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CONTENT SADRŽAJ

Vol. 92

INSTITUTE OF FORESTRY • BELGRADE
INSTITUT ZA ŠUMARSTVO • BEOGRAD

SUSTAINABLE FORESTRY **ODRŽIVO ŠUMARSTVO**
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RELATIONSHIP BETWEEN THE VISUAL TREE RATINGS AND WOOD SOUND VELOCITY OF POPLAR TREES

Ivana ŽIVANOVIĆ[1], Aleksandar LUČIĆ[1], Nenad ŠURJANAC[1], Goran ČEŠLJAR[1], Ilija ĐORĐEVIĆ[1], Filip JOVANOVIĆ[1]

Abstract: *Fifty-six Populus spp. trees were examined in Belgrade, Serbia, with a focus on assessing vitality and decorativeness using the Visual Tree Assessment (VTA) method and measuring wood sound velocity. The study aimed to explore the connection between visual indicators of tree condition and internal structural properties based on sonic wave velocities. Vitality and decorativeness ratings ranged from 2 to 5 (out of 5), with mean values of 2.80 and 2.93, respectively; wood sound averaged 788,39 m/s. Statistically significant correlations (r = 0.52 for vitality, r = 0.53 for decorativeness) confirmed the possibility of integrating VTA and sonic measurements. Mathematical models were developed that successfully predict tree vitality and decorativeness based on sound velocity. It can be concluded that this combined approach improves tree health assessment accuracy, supports timely interventions, and contributes to sustainable urban greenery management.*

Keywords: decorativeness, vitality, sound velocity, Populus spp., mathematical models

KORELISANOST VIZUELNIH OCENA STABALA I BRZINE PROSTIRANJA ZVUKA U DRVETU TOPOLA

Sažetak: *Analizirano je 56 stabala topole (Populus L.) na području Beograda, sa fokusom na procenu vitalnosti i dekorativnosti metodom vizuelne procene stabala (VTA), uz merenje brzine zvučnih talasa u drvetu. Cilj istraživanja je da se prouči povezanost vizuelnih indikatora stanja stabala i unutrašnjih strukturalnih svojstava na osnovu brzine zvučnih talasa. Ocene vitalnosti i dekorativnosti su se kretale u rasponu od 2 do 5 od 5, s prosečnim vrednostima od 2,80 i 2,93, dok je brzina zvuka u drvetu pokazala prosečnu vrednost od 788,39 m/s. Statistički značajne korelacije utvrđene su između brzine zvuka u drvetu i vizuelnih parametara (r = 0,52 za vitalnost, r = 0,53 za dekorativnost), što ukazuje na mogućnost integracije VTA metode i zvučnih merenja. Razvijeni su matematički modeli kojima se pouzdano mogu predvideti vitalnost i dekorativnost drveta na osnovu brzuine zvuka. Zaključuje se da ovaj kombinovani pristup poboljšava preciznost procene zdravlja stabala, podržava pravovremene intervencije i doprinosi održivom upravljanju urbanim zelenilom.*

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Ključne reči: dekorativnost, vitalnost, brzina zvuka, *Populus* spp., matematički modeli

1. INTRODUCTION

Belgrade, the capital of Serbia, located at 116.75 m elevation (44°49'14" N, 20°27'44" E), covers 359.92 m² of urbanized area (City of Belgrade, Secretariat for Information, 2022). The city has 2,907.37 ha of green spaces, including parks and squares (393.00 ha), residential greenery (1,077.67 ha), roadside green spaces (174.89 ha), urban forests (650.88 ha), coasts, shores, and Great War Island (225.83 ha), protective zones (35.77 ha), and other types of green areas (349.24 ha) (Milanović, 2006). Belgrade's rich ecological diversity and unique microclimatic conditions have resulted with varied plant communities throughout the area. Native deciduous species, such as lindens (*Tilia* spp.), maples (*Acer* spp.), ashes (*Fraxinus* spp.), poplars (*Populus* spp.), and hornbeams (*Carpinus* spp.) dominate in this area, whereas oaks (*Quercus* spp.) are less common. Introduced species include acacia (*Robinia pseudoacacia* L.), horse chestnut (*Aesculus hippocastanum* L.), catalpa (*Catalpa bignonioides* Walter), as well as conifers, such as cedar (*Cedrus* spp.) (Maksimović et al., 1979). Human influence has expanded the diversity of dendroflora species, enhancing the city's green spaces.

