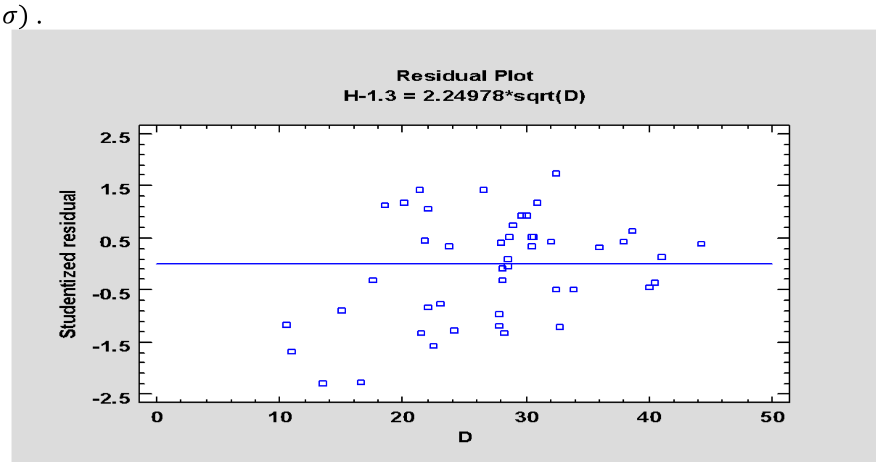
The predictive efficiency of the allometric equations was evaluated in two stages. First, models were compared using R² to select the best from each group. Then, precision was assessed using MAE, bias, Salih's index, and Furnival's index. The selected equations for the studied locations are shown in (Table- 3).

Table 3: The selected equation for the studied locations

| Location | Selected allometric equation |
|---|---|
| Zawita | $H = 1.3 + 2.24978\sqrt{D}$ |
| Atrosh | $H = 1.3 + 2.3278\,ln\,(D)$ |
| Belkef | $H = 1.3 + 2.025\sqrt{D}$ |

Each selected equation underwent residual homogeneity and validation tests. For brevity, the methodology is shown for Zawita. To assess homoscedasticity and validity, residuals (H-$\widehat{H}$) were plotted against ($\sqrt{H}$) (Figure 3), confirming the normal distribution:

Residuals$\sim NID(0, \sigma)$ .

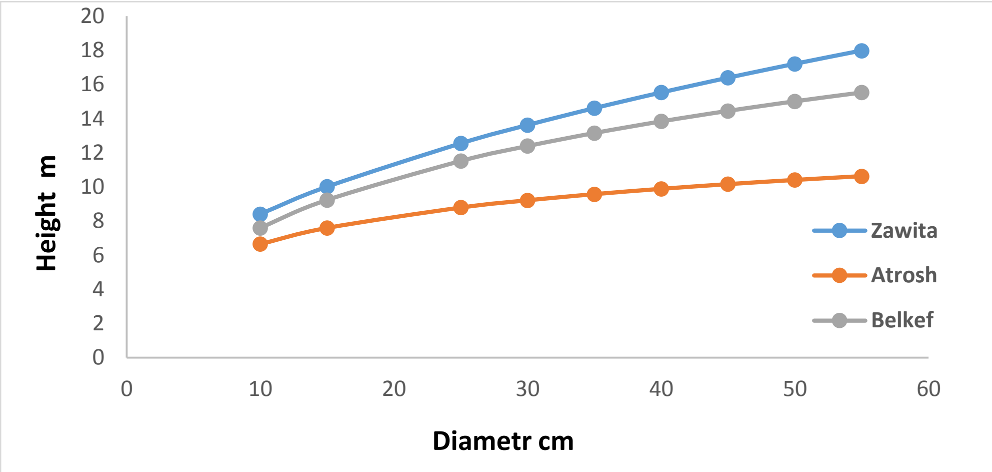



(Figure- 3): Plotting of residuals against the corresponding values of the independent variable

### 3.2.1-Comparison between the height-diameter equation models for all three locations.

By inputting diameter values into the selected allometric equations, tree heights were estimated and plotted (Figure- 4).

