# SEEFOR

## SOUTH-EAST EUROPEAN FORESTRY

www.seefor.eu

HRVATSKI ŠUMARSKI INSTITUT
CROATIAN FOREST RESEARCH INSTITUTE

Vol 10 No 2
pp 97-191
December 2019

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

International scientific journal in field of forestry

# SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

An international scientific journal in scientific area of biotechnology science and scientific field of forestry

**Full title:**
South-east European forestry

**ISSN Abbreviated title:**
South-east Eur. for.

**Published by:**
Croatian Forest Research Institute (Croatia); University of Banja Luka, Faculty of Forestry (BIH); University of Sarajevo, Faculty of Forestry (BIH); Institute of Lowland Forestry and Environment (Serbia); University of Belgrade, Faculty of Forestry (Serbia); Institute of Forestry (Serbia); Ss. Cyril and Methodius University in Skopje, Faculty of Forestry (Macedonia); Hungarian Forest Research Institute (Hungary)





**Publisher / Editorial Office:**

Croatian Forest Research Institute, Cvjetno naselje 41, HR-10450 Jastrebarsko, Croatia
Tel: 00 385 (0)1 62 73 000; Fax: 00 385 (0)1 62 73 035;

E-mail: seefor@sumins.hr
URL: www.seefor.eu

**Indexing Databases:**
CAB Abstracts, CrossRef, DOAJ, Emerging Sources Citation Index (ESCI - Web of Science Core Collection), Scopus (Elsevier), Forestry Abstracts, Google Scholar

**Prepress:**
Bananaton d.o.o., Smokvica 73a, HR-20272 Smokvica
E-mail: bananagraf@banangraf.com; URL: www.bananagraf.com

**Press:**
Denona Ltd., Marina Getaldića 1, HR-10000 Zagreb
URL: www.denona.hr

**Circulation:**
500

SEEFOR SOUTH-EAST EUROPEAN FORESTRY
OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

# Contents

South-east European forestry - Vol 10 No 2, pp 97-191, December 2019

SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

ORIGINAL SCIENTIFIC PAPER

DOI: https://doi.org/10.15177/seefor.19-14

# Regeneration and Early Tending of Black Locust (*Robinia pseudoacacia* L.) Stands in the North-West of Romania

**Valeriu-Norocel Nicolescu[1], Cornelia Buzatu-Goanță[2]*, Debbie Bartlett[3], Nicolae Iacob[4]**

**(1)** Transilvania University of Brasov, Faculty of Silviculture and Forest Engineering, Șirul Beethoven 1, RO-500432 Brasov, Romania; **(2)** Banat's University of Agricultural Sciences and Veterinary Medicine "King Michael I of Romania", Faculty of Horticulture and Forestry, Calea Aradului 119, RO-300645 Timișoara, Romania; **(3)** University of Greenwich, Faculty of Engineering and Science, University of Greenwich, Kent ME4 4TB, United Kingdom; **(4)** National Forest Administration-ROMSILVA, Săcueni Forest District, Bihor County Branch, RO-417435 Săcueni, Romania

* **Correspondence:** e-mail: corneliahernea@yahoo.com

**Citation:** NICOLESCU V-N, BUZATU-GOANȚĂ C, BARTLETT D, IACOB N 2019 Regeneration and Early Tending of Black Locust (*Robinia pseudoacacia* L.) Stands in the North-West of Romania. *South-east Eur for* 10 (2): 97-105. DOI: https://doi.org/10.15177/seefor.19-14

**Received:** 19 Jun 2019; **Revised:** 8 Jul 2019; **Accepted:** 8 Jul 2019; **Published online:** 13 Aug 2019

## ABSTRACT

**Background and Purpose:** The aim of this study is to highlight the importance of black locust (*Robinia pseudoacacia* L.), a North American-originating tree species of major importance in Romania, in extreme site conditions such as sand dunes. In this respect, a Research and Development (R&D) project has been carried out in Carei-Valea lui Mihai Plain (north-west of Romania) since 2016.

**Materials and Methods:** Three sub-compartments were selected in IV Valea lui Mihai Working Circle, Săcueni Forest District: two pure natural regenerations by root suckers of black locust at different ages (sub-compartments 3B and 52A%) and a mixed black locust - black cherry stand (sub-compartment 23D). Biometrical measurements and analyses as well as biomass estimations were performed. A thorough statistical analysis using the data on initial, extracted and residual trees/stands was also performed.

