Assessment of the growing stock and annual increment of *Pinus brutia* Ten. stands in Kfardebel, Latakia, Syria

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Abstract. The study assessed the growing stock and wood increment of *Pinus brutia* Ten growing on the Kfardabil-Jabla plantation in Syria. The plantation was created in 1974–1976. Biometric field surveys were carried out over three time periods. In the plantation under study, circular sampling plots with a radius of 11.4 m were made. In the course of the study, we used a polynomial distribution to estimate the height of the measured trees, which makes it possible to predict changes in the plantation growth parameters in the future. There was a substantial increase in the growing stock in the study area: from 197.5 m³ per hectare in 2011 to 213.3 m³ per hectare in 2020. The annual timber increment fell from 2.0 m³ in 2011–2014 to 1.3 m³ per hectare in 2014–2020, which is likely to be associated with age-related changes and excessive stand density. We recommend to remove slow growing trees to reduce the density of the stand and make space for the remaining. The results obtained on the increments and volumes of wood on the *Pinus brutia* Ten plantation show the potential volume of wood to be harvested in accordance with the principle of sustainable forest management.

1. Introduction

*Pinus brutia* Ten is a coniferous tree species native to the Middle East, and its natural distribution range is confined to this region. Geographically, this tree can be considered a typical Eastern Mediterranean element of plant communities [1-4]. This species is widespread in the Mediterranean region, but natural stands are concentrated mainly in Eastern Mediterranean. There are forest plantations of this species in the north of the Mediterranean region: Spain, France and Italy.

In Eastern Mediterranean, natural stands of *Pinus brutia* Ten are widespread from Greece to Lebanon, in Turkey, Syria, Cyprus and Iraq [1-6]. In the Mediterranean region, various species of the genus *Pinus* have been studied, and significant relationships have been found between climate and tree growth. *Pinus brutia* Ten showed positive correlations with rainfall in Eastern Mediterranean [2-4].

*Pinus brutia* Ten plays an important role in the formation of short Mediterranean forests in the eastern Mediterranean basin (figure 1). Thanks to its successful adaptation to dry climate and the ability to quickly regenerate on abandoned lands, *Pinus brutia* Ten is an ecologically valuable species. This species is one of the most important trees in afforestation for industrial or protective purposes in dry conditions.
Intensive sustainable forest management of forest communities should preserve their biological diversity, productivity, ability to regenerate, and general resistance to external pressures. When assessing forest growth and productivity, one should consider these factors in order to support forest ecological and economic functions at local, national and global levels, so as not to harm other natural ecosystems [7-12]. A forest community as an ecosystem consists not only of trees and shrubs, but also of herbaceous plants, algae, lichens, fungi and bacteria; it also creates habitat for forest invertebrates, birds and animals. All of these organisms interact with each other, and directly affect forest soil which provides the necessary nutrients. Plant growth is defined as the biomass, or volume produced by a plant or a specific group of trees, over a given period, and understanding the patterns of this process allows optimal forest management decisions to be made [13].

The science that study growth and development of forest communities can then be defined as the science that designs and develops forest growth models and software that can be used to develop sustainable forest management plans [14].

There are several mathematical models that describe and evaluate tree growth. To predict the growth of a plantation, a mathematical model must be defined, since it is defined as a model, plan, representation, or a specific description intended to demonstrate the structure or how it works. In other words, a project or system is a short embodiment or simplified representation of a specific problem (Vanclay, 1988). Most of the mathematical models used to assess and predict the growth of forest stands are based on traditional equations, which make their scientific and practical basis. These models contain mathematical constants or parameters, most of which are obtained experimentally. Therefore, many statistical tests must be performed to ensure the reliability of a model before it can be validated [15].

One of the most important variables widely used in forestry is tree diameter at 1.3 m DBH, which is closely related to volume [16]. Diameter at a height of 1.3 m is a variable that is often used in forestry, and it is closely related to tree size and value; from this point of view, it is one of the most important foundations of forestry for making management decisions. Stand growth estimation over time usually depends on the accuracy of measuring the diameter-height ratio, as many growth and productivity models require both diameter and height to be entered as basic variables [14].