The plot shows that trees in Zawita are taller than those in Atrosh and Belkef, likely due to better tree density, climate, and soil conditions in Zawita.




(Figure -4): Height – Diameter relationship of Zawita, Atrosh, and Belkef location

**3.2.2- The dry weight relationship with some easily measured tree parameters**

Using Statgraphics Centurion, the dry weight of trunks and branches was regressed on DBH and total height across three locations, resulting in six allometric equations. These were evaluated for precision to select the best models for each location. Detailed procedures are shown for Zawita only.

**3.2.2.1- Zawita location**

**For the main trunk**

Six allometric regression equations were developed by regressing trunk dry weight on DBH and total tree height (Table-4).

(Table -4): Developed regression equations for the dry weight of the main stem of trees as a function of both the diameter and height of the tree

| Eq. no. | Regression equation | $R^2$ |
|---|---|---|
| **1.** | SDW =0.01466 $(D^{1.97}\ H^{0.99})$ | 0.91 |
| **2.** | SDW =0.01466 $(D^{2.66}\ H^{0.022})$ | 0.92 |
| **3.** | SDW=0.0151$(D^{2.31}\ H^{0.54})$ | 0.98 |
| **4.** | $\sqrt{SDW} = 0.50446 + 0.000025\ D^2H + 0.0546\ (H^2 + D)$ | 0.95 |
| **5.** | $\sqrt{SDW} = 0.1169\ (D^{0.777} + H^{0.777})$ | 0.91 |
| **6.** | Ln (SDW) = -3.05-0.1159 $\sqrt{DH} + 1.292\sqrt{D} + \sqrt{H}$ | 0.90 |

All developed regression equations were evaluated based on R², RMSE, MAE, Ohtomo's test, Salih index, and Furnival Index (FI). Out of these evaluation criteria, equation three was selected as the best equation (Table 5). The allometric equations for the main stem and branches that were developed from regressing dry weight against measurable tree parameters were found and shown in (Table -5) as having the best-selected models.

(Table- 5): The selected allometric equations for both the main stem and branches

| Location | Main stem (trunk) | Branches |
|---|---|---|
| Zawita | $SDW = 0.0151D^{2.306}H^{0.538}$ | $BDW = 0.7186 + 0.004743D^2H$ |
| Atrosh | $SDW = 0.00829D^{1.99}\ H^{0.99}$ | $BDW = 0.0097D^{1.5517}H^{1.371}$ |
| Belkef | $SDW = 0.00311D^{2.0914}H^{1.179}$ | $BDW = 0.00915D^{3.205}H^{-1.065}$ |

D = Diameter at breast height, H =Total height

**3.3-Carbon estimation**

To estimate the carbon content, the dry weight is multiplied by a constant factor of 0.5, which is an assumption of the average carbon fraction in the biomass [5, 3, 29] in (Table -6).

(Table- 6): Dry weight and carbon with diameter and height for both stem and branches of (Zawita, Atrosh, and Belkef)

| Location | Tree Part | Carbon Content Equation |
|---|---|---|
| Zawita | Stem | Carbon content = $0.00755\ D^{2.306}\ H^{0.538}$ |
| | Branches | Carbon content = $0.3598 + 0.002372\ D^2 H$ |
| Atrosh | Stem | Carbon content = $0.00414\ D^{1.99}\ H^{0.99}$ |
| | Branches | Carbon content = $0.00485\ D^{1.5517}\ H^{1.371}$ |
| Belkef | Stem | Carbon content = $0.001555\ D^{2.0914}\ H^{1.179}$ |
| | Branches | Carbon content = $0.004575\ D^{3.205}\ H^{-1.065}$ |

The carbon content regression equation can be converted into tables for directly estimating stored carbon in a tree's main stem and branches based on diameter and total height.

