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# Aboveground Live and Dead Biomass Distribution Using Allometric Equation in the Restored Mines of the PPC's Western Macedonia Lignite Center †

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**Abstract:** Forests and forest plantations rank first in storing carbon and play a substantial role in climate change mitigation. Assimilated carbon is stored in the above- and belowground parts of trees, in dead wood, in litter, and in soil. The Greek power generation and supply company PPC S.A. started environmental rehabilitation projects to rehabilitate restored areas after the end of exploitation at the open-cast lignite mines of the Lignite Center of Western Macedonia in the 1980s by planting different tree species, mainly black locust. Today some of these plantations are almost 40 years old and occupy 2,200 ha in total. The dominant planted species is black locust (Robinia pseudoacacia L.), a fast-growing pioneer species, covering 95% of the planted area. Other planted species are Spartium junceum and Cupressus arizonica, covering 2.45% and 1.44%, respectively. The aim of this study was to measure and estimate the live and dead aboveground biomass distribution across the planted sites in the restored waste dumps of Amyntaio and Ptolemaida lignite mines. A total of 215 sample plots of 100 m2 each were set up through systematic sampling at a grid dimension of 500 × 500 m. In each sample plot, the tree species (dbh (cm)), tree height, and height to live crown (m) were recorded for all trees. The aboveground biomass was estimated using an exponential allometric model. The results show that in the tree-planted restored areas of the Amyntaio mine, the aboveground biomass ranges from 20.1 to 90.2 tn ha−1, and in that of the Ptolemaida mine from 11.6 to 75.8 tn ha−1. The spatial biomass distribution seems to show a trend of increase from southeast to northwest in Ptolemaida and from west to north in the Amyntaio mine. The standing dead wood ranges from 0 to 19.8 tn ha−1 for Amyntaio and 0 to 41.9 tn ha−1 for the Ptolemaida mine, and the lying dead wood from 0.5 to 19.5 ha−1 and 0.5 to 66 m3 ha−1, respectively. The overall decay degree that was classified into quality classes from 1 to 5 ranges as: 10% for decay class (1), 27% for decay class (2), 45% for decay class (3), 17% for decay class (4), and 1% for decay class (5). The black locust shows a remarkable ability to survive and grow on disturbed sites, such as the restored mines in the Lignite Center of Western Macedonia. It is very competitive compared with other planted species and has created the necessary forest environment for the natural regeneration of other more shade-tolerant and soil-demanding species, such as oaks and maples.

**Keywords:** climate change mitigation; forest restoration; forest biomass estimation; standing and lying dead wood; variogram model; kriging regression

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## 1. Introduction

Forests and forest plantations rank first in storing carbon and play a substantial role in climate change mitigation [1]. Assimilated carbon is stored in the above- and below-ground parts of trees, in dead wood, in litter, and in soil. The estimation of the quantity of forest biomass is important to assess forest growth and productivity [2]. It is also necessary in estimating carbon stored in a forest or plantation because carbon constitutes about half of the dry biomass [2,3]. The role of forests in carbon sequestration and carbon cycle is generally important [3].

Open-cast coal mines have a great negative impact on landscape degradation [4]. Moreover, one of the major environmental concerns regarding open-cast coal mining areas is the generation of dust through blasts, transportation onto large tracks or conveyors, and processing activities, which have a severe impact on air quality. In European countries, more than 50% of mined lands are reclaimed as forests or grasslands [4].

The Greek power generation and supply company PPC S.A. started environmental rehabilitation projects to rehabilitate restored areas after the end of exploitation at the open-cast lignite mines in the Lignite Center of Western Macedonia in the 1980s by planting different tree species, mainly black locust (*Robinia pseudoacacia* L.). Today, this is still an ongoing process, and some of these plantations on the final surfaces of the waste dumps are almost 40 years old, occupying more than 2,200 ha in total. The dominant planted species is black locust, a fast-growing pioneer species, covering 95% of the planted area, followed by weaver's broom (*Spartium junceum* L.) and Arizona cypress (*Cupressus arizonica* Greene), covering 2.45% and 1.44%, respectively. Other planted species comprise oaks, maples, pines, and various deciduous broadleaves in very small percentages. Black locust is a species native to North America and was introduced in Europe at the beginning of the 17th century [5]. In Greece, this species has been mainly introduced and planted for torrent stabilization in the mountains and for soil erosion control on rivers, roads, and railway banks because of its dense root system. It has also been used as an alternative crop in private-owned plantations for its fast-growing capabilities and good adaptation to marginal agricultural lands [6]. Black locust, despite expressed concerns about its invasiveness [7,8], is a species with special capabilities; apart from its fast-growing ability, it is considered an undemanding species [9]. It can tolerate alkaline soils with pH up to 8 [10] and, as a legume species, has the ability of nitrogen fixation [11]. It can tolerate drought and survive on poor soils with less nutrient supply, like in the former open-cast mining areas [12]. The aim of this study was to measure and estimate the live and dead aboveground biomass distribution across the planted sites in the restored waste dumps of the Amyntaio and Ptolemaida lignite mines.