The 1.3 m diameter height (DBH) is the most significant component of the method of mathematical model analysis and statistical tools that allow speedy evaluation of a large amount of data [15-20]. At the same time, this biometric indicator is an easy-to-measure variable. This is important when studying forest communities, where most of the study methods depend on visual observation and for the most part are highly variable. Stand heights are known to be more difficult and expensive to measure, and it takes longer to measure tree heights than tree diameters, especially in dense stands and hard-to-reach places where tree tops are difficult to see [17, 18]. Therefore, diameter-height models can be used to predict heights when height measurements are not available for modeling purposes; missing heights can be calculated using an appropriate diameter-height model.
Thus, information on the distribution of trees by diameter and height classes can be included in the assessments of future forest use and is necessary to predict potential wood volumes. In addition to the statistical description of the distribution over plantations, predicting the development of tree communities using distribution equations is one of the preferred methods in forest research.

2. Methods and Materials

2.1. The study object
The study site is an artificial reforestation site in Kfardebel, which is located on the highway connecting the city of Jable and the Harf al-Misitara area, "at a distance of 3.3 km." This site rises 250–260 meters above sea level. The area of the site is about 110 hectares. The geographic coordinates of the site are: 36.0535 E and 35.3709 N (figure 2 ). In 1973–1976, afforestation was carried out on this site as part of the state plan for artificial afforestation.

![Figure 2](image2.jpg)

**Figure 2.** The location of the artificial afforestation site with *Pinus brutia* Ten in Latakia province, Syria.

The soils of the forest area belong to the Rendznya type, occurring on the Marnian and marinite limestones; soil horizons A and C are present. The organic horizon is not very thick, and the limestone-type humus and the soil adsorption complex are saturated with calcium [2, 3]. The site is located in a warm semi-humid bioclimatic region and the Mediterranean vegetation ecoregion characterized by thermophilic plants such as *Ceratonia siliqua* and *Olea sylvestris* (figure 3).

![Figure 3](image3.jpg)

**Figure 3.** The *Pinus brutia* Ten plantation in Latakia province, Syria.
2.2. Research methodology

During the study, the following equipment was used:

1. Metric tape for measuring distances.
2. Calibration fork for measuring tree diameters.
3. Haga device (for measuring tree heights).
4. GPS device (for determining tree coordinates).
5. Paint bags for marking measured trees.

Seven circular sampling plots with a radius of 11.3 m were made in the study area, so that the area of each plot was 400 m², as at the beginning of the project in 2011. In 2014, additional 15 circular plots with the radius of 11.3 m were also made.

The plots were arranged in such a way as to capture the statistical variation within the population of *Pinus brutia* Ten in terms of tree density, slope exposure and variation in site fertility. All tree diameters were measured at the sites created during 2011, and the measurements were repeated in 2014. In the summer of 2020, the measurements were made again. In total, 3,617 trees were measured in all plots.

The work steps can be summarized as follows:

1. After completing the process of measuring the diameters of trees in the study objects, tree heights representing all diameter sequences were measured to simulate the diameter-height relationship.
2. A model using a second order polynomial (parabola) was used to estimate tree heights, and the model parameters were obtained using the Excel program:

   \[
   H = a_0 + a_1 \times DBH + a_2 \times DBH^2
   \]  

   where: \(H\) - estimated height; \(a_0, a_1, a_2\) - height model constants; \(DBH\) - trunk diameter at 1.3 m above surface level.

   Coefficients of polynomials of low degrees can have a specific interpretation depending on the content of the time series. In biological research, polynomials of no higher than the third order are usually used, and the use of equations of a higher order will reflect random deviations, which contradicts the meaning of the trend. A second degree polynomial is applicable in those cases when the process is uniform, i.e. there is a uniformly accelerated growth or a uniformly accelerated decline. As is known, if the parameter \(a_2 > 0\), then the branches of the parabola are directed upwards, and if \(a_2 < 0\), then downwards. Parameters \(a_0\) and \(a_1\) do not affect the shape of the parabola, but only determine its position.

   The family Pinaceae is characterized by the presence of trunk curvature, that is, a decrease in diameter with height as the age of the tree increases.

   \[
   f = 0.42 + 0.12 \times \exp(-0.39 \times (DBH - 10)) \times 0.1
   \]

   where: \(f\) - the parameter of the trunk shape; \(DBH\) - trunk diameter at 1.3 m above surface level.