### 3.3.1-Comparison of Carbon content for trees across different locations

Simultaneous comparisons of carbon content equations between all sites (or pairwise) can be performed. One approach would be to compute the ratio of the allometric equations for trees with known diameter and height. For instance, the stem carbon content equations for Zawita and Atrosh can be compared by evaluating the following ratio:

$$The\ ratio\ = \frac{stem\ carbon\ equation\ of Zawita}{stem\ carbon\ equation\ of\ Atrosh} = \frac{c = 0.0151*(D^{2.306}*H^{0.538})}{C = 0.00829*D^{1.99}*H^{0.99}}$$

This ratio gives a direct estimate of how much carbon content differs among trees at Zawita and Atrosh for trees of the same dimension. Similar comparisons can be made over other locations and between tree parts (stem and branches).

### 3.3.2- Biometric comparison

Comparative analysis of the height–diameter relationships and estimated carbon contents in the stems ($\widehat{SM}$) and branches ($\widehat{BM}$) across three locations

(Table- 7) Estimated heights and carbon contents for stems and branches at different diameters across Zawita, Atrosh, and Belkef.

| | Zawita | | | Atrosh | | | Belkef | | |
|---|---|---|---|---|---|---|---|---|---|
| D | $\widehat{H}$ | $\widehat{SM}$ | $\widehat{BM}$ | $\widehat{H}$ | $\widehat{SM}$ | $\widehat{BM}$ | $\widehat{H}$ | $\widehat{SM}$ | $\widehat{BM}$ |
| 10 | 8.4 | 9.6 | 4.7 | 6.7 | 5.3 | 4.7 | 7.7 | 4.3 | 1.7 |
| 20 | 11.4 | 55.8 | 22.3 | 8.3 | 26.1 | 18.3 | 10.4 | 25.7 | 11.2 |
| 30 | 13.6 | 156.8 | 58.8 | 9.2 | 65 | 39.9 | 12.4 | 74.3 | 34 |
| 40 | 15.5 | 326.7 | 119 | 9.9 | 123.6 | 68.7 | 14.1 | 157.9 | 74.5 |
| 50 | 17.2 | 577.6 | 205. | 10.4 | 202.7 | 104. | 15.6 | 284 | 137 |

This comparison illustrates the variations in three dimensions and carbon allocation patterns across different environmental conditions.

### 3.3.3 Carbon Ratio Determination

#### 3.3.3.1 Ratio of Carbon Content Between Branches and Stems Within the Same Location

The carbon allocation ratio of branch carbon to stem carbon at one site was affected by species traits, tree age, environmental conditions, etc. This ratio can be determined by dividing the carbon content equation for the branches by that of the stems. For example, for the Zawita location.

$$Ratio = \frac{0.3598 + 0.002372D^2H}{0.00755(D^{2.306}*H^{0.538})} = \frac{0.3598}{0.00755(D^{2.306}*H^{0.538})} + \frac{0.002372D^2H}{0.00755(D^{2.306}*H^{0.538})}$$

Since the constant term (0.3598) becomes negligible for large trees, the ratio simplifies to:

$$Ratio \cong \frac{0..314*H^{0.462}}{D^{0.306}}$$

This means that the ratio depends on diameter and height. For a tree of 40 cm in diameter and 15.5 m tall, this ratio comes to about 36%, indicating that the branch carbon content is approximately 36% of the stem carbon content. This simplifies the calculations when we also want to find the branch-to-stem carbon ratios for both Atrosh and Belkef.

#### 3.3.3.2 Ratio Between Identical Dimensions Across Different Locations

The ratio of the carbon trunk contents (or dry weights) calculated using the corresponding allometric equation is used to compare trees of the same size from different places.