## 2. Methods

The data used in the present study were collected from the restored former open-cast mining areas of the Lignite Center of Western Macedonia. The plantations are located near Amyntaio City within the geographic coordinates of 40.56 to 40.61 N and 21.62 to 21.69 E and near Ptolemaida City within the geographic coordinates of 40.39 to 40.51 N and 21.7 to 21.89 E. The total size of the planted area is approximately 22,000 ha. For the estimation of the distribution of the aboveground biomass, a total of 215 sample plots of 100 $m^2$ each were set up through systematic sampling at a grid dimension of 500 × 500 m in the restored former open-cast mining areas of Amyntaio and Ptolemaida. In each sample plot, the tree species, diameter at breast height (dbh) in cm, tree height (Ht), and height to live crown (Hlc) in m were recorded for all trees. The lying dead wood was recorded for all trees or pieces of trees that were lying within the surface of the plot; the measured variables were the diameter at the two ends of the tree or log in cm, the length in m, and the decay degree in a scale of 1 to 5 as follows: (1) intact bark, small branches (<3 cm) present, intact wood texture, log elevated on support points; (2) intact bark, no twigs, log elevated but slightly sagging; (3) traces of bark, no twigs, wood hard, texture with large pieces, log sagging near ground; (4) no bark, no twigs, texture small, wood soft, texture with blocky pieces, all of log on ground; (5) no bark present, no twigs, wood soft and powdery texture, all of the log on ground [13]. The aboveground biomass was estimated using an exponential allometric model of the form $M = a*dbh^b$. For the calibration of the allometric equation, 30 black locust trees covering the entire diameter range were destructively sampled during the summers of 2019 and 2020. The diameters at stump height (D0.3 in cm) and at breast height (D1.3 in cm) were measured before the tree felling. The sampled trees were cut at the stump height (0.30 m), and after felling, the total tree height (H in m), diameter at 50% of the bole length (D0.5 in cm), and diameter at the base of the live crown were recorded. Each one of the 30 stems was divided into six sections (including the stump) after felling, and fresh biomass of each stem section was measured in the field. From each section, a stem disk 7 cm wide was removed, weighed, taken to the laboratory, and oven-dried at 80° C until a constant weight was reached to determine the fresh/oven-dried biomass ratio. The fresh biomass of the whole crown was also weighed in the field and taken to the laboratory and oven-dried at 80° C until a constant weight was reached [14].

For the estimation of the spatial distribution of the aboveground biomass, a geostatistical approach was applied. The spatial analysis was conducted in R programing language [15] using gstat library for variogram analysis and modeling. The parameters of the best variogram model (nugget, range, and partial sill) were used in ordinary kriging interpolation [16].

## 3. Results and Discussion

Black locust stands show high heterogeneity with dbh ranging from 1.4 to 22.3 cm and its biomass per hectare ranging from 0.6 to 256.6 ton $ha^{-1}$. More specifically, in the tree-planted restored areas of the Amyntaio mine, the aboveground biomass ranges from 20.1 to 90.2 tn $ha^{-1}$, and in the tree-planted restored areas of the Ptolemaida mine, it ranges from 11.6 to 75.8 tn $ha^{-1}$. The spherical, Gaussian, and exponential variogram models that fitted in the dataset are those that usually apply in ecological studies [17]. Based on the semivariograms of the aboveground biomass in both sites effectively described by the spherical model, changes in the spatial distribution of aboveground biomass are affected by both structural and random factors. The magnitude of the spatial correlation of aboveground biomass is considered medium with the nugget-to-total-sill ratio being between 25% and 75%. Besides the structural factors' effect, the effects of random factors, such as sampling grid resolution, plot size, and precision of the allometric equation on the biomass estimation, also play an important role in the relatively high nugget effects recorded. The spatial biomass distribution seems to show a trend of increase from southeast to northwest in Ptolemaida and from west to north in the Amyntaio mine, showing the spatial direction of the planting process in the past years. The standing dead wood ranged from 0.37 to 19.8 tn $ha^{-1}$ for Amyntaio and 0.06 to 41.9 tn $ha^{-1}$ for the Ptolemaida mine, and for the lying dead wood, 0.5 to 19.5 $ha^{-1}$ and 0.5 to 66 $m^3$ $ha^{-1}$, respectively. The overall decay degree that was classified into quality classes from 1 to 5 ranges as: 10% for decay class (1), 27% for decay class (2), 45% for decay class (3), 17% for decay class (4), and 1% for decay class (5). Eighty-three percent of the dead wood concentrates in decay classes 1, 2, and 3, denoting an increase in competition and self-thinning of the trees in the last 10 years, considering that these plantations have not been thinned before.

## 4. Conclusions

- The spatial distribution of the aboveground biomass of black locust in the Lignite Center of Western Macedonia was effectively estimated using an ordinary kriging approach.

- The total aboveground biomass estimated by ordinary kriging was 138,778 tons for the Amyntaio mining area and 44,052 tons for the Ptolemaida mining area and 182,830 tons in total.
- The standing and lying dead wood -represent 5%–7% of the standing wood mass, and it is expected to increase if the forest created from these plantations remains out of management in the future.
- Black locust (*Robinia pseudoacacia* L.), due to its nitrogen-fixing and stress-tolerant characteristics, shows a remarkable ability to survive and grow on disturbed sites, such as the restored land in open-cast lignite mines of the Lignite Center of Western Macedonia. It is fast-growing and thus very competitive compared with other planted species forming stands with full canopy closure and, consequently, has created the necessary forest environment for the natural regeneration of other more shade-tolerant and soil-demanding species, such as oaks and maples.

**Author Contributions:** Conceptualization, G.S. and N.N.; methodology, G.S. and N.N.; software, G.S. and N.N.; validation, M.F. and N.N.; formal analysis, G.S. and N.N.; investigation, G.S.; data curation, G.S and N.N.; writing—original draft preparation, G.S; writing—review and editing, G.S and M.F.; supervision, K.R.; project administration, K.R.; funding acquisition, K.R. All authors have read and agreed to the published version of the manuscript.

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