Poplars (*Populus* L. fam. *Salicaceae)* are fast-growing broadleaved tree species inhabiting river banks and sites with accessible water supplies (Keča et al., 2014). The genus comprises 25–30 species native to the Northern Hemisphere. According to the National Forest Inventory (NFI) poplar stands cover about 48,000 ha, or 2.1% of the total forest area in Serbia (Banković *et al*., 2009). Poplar trees have garnered attention in previous decades for their great potential to contribute significantly to the quality and quantity of urban greenery. Poplars are ideal for urban areas due to: (1) the rapid growth and production of large biomass; (2) the ability to improve the microclimate through shading and pollution filtration; and (3) a great potential for heavy metals phytoextraction(Łukaszkiewicz *et al*., 2024).

Assessing the health and mechanical condition of trees in urban environments has become increasingly important due to the need to maintain public safety as well as the aesthetic and ecological value of green spaces. Urban trees are exposed to various stress factors, limited rooting space, soil compaction, mechanical injuries, and environmental pollution, which can promote the development of internal and external defects that are not always detectable through visual observation.

Modern approaches to evaluating tree stability integrate visual indicators with biomechanical principles that describe how trees respond to loading and tissue degradation. Changes in stem form, crown architecture, or vitality provide essential information for identifying potential structural weaknesses. However, numerous studies have shown that substantial internal defects often develop before they become externally visible, which may lead to an underestimation of risk when assessments rely solely on outward symptoms (Goh *et al*., 2018; Mahon *et al*., 2007).

For this reason, contemporary urban arboriculture increasingly relies on combining visual assessment with non-destructive techniques that provide information on wood condition and its ability to transmit mechanical energy. These approaches enable a more accurate estimation of degradation extent, a better understanding of the relationship between internal wood quality and mechanical properties, and ultimately an improved evaluation of the residual load-bearing capacity of trees. Integrating qualitative visual observations with quantitative indicators contributes to more reliable decision-making in tree management, particularly in high-risk urban areas (Živanović *et al*., 2019; Živanović *et al*., 2022).

In this paper, the wood speed velocities measured in 56 poplar trees were compared with vitality and decorativeness visual ratings. The objective of this research is to establish a connection between the vitality and decorativeness of poplar trees, as evaluated through a detailed visual inspection, and the sound wave velocities obtained through measurements conducted on the same trees. By integrating these two factors, the study aims to provide deeper insights into how visual assessments correlate with the physical-mechanical properties of trees, as indicated by acoustic measurements. Understanding this relationship can contribute significantly to developing comprehensive methods for tree health evaluation, combining both subjective visual parameters and objective scientific data for a more holistic assessment approach.

2. MATERIAL AND METHODS

The sample consisted of 56 trees of *Populus* in the city of Belgrade (Figure 1).

