Research Article

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Effect of elevation on wood density of oriental beech (*Fagus orientalis* lipsky): A case study from Daday

Emre KUZUGÜDENLİ[a,*]

[a] *Department of Forestry, Yenisarbademli Vocational School, Applied Sciences University of Isparta, Isparta, Turkey*

Highlights

- Elevation has a strong negative effect on oven-dry wood density in Fagus orientalis
- Mean wood density decreased by 13% from low to high elevation zones
- The relationship between elevation and wood density showed a very strong correlation (r = –0.84)
- Low-elevation stands are more suitable for producing high-quality beech timber

Abstract

This study examines the relationship between oven-dry wood density and the site factor of elevation in Oriental beech (*Fagus orientalis* Lipsky). The research was conducted in three natural stands located at different elevation zones (low: 250–500 m, mid: 800–1100 m, high: 1400–1700 m) within the Daday Forest District of Kastamonu province in Turkey. From each elevation group, wood samples were collected from 10 trees and analyzed according to the TS 2472 standard for oven-dry density. The data were evaluated using ANOVA and Pearson correlation analysis. Results revealed a strong negative correlation between elevation and wood density ($r = –0.84$; $p < 0.001$). The mean oven-dry density was 0.712 g/cm³ at low elevation, decreasing to 0.617 g/cm³ at high elevation. These findings demonstrate that wood quality depends not only on species but also on site conditions, offering valuable insights for silvicultural planning and industrial wood production.

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1. Introduction

Wood is a key renewable raw material that plays a central role not only in the forestry sector but also in construction, furniture, paper, and bioenergy industries. Among the most critical physical properties influencing the industrial value and performance of wood is wood density, defined as the dry mass per unit volume. This property is directly linked to structural integrity, processing behavior, and durability of wood products. High-density woods are typically more durable and mechanically resistant but are harder to process, whereas low-density woods are lighter and easier to work with but may lack strength and decay resistance [1].

Wood density is influenced by both genetic characteristics and site conditions. Environmental factors that shape wood formation are commonly categorized into four major categories: physiographic, climatic, edaphic, and biotic [2]. Among these, elevation (i.e., altitude above sea level) is a major physiographic factor with the capacity to affect wood structure directly and indirectly. Increasing elevation often brings a decrease in mean annual temperature, shorter growing seasons, changes in radiation, and variations in soil development and moisture availability. These environmental shifts affect photosynthesis, cambial activity, and xylem differentiation, ultimately modifying wood anatomy and density [3].

Numerous studies have reported that elevation can significantly affect wood density. In particular, many species show a negative correlation between elevation and wood density, attributed to cooler temperatures and limited cambial activity at higher altitudes [4]. Chave et al. [5], in a comprehensive study of 2,456 tropical tree

* *Corresponding author: emrekuzugudenli@isparta.edu.tr (E., Kuzugüdenli), +90 536 783 2444*

species, found that wood density declined with elevation, suggesting that reduced lignification and lower vessel wall thickness were responsible. Similarly, Govorčin et al. [6] reported that beech trees in Croatia showed decreasing mechanical and density properties with increasing elevation.

On the other hand, not all studies agree on this trend. Kiaei [7], investigating *Carpinus betulus* L. in northern Iran, observed a positive correlation between elevation and wood density. This anomaly was explained by differences in tree age—higher elevation stands comprised younger trees with higher juvenile wood content. Such discrepancies highlight the importance of controlling for variables like tree age, soil type, and competition when analyzing site–wood property relationships [8].

In Turkey, Oriental beech (*Fagus orientalis* Lipsky) is one of the most ecologically and economically important native tree species, with a wide natural distribution in the Black Sea region. Its high-quality wood is widely used in furniture and veneer industries, and the species is considered highly responsive to ecological gradients, making it a suitable model for studying site–trait interactions [9]. Previous research on *F. orientalis* indicates that elevation affects multiple wood properties, including fiber length, ring width, vessel diameter, and ultimately, density [10].

Elevation also impacts the structure of annual growth rings. Trees growing at higher elevations generally experience shortened growing seasons and reduced cambial activity, resulting in narrower rings and less lignified latewood. These changes can lead to lower overall wood density [11]. However, species-specific traits, microsite effects, and stand structure can moderate or obscure these elevation-induced patterns, underlining the need for species- and site-specific investigations [12].

This study aims to investigate the relationship between elevation and a single wood property, oven-dry wood density, in oriental beech under natural forest conditions in Turkey. By isolating a single site factor and a single wood trait, the study avoids the complexity of multivariate ecological analyses and instead provides a focused and interpretable assessment of how altitude affects wood structure. The results are expected to contribute to more informed silvicultural planning and sustainable forest management, particularly in site selection and stand design for high-quality wood production.

2. Materials and Methods

2.1. Study area

The study was carried out in the Daday Forest Enterprise Directorate, located in Kastamonu Province, situated within the Western Black Sea Region of Turkey. This region exhibits a wide altitudinal gradient, ranging from 250 meters to approximately 1700 meters above sea level, making it well-suited for evaluating the effects of elevation on tree growth characteristics within a relatively homogeneous climate zone. The area is topographically diverse, with undulating mountainous terrain and a predominance of north- and east-facing slopes.