**Results:** The main outputs of the project are as follows: (1) Black locust was established naturally by root suckers and the stocking of newly established stands can be as high as 50,000 suckers·ha$^{-1}$; (2) The initial growth of black locust regeneration is quick and the young regeneration can close the canopy in 1-2 years, resulting in an appropriate dune fixation and wind erosion control; (3) The young pure or mixed black locust-dominated stands are left untended until the first cleaning-respacing (mean diameter 5-6 cm), when the stand shows high stocking/density and a wide variation in tree size. This intervention is from below, heavy (intensity over 25% by number of trees or basal area) and of negative selection type, removing mostly low Kraft's class, dead or dying, and defective trees.

**Conclusions:** This R&D project has shown the high potential of black locust to establish naturally by root suckers after a low coppice cut and stump removal, as well as the fast initial growth of regenerated black locust. The quick canopy closure of young regeneration results in an appropriate dune fixation and wind erosion control.

**Keywords:** black locust, natural regeneration, release cutting, cleaning-respacing, initial growth

## INTRODUCTION

### Black Locust in the World, in Europe and in Romania

Black locust (*Robinia pseudoacacia* L.) originates from the eastern part of the United States, where it is found in two areas, in the eastern (Pennsylvania, Ohio, Alabama, Georgia and South Carolina) and western area (Missouri, Arkansas, and Oklahoma) [1].

Globally, black locust was introduced and became naturalized in all sub-Mediterranean and temperate regions: Asia (i.e. South Korea - over 1.2 million ha; China - over 1 million ha; India, Pakistan, Japan), Australia, New Zealand, Africa (North and South), South America (Argentina, Chile) [2-7]. Black locust is now rivaling poplar as the second most planted broadleaved tree species in the world, after the eucalypts [8-10]. This expansion worldwide is due to the fact that black locust is an economically important multipurpose tree, in wood production (e.g. firewood, pulpwood, flooring, railway sleepers, boat building, fences, construction, barrel staves, veneer, solid furniture), fodder production, honey production, as a source of bio-oil, for biomass production and carbon sequestration, soil stabilization, erosion control, re-vegetation of landfills, mining areas and wastelands, in biotherapy, and landscape architecture [11-22].

Black locust was the first North American forest tree species to be imported to Europe at the beginning of the 17th century (1601) [12, 18, 23, 24]. Currently, black locust is naturalized in thirty-two European countries (Pyšek *et al.* 2009, in [21]), covering a total area of 2,306,607 ha [25], and it is the most used non-native broadleaved tree species on the continent.

In Romania, black locust was introduced as a park tree around 1750, probably from Turkey, in the southern and eastern provinces (Wallachia and Moldova), as well as through Serbia and Austro-Hungary in Transylvania (centre) and Banat (south-west) provinces [26]. The first forest plantation including black locust was established in the south-west of Romania (Oltenia Plain) in 1852, in order to stabilize mobile sand dunes [26, 27]. After 1883, it was widely introduced throughout the country for the same purpose as sand dune systems extend to about 266,000 ha in Romania (about 1% of the national territory [28, 29]).

The area covered by black locust in 1922 was only 28,000 ha [30], expanding to ca. 100,000 ha by the mid-1950s [12] and further to approx. 250,000 ha at the present time (4% of national forest land, mostly in the south of the country, on sand dunes and areas with heavy soils in the forest steppe zone) [20, 31].

## Regeneration and Early Growth of Black Locust

In different parts of the world, black locust is regenerated by one of three methods:

a) **Planting** in spring using 1-year-old seedlings, normally bare-rooted, 0.5-1.0 (or even 2) m tall, produced in conventional nurseries [3, 32, 33]. The initial stocking rate of black locust plantations in Europe is very variable: 1,100-1,900 seedlings·ha$^{-1}$ in France (Bourgogne) [34], 1,200-1,700 seedlings·ha$^{-1}$ (4×2 m, or 3×2 m) in France (Aquitaine and Poitou-Charentes) [35], 2,000-2,500 seedlings·ha$^{-1}$ (2.5×2.0 m, or 2.5×1.6 m) in Poland [10] to 4,000-5,000 seedlings·ha$^{-1}$ (2.0×1.25 m, or 2.0×1.0 m in Romania; 2.4×0.7-0.8 m, or 2.4×1.0 m in Hungary) [33, 36-38].

b) **Naturally by seed**. This is rare, as the hard and impermeable seed coat limits germination in the forest/natural environment. However, there are some examples of natural regeneration in the literature [12, 15], this process being facilitated by seed wounding with heavy machinery, or natural thermal shock [24].

c) **Naturally by vegetative regeneration** from stool shoots and root suckers. As black locust coppices freely this is considered the most cost-effective management system for the species [21, 23]. The method is cheap, efficient and allows local people to collect stem wood, which is highly valued as firewood. Root suckers live longer and are healthier (i.e. show less rot at the same age) than stool shoots; however, the latter grow quicker up to 12-15 years of age than root suckers [12, 13]. The most common rejuvenation method is by root suckers since black locust develops horizontal, shallow and wide-spreading roots which can extend 15-20 m from the parent tree [3, 12, 15].