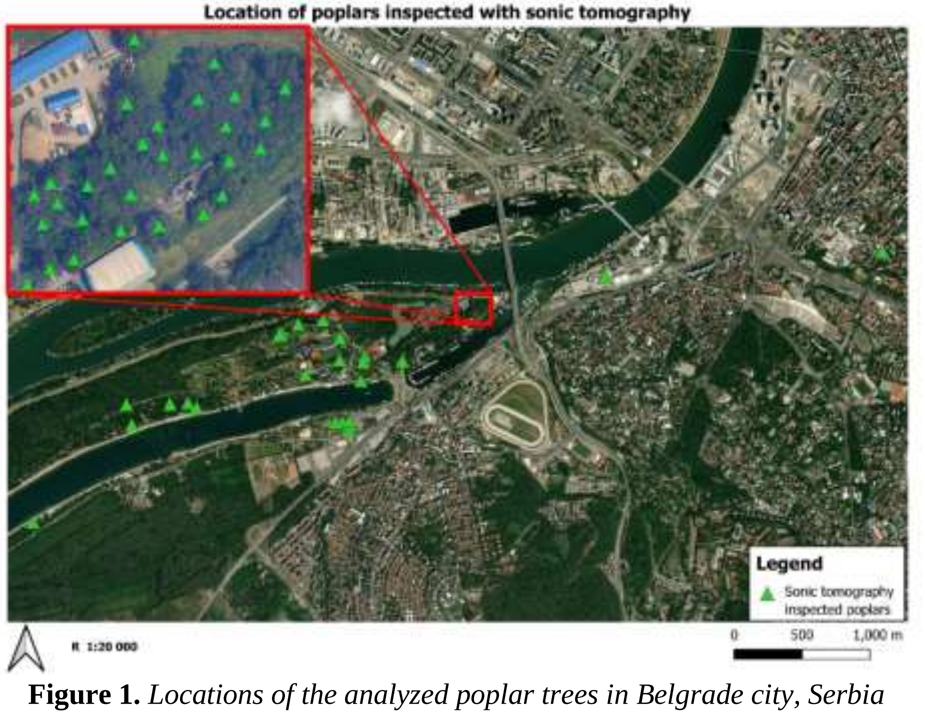


Figure 1. *Locations of the analyzed poplar trees in Belgrade city, Serbia*

The examined trees belonged to four poplar taxa [36 trees of *Populus alba* L., eleven trees of *P. nigra* L., four trees of *P. euroamericana* (Dode) Guinier, and five trees of *P. x canadiensis* Moench]. The vitality and decorativeness of the trees were evaluated using the Visual Tree Assessment (VTA) method (Mattheck and Breloer, 1994), according to the rating scales defined in Table 1.

Table 1. Rating scales for vitality and decorativeness of trees.

Grade	Vitality	Decorativeness
5	Excellent, healthy and strong trees, with no visible insect damage or disease and no mechanical wounds.	Visually imposing and aesthetically valuable trees.
4	Trees in good condition, healthy, with only slight signs of injury, disease or physiological weakness.	Trees with a visually balanced form.
3	Trees with some mechanical, phytopathological or entomological damage.	Trees that have a clearly outlined crown in silhouette.
2	Trees with clearly visible mechanical damage from insects and/or diseases.	Trees of a disharmonious and disproportionate silhouette with insufficiently clearly delineated habitus.
1	Dead or nearly dead trees.	Trees without aesthetic value.

The sound propagation velocities were measured at breast height using the Arbotom 2D Impulse Tomograph, manufactured by the German company Rinntech. At the start of the measurements, a compass was used to locate the north side of each tree, where the first sensor was placed. Additional sensors were then positioned clockwise around the tree's circumference at intervals of at least 15 cm. Depending on the diameter of the tree, 3–12 sensors were used for analysis. Based on the measurements of sound propagation velocities, the average sound wave velocity was calculated for each analyzed tree.

The obtained numerical data were processed using descriptive and regression statistical methods. Raw data were used to calculate the mean values of all variables and to determine the standard deviation and coefficient of variation for every mean value. The relationship between the visual tree ratings and wood sound velocity was identified using the Pearson’s linear correlation test. Statistical analyses were performed using Statgraphics software, version XVI.I (2009; Statpoint Technologies, Inc., Warrenton, Virginia, US).