For example, trees with a 30 cm diameter, located in Belkef and Atrosh. Utilizing the height–diameter relations, the

determined heights are estimated as: 12.4 m for Belkef and 9.2 m for Atrosh.
Hence, the trunk dry mass ratio is determined from Belkef to Atrosh as:

$$Ratio = \frac{0.00311 * D^{2.0914} * H^{1.179}}{0.00829 * D^{1.99} * H^{0.99}}$$

For a tree with a diameter of 30 cm, the ratio was found to be ~1.14; meaning that a tree of this size in Belkef (and presumably throughout the wide plateau on the western side of the valley) has a slightly higher dry mass than one of the same size growing in Atrosh (and presumably throughout the riparian bands growing along the Great Zap
The ratio is a function of diameter and height and consequently varies with different tree dimensions.
Likewise, for a similar diameter of 30 cm, the estimated tree height was 13.6 m and 9.2 m at Zawita and Atrosh, respectively. The calculated carbon content ratio between Zawita and Atrosh was:

$$Ratio = \frac{0.00755 * D^{2.306} * H^{0.536}}{0.00415 * D^{1.99} * H^{0.99}} = 2.41$$

The resulting ratio is approximately 2.41, indicating that trees of the same diameter store significantly more carbon at Zawita than at Atrosh. Analogous comparisons can also be extended to the branch carbon contents across different locations.

## Conclusion

The analysis of the developed allometric equations for predicting dry weight from tree diameter and height revealed several key patterns. The sum of the exponents for diameter and height ranged from 2.2 to 3.2, indicating a relatively stable stability index across models. Scaling factors varied between 0.00311 and 0.015, reflecting differences in biomass allocation patterns among species due to inherent biological traits and site-specific conditions. Furthermore, the ratio of branch to trunk dry weight or carbon content was found to vary with species identity, tree age, and environmental factors, highlighting the complexity of biomass distribution within and among trees. Across all study sites, a curvilinear relationship between height and diameter was observed, emphasizing the necessity of incorporating both variables in predictive models to more accurately represent tree architecture and growth dynamics.

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# تقدير الكتلة الحيوية وتخزين الكربون في السيقان و اغصان أشجار *Pinus brutia* Ten . في محافظة دهوك، العراق

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الخلاصة
نهدف هذه الدراسة إلى تقدير الكتلة الحيوية وتحديد مدى فعالية أشجار الصنوبر في خزن الكربون في الساق والافرع لأشجار الصنوبر البروتي الناميه طبيعياً في ثلاثه مواقع ضمن محافظه دهوك في أقليم كوردستان العراق . تم قياس ما بين 43 إلى 60 شجرة في كل موقع بهدف تطوير معادلات تقدير الكتلة الحيوية، تعتمد على القطر عند ارتفاع الصدر والارتفاع الكلي للشجرة، وذلك لتقدير مخزون الكتلة الحيوية والكربون بدقة. أظهرت النتائج أن أشجار موقع زاويتة تمتلك أعلى متوسط لتخزين الكربون، حيث بلغ 326.7 كغم للشجرة ذات قطر 40 سم، مقارنة بـ123.6 كغم في موقع أتروش و157.9 كغم في موقع بلكيف. كما قُدّر إجمالي الكربون المخزون في الساق والأفرع ليصل إلى 577.6 كغم في زاويتة للشجرة ذات قطر 50 سم، ما يعكس تفوق هذا الموقع في قدرته على عزل الكربون مقارنة بالموقعين الآخرين. تؤكد هذه النتائج الأهمية البالغة للإدارة المستدامة للغابات الطبيعية في المنطقة، ودورها في دعم وتوجيه السياسات المناخية نحو التخفيف من تغيّر المناخ، من خلال تعزيز دور الغطاء الغابي في امتصاص الكربون وتخزينه

الكلمات المفتاحية: صنوبر البروتي (***Pinus brutia Ten.***)، تخزين الكربون ، العلاقة بين القطر بالارتفاع, معادلات الومتريه .