## Early Management of Black Locust Stands

The application of early management operations such as release cutting and cleaning-respacing in black locust stands varies according to the regeneration method as follows:

a) In **plantations** with up to 5,000 seedlings·ha$^{-1}$ there is no need for any release cutting [10, 18, 40]. In such stands cleaning-respacing begins after canopy closure, at 4-5 years. and the stocking should be reduced to about 2,500 trees·ha$^{-1}$ [10]. The second cleaning follows 2-3 years later, with a further reduction to ca. 1,700 trees·ha$^{-1}$ [10].

b) In **black locust coppice stands** regenerated from stool shoots and root suckers, release cutting is necessary to reduce the number of shoots per stool to 1 or 2 and to protect root suckers from stool shoot competition [13, 39]. Normally two release cuttings are performed, the first one in the first or second year, followed by another 1-3 years subsequently [40, 41]. In Romania, two cleaning-respacing operations are performed in years 3-4 and 6-7, reducing the canopy cover to 80-85%.

In both black locust plantations and coppice stands cleaning-respacing is considered to be "the basis for all good management in black locust stands" [42]. These authors aimed to heavily reduce the number of stems, allowing the potential final crop trees sufficient space to grow. If this intervention is too late or too light, the remaining trees do not develop their crowns normally (they are deformed or very small) as this is a strong light-demanding species and is intolerant of shade/competition [12, 14, 16]. The cleaning-respacing is based on negative selections (particularly in the first intervention) removing defective trees, for example, those that are forked (this species is sensitive to early frosts, leading to forking [13, 43]), badly formed, wounded, bent-over (the effect of strong phototropism), combined with positive selections where even well-formed and healthy individuals are removed to provide additional growing space to those selected to remain [43]. Halupa and Rédei [42] highlighted the importance of cleaning-respacing to produce regular spacing of the remaining trees.

In the context of these characteristics of black locust stands and silviculture in the early stages, a Research and Development (R&D) project was launched in 2016, in order to evaluate the regeneration and early tending of black locust stands in the north-west of Romania. The objectives of this project are (1) to assess the regeneration potential of black locust by root suckers, (2) to assess the early growth of root sucker stems, and (3) to follow and evaluate the early results of these interventions in terms of quality, growth and yield of young black locust stands.

## MATERIALS AND METHODS

### Study Sites

In order to achieve the objectives set out above, fieldwork was undertaken in black locust stands managed by the Săcueni Forest District, part of Bihor County Branch, National Forest Administration ROMSILVA. These stands are located in the north-west of Romania (Carei-Valea lui Mihai Plain; 46°58' N, 22°16' E), and comprise three sub-compartments which are part of the IV Valea lui Mihai Working Unit.

The study area had the following main characteristics. Landform is continental sand dunes, of river and wind origin, formed in the Holocene, with a SW-NE and NW-SE orientation and an elevation between 140 and 160 m [44]. According to Spîrchez *et al.* [44] and Târziu and Spârchez [45], the local soils are part of the Psamments suborder, Entisols order (sandy soils), with the following characteristics: (i) very deep but poor, with low fertility and low nutrient (N, P, and K) content; (ii) light soil texture (85-90% sand, mostly fine); (iii) moderately acid to neutral (5 to 7) pH; (iv) maximum fraction of humus is 1% in the upper 25 cm of soil; (v) presence of a hard and poorly drained ortstein (ironpan) horizon, Al, Fe, Mn, and humus compounds-rich from the overlying shallow O horizon [44]. This horizon restricts water infiltration during the driest summer periods, when the sand gets very warm at the surface, and provides, to a considerable depth, important water supply for the forest vegetation.