The region is classified as a transition zone between the Black Sea maritime climate and the semi-continental interior climate. It receives annual precipitation of approximately 900–1100 mm and has mean annual temperatures ranging between 9°C and 11°C [13]. The forests in the region are dominated by Oriental beech, along with Scots pine (*Pinus sylvestris*), fir (*Abies nordmanniana* subsp. *bornmuelleriana*), and several species of oak (*Quercus* spp.). These conditions provide a stable ecological framework for the analysis of site–wood property interactions [14].

2.2. Sampling design

To examine the relationship between elevation and oven-dry wood density, three distinct elevation bands were defined:

- Low elevation: 250–500 m
- Mid elevation: 800–1100 m
- High elevation: 1400–1700 m.

In each elevation band, 10 mature Oriental beech trees were selected, totaling 30 sample trees. Trees were selected based on their dominance in the canopy, absence of visible defects, and similar stem forms. Stands were chosen with comparable site characteristics (e.g., slope, aspect, soil type) and management history to minimize confounding environmental variation. The trees ranged in age from 80 to 120 years, which helped minimize potential age-related variation in wood properties [15].

2.3. Wood sampling and density determination

From each sample tree, a 5-cm-thick cross-sectional disc was removed at breast height (1.30 m). Discs were labelled and transported to the laboratory. In the lab, the samples were first air-dried, then oven-dried at 103 ± 2°C until reaching constant weight.

Each disc was subdivided radially into three 2 × 2 × 3 cm prisms representing different positions between the pith and bark. For each prism, volume was measured using the water displacement method, and oven-dry mass was determined with an analytical balance (±0.001 g precision) (see Figure 1.).

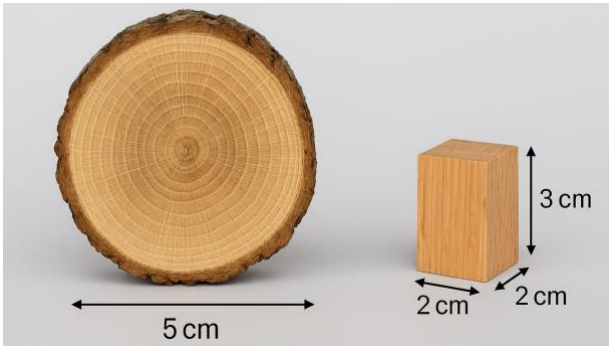

Figure 1. Wood sampling procedure: Cross-Sectional disc (left) and prism used for density analysis (right)

2.4. Statistical analyses

All data were evaluated for normality using the Shapiro-Wilk test, and results indicated normal distribution in all groups. Thus, parametric statistical methods were used. Differences in mean oven-dry density among the elevation groups were analysed using one-way ANOVA. Where significant differences were found, Tukey's HSD test was applied for post-hoc comparisons [16].

The strength and direction of the relationship between elevation and wood density were assessed using Pearson correlation analysis. Correlation coefficients were interpreted based on Evans (1996), as follows:

- 0.00–0.19: Very weak
- 0.20–0.39: Weak
- 0.40–0.59: Moderate
- 0.60–0.79: Strong
- 0.80–1.00: Very strong [17].

All statistical analyses were performed using SPSS v25.0, and significance was tested at $p < 0.05$.

2.5. Limitations

This study deliberately focused on a single wood trait (oven-dry density) and one environmental factor (elevation) to isolate their relationship. While other variables such as soil chemistry, competition, or light availability may influence wood formation; however, their effects were minimized by carefully selecting homogeneous stand conditions. Nonetheless, future studies may expand upon these results by incorporating additional structural or anatomical traits such as vessel diameter, ring width, or fiber length using micro-sectioning and image analysis techniques [18].

3. Results

Statistical analysis revealed that oven-dry wood density in oriental beech varied significantly across the three elevation classes. The mean density values for each group showed a consistent decreasing trend with increasing elevation, as summarized in Table 1 and Figure 2.

Table 1. Mean oven-dry wood density by elevation class

Elevation Class	Mean Density (g/cm³)	Std. Dev.	Min.	Max.
Low (250–500 m)	0.712	0.017	0.689	0.735
Mid (800–1100 m)	0.664	0.020	0.637	0.689
High (1400–1700 m)	0.617	0.018	0.591	0.639

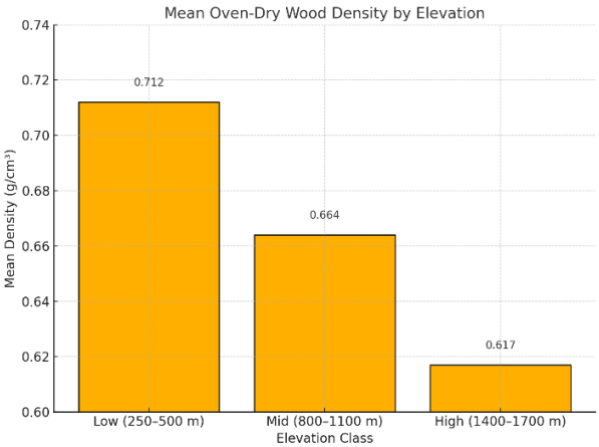

Figure 2. Mean oven-dry wood density by elevation class

The ANOVA test indicated that the differences among the three elevation groups were statistically significant ($F = 58.43$, $p < 0.001$). According to the Tukey HSD test, all pairwise group comparisons were also significant:

- Low vs. Mid: $p = 0.001$
- Low vs. High: $p < 0.001$
- Mid vs. High: $p = 0.002$.