3. Wood stocks were first estimated for individual trees, then at the sample level, and finally for each hectare.

3. Results and Discussion

3.1. Predictions of the *Pinus brutia* Ten height grows model in the study area

Most of the mathematical models used to assess and predict forest stand growth are based on traditional equations, which make their scientific and practical basis [15]. The parabola equation was used to estimate tree height in the study area, the *Pinus brutia* Ten plantation. The height curve is a mathematical relationship of a nonlinear regression type, in which tree height is a dependent variable and tree diameter is an independent variable; in figure 4, these are shown as blue dots. The graph represents the measured values as dots, and the line represents the mathematical model, or estimated values.
The second order polynomial equation is given by:

\[ H = a_0 + a_1 \times DBH + a_2 \times DBH^2 \]  

(3)

The value of the coefficient of determination for this equation was \( R^2 = 0.82 \), which is relatively high and indicates that 82% of the values have been predicted by this model. The \( R^2 \) value of 0.82 and the values of the constants \((a_0, a_1, a_2)\) were obtained using the Excel program. The values of the constants of the growth model are as follows (table 1).

**Table 1.** The height curve constants used in estimating tree heights.

|      |      |      |
|------|------|------|
| \( a_0 \) | \( a_1 \) | \( a_2 \) |
| 4.239 | 0.6341 | -0.0059 |

The resulting equation reflects well the relationship between the diameters of the Pinus brutia Ten trees on the plantation and allows to predict the future growth of the tree stand, the inventory indicators of trees and, consequently, the wood volume.

The obtained values of the model constants can be interpreted as an increase in tree height \((a_1)\), and an acceleration of this process \((a_2)\) at the initial levels of the series at \( t = 0(a_0) \).

### 3.2. Estimation of timber stocks and annual growth

Since the beginning of the experiment in 2011, 526 trees have been measured, distributed between seven experimental sites, and the wood stock during this period was 197.5 m³ per ha. In 2014, a re-measurement process was carried out with an increase in the number of samples and the number of measured trees. The annual growth rate for the period 2011–2014 amounted to 2 m³ per hectare per year. In 2020, the same work was repeated with an increase in the areas of sites and the number of trees to increase the accuracy of the work and reduce variation in the study area.

**Table 2.** The results of the growing stock measurements in the sampling plots with *Pinus brutia* Ten at selective level for 2020.

| #1 (m³) | #2 (m³) | #3 (m³) | #4 (m³) | #5 (m³) | #6 (m³) | #7 (m³) | Average experimental area growing stock (m³) | Average growing stock per hectare (m³) |
|---------|---------|---------|---------|---------|---------|---------|---------------------------------------------|-------------------------------------|
| 79.84   | 65.67   | 57.76   | 70.94   | 68.47   | 75.2    | 119.6   | 76.78                                      | 213.3                               |

The number of trees measured in 2020 was 3,617. Wood stock reached 213.3 m³ per ha, and the annual growth rate for the period from 2014 to 2020 was 1.3 m³ per ha per year. Figure 5 shows the timber stock figures obtained during the study periods and shows a significant increase in timber stock.
on the Pinus brutia Ten plantation. However, the decrease in the annual timber increment in 2014–2020 to 1.3 m³ per hectare per year over this period may be due to several factors:

1 - Age-related changes and a corresponding decrease in the annual growth rate.
2 - Lack of thinnings resulting in a high stand density, which lead to increased competition and a decrease in growth rates.

![Figure 5. Values of timber stock on the Pinus brutia Ten. Plantation during the study period.](image)

4. Conclusion

In the course of the study, we used a polynomial distribution to estimate the height of the measured trees, which makes it possible to predict changes in the Pinus brutia Ten. plantation growth parameters in the future.

There was a substantial increase in timber stock in the study area: from 197.5 m³ per ha in 2011 to 213.3 m³ per ha in 2020.

The annual timber increment fell from 2.0 m³ in 2011–2014 to 1.3 m³ per hectare in 2014–2020, which is likely to be associated with age-related changes and excessive tree density. We recommend to remove slow growing trees to reduce the density of the stand and make space for the remaining Pinus brutia Ten. trees.

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