The local climate is classified as temperate-continental, compared to a humid climate in the native range of black locust [1]. Mean annual temperature: 10.3ºC; maximum monthly temperatures in July: 20.7ºC; minimum in January: -1.6ºC. Mean annual total precipitation: 573.3 mm. The maximum monthly precipitation is in June is 83 mm, and the minimum in March is 30 mm.

Potential mean annual total evapo-transpiration is around 600 mm, similar to the mean annual total precipitation. Maximum wind speed is 4.0 $m \cdot s^{-1}$ (South), so no wind damage to forest vegetation normally occurs (the black locust stands have deep vertical roots to depths of 2-3 m or more [44]). The only exception was the event on August 3, 1988, when the wind speed reached 18 m/s and the volume of damaged black locust reached 1,087 $m^3$ (3,599 trees) [46]. Mean length of frost-free period is 270 days, much longer than in the native range, where it is between 150 and 210 days [1]. The mean annual aridity (de Martonne) index is 28.2, so the area is considered to be located in the transition zone between the plain forest zone, moderately humid, and the forest steppe zone.

### Forest Vegetation

The first black locust plantations (200 ha, 2×2 m initial spacing) on sandy soils in the Carei-Valea lui Mihai Plain were established in 1892 [44, 47]. Until 1933 only small-scale plantations including Scots pine (*Pinus sylvestris* L.), black pine (*Pinus nigra* Arn.), pedunculate oak (*Quercus robur* L.), northern red oak (*Q. rubra* L.), pin oak (*Q. palustris* Muenchh.), and black cherry (*Prunus serotina* Ehrh.) were established on about 18 ha. Further plantations were established between 1933 and 1940 (792 ha), 1946-1959 (1,958 ha), and 1960-1980 (450 ha), with the majority being situated on low-fertility former agricultural land [44]. Currently forest vegetation covers about 12% of the total area of the Carei-Valea lui Mihai Plain, with black locust being the main tree species covering over 80% of the total forest area (ca. 3,000 ha).

In the Carei-Valea lui Mihai Plain, black locust has been used since 1892 on (i) low-fertility former agricultural land, or (ii) for replacing low-productive tree species such as *Quercus robur* L., *Tilia cordata* Mill., *Acer campestre* L., and *Ulmus minor* Mill., in order to prevent wind erosion and sand dune movement and to produce firewood. Subsequently, black locust stands were treated as simple coppice, usually on a rotation of 20-30 years, but up to 35 years, similar to the time scales found in the USA [14], India [3], France [34, 35] and Hungary [38, 48].

### Experimental Material

In this context, three sub-compartments (scpt.) - 3B, 23D and 52A% - were selected for the R&D project. The main characteristics of these stands are: (1) Scpt. 3B - pure natural regeneration by root suckers of black locust, 1-year old, following simple coppice cut (winter 2015-2016) and the removal of stumps; (2) Scpt. 52A% - pure natural regeneration by root suckers of black locust, 2-years old, following simple coppice cut (winter 2013-2014) and the removal of stumps; (3) Scpt. 23D - mixed black locust-black cherry stand, 12-years old, originating from root suckers after a simple coppice cut (2004) and the removal of stumps. No silvicultural interventions had been performed since the establishment.

### Experimental Design

In order to carry out the fieldwork, different experimental plots were designed: (1) Scpt. 3B - six plots of 25 $m^2$ (5×5 m) each, established in April 2017 (Figure 1); (2) Scpt. 52A% - two plots of 25 $m^2$ (5×5 m) each, established in June 2016; (3) Scpt. 23D - two plots of 150 $m^2$ (15×10 m), established in July 2016.

### Root Suckers/Tree Measurements

Root collar diameter and total height were measured for all initial and remaining root suckers, after the release cutting carried out in all plots from scpts. 3B and 52A%. Diameter at breast height (DBH) and total height for all initial and remaining trees after cleaning-respacing were measured in scpt. 23D. The location (x-y) of each remaining tree as well as four perpendicular crown radii for such trees was also measured.

### Biomass Estimation

The suckers cut during the release intervention (scpt. 3B) were bundled in each plot and transported to the laboratory. The dry matter content was determined by drying material at 105ºC, until constant weight was reached. To assess biomass production, an allometric relationship between W and stem diameter was used according to:
$W=bD^c$, where W - biomass, D – root collar diameter, b and c – constant parameters.