3. RESULTS

The vitality and decorativeness of the examined poplar trees ranged from grade 2 to grade 5, with mean values of 2.80 and 2.93, respectively. The descriptive statistics revealed a moderate variability of these visual tree condition ratings (coefficient of variation was 20.80% for the vitality and 22.17% for the decorativeness of trees). On the other hand, the wood sound velocity ranged from 375.00 m/s to 2090.00 m/s, with a mean value of 788.39 m/s. In comparison to the vitality and decorativeness, the wood sound velocity was more variable tree condition parameter (coefficient of variation 37.15%) (Table 2).

Table 2. *Descriptive statistics for visual ratings of tree condition and wood sound velocity of poplars*

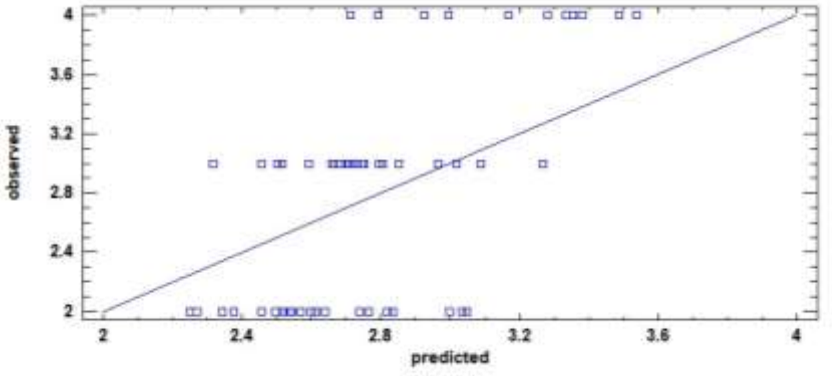
Tree condition parameters	Mean value	Standard deviation	Coeff. of variation (%)	Minimum value	Maximum value
Vitality (1–5)	2.80	0.75	26.71	2	4
Decorativeness (1–5)	2.93	0.74	25.10	2	5
Wood sound velocity (m/s)	788.39	292.90	37.15	375	2090

Table 3 and Figure 2 show linear models which describe the relationship between the visual ratings of vitality and decorativeness and wood sound velocity of poplar trees. According to the obtained results, almost the same as a correlation occurred between the ratings of tree decorativeness and the wood sound velocity (r = 0.534) than between the ratings of tree vitality and the wood sound velocity (r = 0.523). Both values are statistically significant ($p < 0.05$) with similar standard errors of estimate (0.523 for vitality and 0.534 for decorativeness). These results indicate that the visual ratings of trees are good indicators of tree condition and health of poplars, although some preference might be given to the decorativeness ratings. Using the obtained linear regression models, visual tree condition parameters can be calculated based on wood sound velocity.

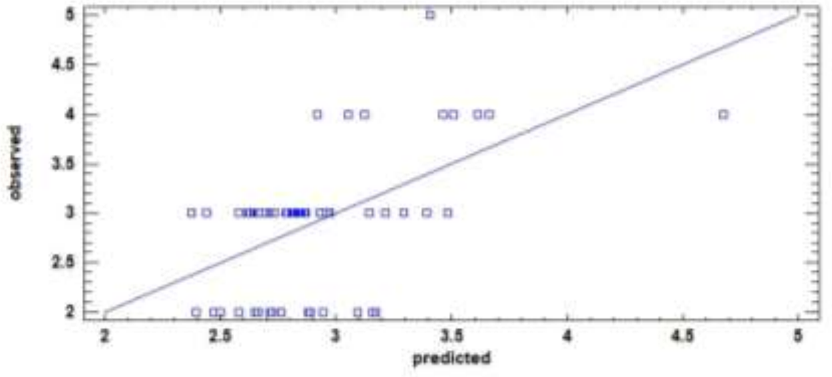
Table 3. *Linear regresion models of tree condition ratings based on average sound velocity in wood of poplars*

Tree condition parameters	Linear regression model	Correlation coefficient	Standard error of estimate
Vitality	1.74819 + 0.00133865*Avg sound velocity	**0.523**	0.249
Decorativeness	1.87164 + 0.00134061* * Avg sound velocity	**0.534**	0.242

Note: Bold values denote statistically significant correlation coefficients.