These results suggest that even modest differences in elevation (300–400 meters) can lead to substantial changes in wood density in Oriental beech.

3.1. Correlation between elevation and wood density

To further clarify the relationship, Pearson correlation analysis was conducted between elevation (as a continuous variable) and wood density values. The result showed a very strong and negative correlation ($r = –0.84$, $p < 0.001$). This finding confirms that as elevation increases, oven-dry wood density in oriental beech

decreases significantly. This is consistent with physiological expectations: at higher elevations, lower temperatures and shorter growing seasons can reduce cell wall thickening, thereby lowering wood density [4-6].

3.2. Qualitative field observations

Although the study primarily focused on density values, qualitative anatomical differences were also noted during visual inspection of the cross-sectional discs. Trees from higher elevations generally exhibited:

- Narrower growth rings
- Less distinct earlywood–latewood boundaries
- Lower vessel density and less compact fiber zones.

These features are congruent with anatomical responses reported in previous research on beech and similar temperate broadleaf species growing under suboptimal conditions [10,11].

4. Discussion and Conclusion

The findings of this study clearly demonstrate that elevation is a significant environmental factor influencing oven-dry wood density in oriental beech. The results indicate a consistent and statistically significant decrease in wood density with increasing elevation, with a strong negative correlation ($r = –0.84$, $p < 0.001$). Trees growing at low elevations (250–500 m) produced significantly denser wood than those at mid (800–1100 m) or high elevations (1400–1700 m), a pattern aligned with the known eco-physiological responses of temperate forest species to altitude gradients.

Several mechanisms may explain the reduction in wood density at higher elevations. First, shorter growing seasons and reduced thermal accumulation at higher altitudes limit the duration and intensity of cambial activity, resulting in narrower annual rings and decreased cell wall thickening [4-6]. This phenomenon is particularly important for diffuse-porous hardwoods like beech, where latewood formation contributes substantially to overall density [10]. Furthermore, lower temperatures may alter hormonal balances and resource allocation during xylem development, potentially decreasing lignin and cellulose deposition [19].

These results are consistent with similar studies conducted on both *Fagus sylvatica* [6] and other broadleaved species in mountainous regions [16]. However, discrepancies in the literature—such as Kiaei's [7] report of higher densities at greater altitudes—highlight the complexity of ecological controls on wood structure. Differences in genetic provenance, site productivity, age structure, and stand dynamics may produce species- or region-specific deviations from general patterns [8].

From a silvicultural and industrial perspective, the implications of this study are significant. For forest managers aiming to optimize wood quality in beech stands, low to mid-elevation sites should be prioritized for conservation and timber production purposes. These zones are more likely to produce high-density wood suitable for structural uses, furniture, or veneer manufacturing. In contrast, stands at higher elevations may yield lighter wood more appropriate for pulp or fuelwood purposes. Therefore, elevation data should be integrated into forest management plans, particularly in species–site matching strategies, stand rotation planning, and future yield projections under changing climatic scenarios [13,14].

The results also underscore the value of single-variable ecological studies in isolating specific environmental effects on tree traits. While multivariate models can offer broad predictive power, targeted studies such as this provide clearer insight into cause–effect relationships, especially when carefully controlled for confounding factors such as tree age, stand structure, and soil type [15].

5. Recommendations

Based on the results of this study, the following recommendations are offered:

i. In forest planning, particularly for oriental beech, sites located at lower elevations (below 800 m) should be preferred for high-density wood production.

ii. Future studies should integrate xylem anatomical analysis, dendrochronological methods, and physiological measurements (e.g., lignin/cellulose ratios) to explain the density–elevation relationship at finer resolution.

iii. Incorporating GIS-based modeling with topographic, climatic, and edaphic data layers could help scale this approach to broader landscapes.

iv. Provenance trials and common garden experiments could be used to determine the relative roles of genetics vs. environment in observed wood density variation.

6. Conclusion

In conclusion, elevation plays a significant and measurable role in shaping the oven-dry wood density of oriental beech in natural stands of the Western Black Sea Region of Turkey. The clear decline in density with increasing elevation supports both ecological theory and practical expectations in forestry expectations. This study contributes to the growing body of knowledge on wood

ecology and highlights the importance of integrating environmental gradients into forest productivity and quality assessments.

Declaration of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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