### Silvicultural, Biometrical and Statistical Analysis

Using the data collected in the field the following calculations were performed: stocking (no. of trees·ha$^{-1}$) before and after release cutting and cleaning-respacing, in order to determine the intensity of the interventions; density (m$^2$·ha$^{-1}$) before and after cleaning-respacing, with the same purpose; mean collar diameter in release cutting, DBH in cleaning-respacing of the initial, extracted and remaining trees and their standard deviations; mean height (in both release cutting and cleaning-respacing) of the initial, extracted and remaining trees and their standard deviations; dry biomass of extracted, remaining and initial suckers in scpt. 3B; coefficients of variation of diameters and heights (initial, extracted and remaining suckers or trees); significant differences between means were tested using ANOVA and Duncan post hoc test [49].

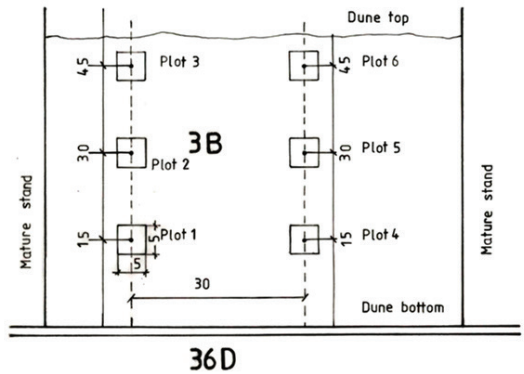


**FIGURE 1.** Location of plots 1-6 within the scpt. 3B.

## RESULTS AND DISCUSSION

### (A) Regeneration of Black Locust Stands

In the two sub-**compartments analyzed with respect to natural regeneration of black locust by root suc**kers, the most relevant results are as follows:

**(i) 1-year old natural regeneration (scpt. 3B)**

The potential for natural regeneration of black locust from root suckers was very high and the initial stocking after one growing season ranged between 15,200 and 67,600 suckers·ha$^{-1}$ (50,800 on average). The initial stocking was higher than the one found in the study conducted in France, which recorded over 40,000 suckers·ha$^{-1}$ by using this regeneration method (Pagès 1985, cited in [35] – Figure 2).

This very high stocking allowed for very heavy interventions (over 25% of the number of trees [40]) with release cutting (from 68.42% to 91.89%, over 80% in the majority of plots), reducing the stocking per ha to between 4,800 suckers and 9,200 suckers (7,200 suckers on average) (Table 1).

Significant differences ($F=4.735$, $p=0.0003$) were registered in terms of root collar diameter for root suckers located on the dune top, in the middle of the slope and the bottom of the dune at the beginning of the experiment. The same pattern was observed for the removed root suckers ($F=4.942$, $p=0.0002$).

The suckers removed by release cutting were the smallest (or thinnest) ones. Consequently, the arithmetic mean collar diameter of black locust suckers increased from 7.36±3.91 - 9.81±5.32 mm to 11.67±4.12 - 14.72±6.76 mm, the coefficients of variation of diameters being the lowest in the remaining root suckers. No significant differences were registered for the remaining root suckers ($F=1.010$, $p=0.416$) (Table 2).

The suckers extracted through this intervention were also the shortest, so the arithmetic mean height of black locust suckers increased from 87.79±40.18 - 100.18±63.29 cm to between 126.33±35.06 and 175.67±44.88 cm, the coefficients of variation of heights being also the smallest in the remaining root suckers. In terms of root sucker height,

**TABLE 1.** Stocking in the six plots located in the 1-year old regeneration and the intensity of release cutting.

| Plot no. | Number of root suckers per plot/ha | | | | | | Intensity of intervention % |
|---|---|---|---|---|---|---|---|
| | Initial | | Extracted | | Remaining | | |
| | plot | ha | Plot | ha | plot | ha | |
| 1 | 156 | 62,400 | 135 | 54,000 | 21 | 8,400 | 86.54 |
| 2 | 148 | 59,200 | 136 | 54,400 | 12 | 4,800 | 91.89 |
| 3 | 119 | 47,600 | 101 | 40,400 | 18 | 7,200 | 84.87 |
| 4 | 38 | 15,200 | 26 | 10,400 | 12 | 4,800 | 68.42 |
| 5 | 169 | 67,600 | 146 | 58,400 | 23 | 9,200 | 86.39 |
| 6 | 130 | 52,000 | 109 | 43,600 | 21 | 8,400 | 83.85 |
| Average no. | 127 | 50,800 | 109 | 43,600 | 18 | 7,200 | 85.83 |
| Range | | 15,200-67,600 | | 10,400-58,400 | | 4,800-9,200 | |