A)



B)

Figure 2. *Correlation between visual tree ratings (A. tree vitality, B. tree decorativeness) and average sound velocity in wood of poplars.*

4. DISCUSSION

Using Arbotom Sonic Tomograph, an investigation was conducted on 27 poplars to assess their internal condition and confirm the findings obtained through Visual-Tree Assesment (VTA). Visual Tree Assessment (VTA), developed in 1994 by Claus Mattheck and Helge Breloer, is a method for evaluating tree stability and detecting defects. It relies on the principle that trees reinforce weak areas in response to mechanical stress. Arborists use VTA to identify external signs of internal decay, such as bulges, dents, or cracks, indicating structural weaknesses. If defects are suspected, further testing like sonic wave velocity measurements or drilling may be used. Widely adopted in arboriculture, VTA is a non-invasive method that assesses tree safety and risks effectively. Initially, signs of potential problems were identified through VTA, evaluating the vitality and decorative value of the trees. To further validate these assessments, sound analysis was applied.

The results showed a significant correlation between the ratings obtained through VTA and the data collected using Arbotom tomography. The correlation coefficient was 0.52 for vitality and 0.53 for decorative value, confirming that the sound method can reliably complement and validate VTA assessments.

Studies conducted by Mattheck and Bethge (1994) demonstrated that tree safety can be assessed by measuring sound velocities, making it a reliable method for detecting internal defects. A successive approach was recommended, where visual assessments are performed first (VTA), followed by sound measurements to confirm initial concerns. Their research also showed that root decay can be detected if it extends into the base of the tree, further supporting the use of sound technology in tree diagnostics. However, it was noted that certain types of decay, such as embrittlement (a reduction in strength without loss of stiffness), cannot be detected in early stages.

Additionally, this connection between the two methods was also confirmed by the research of Saad (2023), where PiCUS Sonic Tomograph was used to detect internal decay, providing scientific confirmation for the suspicions raised by VTA. Their findings emphasized the importance of integrating sound analysis in tree health assessments, proving that VTA and sound methods are closely related and mutually supportive.

Moreover, iron-wood trees were visually inspected for seven main defects, including decay, cracks, root issues, and weak branch unions by Lin *et al*., 2015. Nondestructive testing revealed that decay-damaged trees had lower stress wave velocities compared to undamaged ones, with a threshold of 1636 m/s used for diagnosis. Tomograms showed a distinct pattern of high velocity in healthy areas and low velocity in decay-damaged areas of the stem.

Additional studies further support the combined use of visual assessments and nondestructive tools. Deflorio *et al*. (2008) demonstrated that stress-wave and ultrasonic velocities correlate strongly with wood stiffness and decay progression, making them valuable for early detection of internal defects. Nicolotti *et al*. (2003) showed that tomographic imaging significantly improves the identification of hidden cavities and fungal decay compared to visual inspection alone. Similarly, Rinn (2012) emphasized that integrating VTA with sonic and resistance-based methods increases diagnostic reliability and supports better management decisions in urban tree care. Research by Wang *et al*. (2007) further confirmed that wave-propagation tools are sensitive to density loss and changes in mechanical properties, validating their role in structural assessment.

The findings of these researchers align with the results of this study on poplars, reinforcing that the combination of VTA analysis and sound methods provides more precise data and allows timely interventions in tree maintenance. This approach contributes to the preservation of urban greenery and reduces the risk of tree failure, in accordance with the methods applied by mentioned authors in their studies.

5. CONCLUSION

Based on the results of the conducted research, the integrated application of Visual Tree Assessment (VTA) and sonic tomography represents a consistent approach for evaluating the physiological condition and structural stability of poplar trees. The combination of external visual indicators and internal sonic data provides a comprehensive understanding of tree health, allowing assessment not only of surface symptoms but also of the internal integrity of the wood. Variability observed among the analyzed trees indicates differences in vitality and mechanical condition that can be objectively quantified through sound velocity measurements.