**TABLE 2.** Arithmetic mean collar diameters (mean), arithmetic mean height (mean), standard deviations (SD) and coefficients of variation (CV) of black locust root suckers (initial, extracted, and remaining) in the 1-year old regeneration.

| Plot no. | Initial root suckers | | | | Extracted root suckers | | | | Remaining root suckers | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | ± | SD | CV | Mean | ± | SD | CV | Mean | ± | SD | CV |
| | | | | | **Collar diameter** (mm) | | | | | | | |
| 1 | 7.36[b] | ± | 3.91 | 53.15 | 6.58[b] | ± | 3.35 | 50.92 | 12.38 | ± | 3.57 | 28.84 |
| 2 | 7.87[b] | ± | 4.84 | 61.44 | 7.30[b] | ± | 4.38 | 60.04 | 14.33 | ± | 5.21 | 36.35 |
| 3 | 9.81[a] | ± | 5.32 | 54.22 | 8.93[a] | ± | 4.53 | 50.66 | 14.72 | ± | 6,76 | 45.94 |
| 4 | 7.71[b] | ± | 4.01 | 52.02 | 5.89[b] | ± | 2.32 | 39.40 | 11.67 | ± | 4.12 | 35.31 |
| 5 | 7.71[b] | ± | 4.45 | 57.65 | 7.04[b] | ± | 3.98 | 56.57 | 11.96 | ± | 4.95 | 41.40 |
| 6 | 8.90[ab] | ± | 5.85 | 65.76 | 8.07[ab] | ± | 5.61 | 69.56 | 13.24 | ± | 5.24 | 39.61 |
| All plots | 8.20 | ± | 4.87 | 59.43 | 7.42 | ± | 4.37 | 58.88 | 12.99 | ± | 5.08 | 39.12 |
| | | | | | **Height** (cm) | | | | | | | |
| **1** | 89.08 | ± | 47.64 | 53.48 | 78.62 | ± | 40.67 | 51.73 | 156.33 | ± | 31.94 | 20.43 |
| **2** | 91.61 | ± | 51.15 | 55.83 | 84.20 | ± | 44.74 | 53.13 | 175.67 | ± | 44.88 | 25.55 |
| **3** | 95.58 | ± | 52.88 | 55.32 | 84.91 | ± | 45.51 | 53.60 | 155.44 | ± | 52.46 | 33.75 |
| **4** | 87.79 | ± | 40.18 | 45.77 | 70.00 | ± | 28.40 | 40.57 | 126.33 | ± | 35.06 | 27.75 |
| **5** | 96.81 | ± | 53.91 | 55.68 | 86.66 | ± | 46.81 | 54.01 | 161.22 | ± | 52.25 | 32.41 |
| **6** | 100.18 | ± | 63.29 | 63.18 | 89.19 | ± | 59.32 | 66.51 | 157.19 | ± | 52.55 | 33.43 |
| **All plots** | 100.18 | ± | 53.14 | 56.45 | 83.98 | ± | 46.83 | 55.77 | 156.21 | ± | 46.99 | 30.08 |

**a)**

**b)**

**FIGURE 2.** Aspect of young regeneration by root suckers in: **(a)** 20 April 20 2017, and **(b)** 18 May 2019.
(Photos V.N. Nicolescu).

the analysis of variance showed no significant differences: F=0.896, p=0.483 for initial root suckers, F=1.193, p=0.311 for removed root suckers and F=1.469, p=0.207 for the remaining ones.

The aboveground dry biomass of initial, extracted, and remaining black locust root suckers in the six plots was calculated using the allometric formula $W=0.652D^{2.582}$, $R^2=0.9426$.

The initial aboveground dry biomass in all plots, except plot no. 4, exceeded 1.1 t·ha$^{-1}$ (1.384 t·ha$^{-1}$ on average), the maximum being measured in plots 3 (1.875 t·ha$^{-1}$) and 6 (1.939 t·ha$^{-1}$) (Table 3), which were both located close to the dune top.

As the release cutting intervention had very heavy intensity, the remaining aboveground biomass was less than 0.5 t·ha$^{-1}$, with the exception of plots 3 (0.699 t·ha$^{-1}$) and 6 (0.565 t·ha$^{-1}$), with a mean of 0.462 t·ha$^{-1}$.

**(ii) 2-years old natural regeneration (scpt. 52A%)**

This stand was regenerated identically to scpt. 3B and is located in very similar ecological conditions. In the two plots very strong competition between the suckers started immediately after the canopy closure of the newly established regeneration, i.e. at the end of the first growing season, producing an abrupt reduction in stocking of this 2-years old stand (12,000 suckers·ha$^{-1}$ in plot 1 and 22,000 suckers·ha$^{-1}$ in plot 2) (Table 4).

The mean collar diameters (6.9 mm and 6.7 mm respectively) and mean height (162 cm and 155 cm respectively) are similar in the two plots. The ranges in both of these parameters are similar and no significant

**TABLE 3.** Dry biomass of root suckers in the 1-year old regeneration.

| Plot no. | Dry biomass (t·ha⁻¹) | | |
|---|---|---|---|
| | Extracted | Remaining | Initial |
| 1 | 0.721 | 0.422 | 1.143 |
| 2 | 1.129 | 0.379 | 1.508 |
| 3 | 1.176 | 0.699 | 1.875 |
| 4 | 0.087 | 0.219 | 0.306 |
| 5 | 1.044 | 0.488 | 1.532 |
| 6 | 1.374 | 0.565 | 1.939 |
| Mean | 0.922 | 0.462 | 1.384 |
| Range | 0.087-1.374 | 0.219-0.699 | 0.306-1.939 |

**TABLE 4.** Main characteristics of plots 1 and 2 in the 2-years old regeneration.

| | | Plot 1 | Plot 2 | Overall |
|---|---|---|---|---|
| Number of individuals ha$^{-1}$ | | 12,000 | 22,000 | 17,000 |
| Basal area (m$^2$·ha$^{-1}$) | | 0.53 | 0.93 | 0.73 |
| Collar diameter (mm) | Arithmetic mean | 6.9 | 6.7 | 6.8 |
| | Maximum | 14.4 | 15.1 | 15.1 |
| | Minimum | 3.0 | 2.8 | 2.8 |
| Height (cm) | Arithmetic mean | 162 | 155 | 158 |
| | Maximum | 257 | 264 | 264 |
| | Minimum | 60 | 50 | 50 |

statistical differences occurred (F=0.132, p=0.717 for collar diameter and F=0.372, p=0.543 for height) between the collar diameter and the height of suckers in these two plots (Table 4).

## (B) Cleaning-respacing of young mixed black locust-dominated stands

This intervention was carried out in scpt. 23D, which showed the following main characteristics:

The stand initial stocking was very high (5,467 trees·ha$^{-1}$) in plot 1, and lower (3,533 trees·ha$^{-1}$) in plot 2. These trees had a similar basal area (14.30 m$^2$·ha$^{-1}$ in plot 1 and 13.87 m$^2$·ha$^{-1}$ in plot 2). This made a very heavy intervention possible, with the removal of over 25% trees, reducing the stocking to 2,333 trees·ha$^{-1}$ and the basal area to 9.33 m$^2$·ha$^{-1}$ (plot 1) and 1,733 trees·ha$^{-1}$ and 9.10 m$^2$·ha$^{-1}$ (plot 2) (Figure 3 and Table 5).

The remaining stocking in the two plots is similar to the one recommended in Hungary (1,800 trees·ha$^{-1}$ [48]) and Germany (2,350 trees·ha$^{-1}$ [50]) and marginally lower than the one in Bulgaria (ca. 2,500 trees·ha$^{-1}$ [51]).

As the intensity by the number of trees (57.3% in plot 1, and 50.9% in plot 2) was much higher than by the basal area (34.1% in plot 1 and 34.4 in plot 2), the intervention was from below in both plots, removing mostly trees from the lower diameter classes.

As the intervention removed mostly the smallest (thinnest and shortest) trees, the arithmetic mean diameter and arithmetic mean height increased in both black locust and black cherry, particularly in the former species (Table 6).

Even though black locust and black cherry have similar heights (F=3.781, p=0.054), significant differences were found in the case of diameter (F=67.051, p=0.000).

The intervention produced gaps in the canopy cover, which shows a value after cleaning-respacing of ca. 80% in plot 1, and 75% in plot 2, so that some trees have additional space at the canopy level to develop their crowns and consequently increase DBH.