The relationship between sound velocity and visual parameters of vitality and decorativeness confirms the correspondence between external appearance and internal wood quality. Trees with higher sound velocities generally exhibit better physiological condition and more favorable aesthetic attributes, reflecting their stability and vitality within the urban environment. The established regression relationships enable the estimation of visual parameters based on measurable sonic characteristics, thus extending the diagnostic value of the method.

The integration of VTA and sonic tomography contributes to a more precise, science-based evaluation of urban trees. Such an approach enhances the reliability of decision-making in arboricultural practice, supports preventive maintenance and risk management, and ultimately contributes to the preservation and sustainable development of urban green spaces.

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RELATIONSHIP BETWEEN THE VISUAL TREE RATINGS AND WOOD SOUND VELOCITY OF POPLAR TREES

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Goran ČEŠLJAR, Ilija ĐORĐEVIĆ, Filip JOVANOVIĆ

Summary

A total of 56 poplar trees (Populus sp.) in the Belgrade area were examined to assess vitality and decorativeness using the Visual Tree Assessment (VTA) method and by measuring the velocity of sound waves in wood. VTA, as a widely applied non-invasive method, enables the detection of external symptoms that indicate internal degradation processes in wood, while sound analysis complements this assessment by providing quantitative data on sound propagation velocity through the woody tissue. The mean vitality score was 2.6780, and the mean decorativeness score was 2.8993, both showing moderate variability (coefficients of variation 20.27% and 22.25%, respectively).

The velocity of sound waves exhibited greater variability, with an average value of 663.26 m/s. Statistically significant correlations were found between sound velocity and visual scores ($r = 0.52$ for vitality, $r = 0.60$ for decorativeness), indicating a relationship between external tree assessment and internal structural characteristics. Mathematical models were developed that allow reliable prediction of tree vitality and decorativeness based on sound velocity.

The results demonstrate that combining visual assessment and sonic analysis improves the precision of tree condition diagnostics, enabling timely interventions and contributing to the preservation of urban greenery.

KORELISANOST VIZUELNIH OCENA STANJA STABALA I BRZINE PROSTIRANJA ZVUKA U DRVETU TOPOLA

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Goran ČEŠLJAR, Ilija ĐORĐEVIĆ, Filip JOVANOVIĆ

Rezime

Ispitano je 56 stabala topole (*Populus* sp.) na području Beograda radi procene vitalnosti i dekorativnosti korišćenjem metode vizuelne procene stabala (VTA) i merenjem brzine zvučnih talasa u drvetu. VTA, kao široko primenjena neinvazivna metoda, omogućava detekciju spoljašnjih simptoma koji ukazuju na unutrašnje degradacione procese u drvetu, dok zvučna analiza ovu procenu upotpunjuje kvantitativnim podacima o brzini prostiranja zvuka kroz drvno tkivo. Ocene vitalnosti su imale prosečnu vrednost od 2,80, dok je dekorativnost imala prosečnu vrednost od 2,93, pri čemu su obe pokazale umerenu varijabilnost (koeficijenti varijacije 26,71% i 25,10%).

Brzina zvučnih talasa pokazala je veću varijabilnost, s prosečnom vrednošću 788,39 m/s. Statistički značajne korelacije utvrđene su između brzine zvuka i vizuelnih ocena (r = 0,52 za vitalnost, r = 0,53 za dekorativnost), što ukazuje na povezanost između spoljašnje procene stabala i unutrašnjih strukturalnih osobina. Razvijeni su matematički modeli kojima se pouzdano mogu predvideti vitalnost i dekorativnost drveta na osnovu brzuine zvuka.

Rezultati rada potvrđuju da kombinovanje metoda vizuelne procene i zvučne analize poboljšava preciznost dijagnostike stanja stabala, omogućujući pravovremene intervencije, kao i očuvanje urbanog zelenila.