**FIGURE 3.** Aspect of plot 1 after the intervention. (Photo V.N. Nicolescu)

**TABLE 5.** Main characteristics of stand and of cleaning-respacing carried out in the 12 years-old natural regeneration.

| | | Black locust BL | Black cherry BC | Overall | Species composition (%) |
|---|---|---|---|---|---|
| **Number of trees·ha$^{-1}$** | | | | | |
| Plot 1 | Initial | 4,867 | 600 | 5,467 | 89BL11BC |
| | Extracted | 2,933 | 200 | 3,133 | 94BL6BC |
| | Remaining | 1,933 | 400 | 2,333 | 83BL17BC |
| | Intensity of intervention (%) | 60.3 | 33.3 | 57.3 | |
| Plot 2 | Initial | 2,400 | 1,133 | 3,533 | 68BL32BC |
| | Extracted | 1,267 | 533 | 1,800 | 70BL30BC |
| | Remaining | 1,133 | 600 | 1,733 | 65BL35BC |
| | Intensity of intervention (%) | 52.8 | 47.1 | 50.9 | |
| **Basal area** (m$^2$ · ha$^{-1}$) | | | | | |
| Plot 1 | Initial | 10.87 | 3.43 | 14.30 | 76BL24BC |
| | Extracted | 4.25 | 0.72 | 4.87 | 87BL13BC |
| | Remaining | 6.62 | 2.71 | 9.33 | 71BL29BC |
| | Intensity of intervention (%) | 39.1 | 21.0 | 34.1 | |
| Plot 2 | Initial | 5.61 | 8.26 | 13.87 | 40BL60BC |
| | Extracted | 1.82 | 2.95 | 4.77 | 38BL62BC |
| | Remaining | 3.79 | 5.31 | 9.10 | 42BL58BC |
| | Intensity of intervention (%) | 32.4 | 35.8 | 34.4 | |

**TABLE 6.** Biometrical characteristics of 12-years old naturally regenerated black locust and black cherry before and after intervention.

| | | Black locust | | | Black cherry | | |
|---|---|---|---|---|---|---|---|
| **Arithmetic mean diameter ± standard deviation** (cm) | | | | | | | |
| Initial | Plot 1 | 5.3 | ± | 1.82 | 8.0 | ± | 3.50 |
| | Plot 2 | 5.4 | ± | 1.67 | 9.5 | ± | 2.88 |
| Extracted | Plot 1 | 4.0 | ± | 1.44 | 6.7 | ± | 1.15 |
| | Plot 2 | 4.4 | ± | 1.00 | 8.1 | ± | 2.21 |
| Remaining | Plot 1 | 6.5 | ± | 1.44 | 8.5 | ± | 4.17 |
| | Plot 2 | 6.5 | ± | 1.52 | 10.7 | ± | 2.95 |
| **Arithmetic mean height ± standard deviation** (m) | | | | | | | |
| Initial | Plot 1 | 8.6 | ± | 2.51 | 8.6 | ± | 3.00 |
| | Plot 2 | 9.5 | ± | 2.88 | 10.3 | ± | 1.77 |
| Extracted | Plot 1 | 7.0 | ± | 1.99 | 8.1 | ± | 1.79 |
| | Plot 2 | 7.9 | ± | 1.62 | 9.5 | ± | 1.73 |
| Remaining | Plot 1 | 10.6 | ± | 1.38 | 8.9 | ± | 3.60 |
| | Plot 2 | 10.0 | ± | 1.33 | 11.0 | ± | 1.58 |

## CONCLUSIONS

The R&D project, which began in 2016, focusing on pure and mixed black locust-dominated stands, has led to the following conclusions on regeneration and the early management of such stands:

- The potential of black locust to establish naturally by root suckers after a low coppice cut and stump removal is very high and the stocking of such newly established stands can exceed 50,000 suckers·ha$^{-1}$.
- Despite the unfavourable conditions in the case study area, the initial growth of regenerated black locust is fast and the newly established stand can close the canopy in 1-2 years, resulting in effective dune stabilization and wind erosion control.
- There are significant biometric differences, for example in collar diameter and height, between the young shoots, leading to a high level of natural mortality after canopy closure.
- Economic factors, such as lack of markets and/or workforce, result in young pure or mixed black locust-dominated stands usually being untended in the early stages. The first commercial intervention (cleaning-respacing) occurs when the stand has reached the thicket stage (minimum mean diameter 5-6 cm) and exhibits high stocking and density as well as wide dimensional (diameter and height) variation. Consequently, the first cleaning-respacing intervention is from below, of high intensity and negative selection type, removing mostly low Kraft's class (intermediate/suppressed), dead or dying, and defective (for example forked, wounded, or bent-over) trees.

However, these are only preliminary results and during the next intervention different measurements (e.g. collar diameters and heights - stands for release cutting; diameters, heights and crown radii - stands for cleaning-respacing) will be taken. These will provide an assessment of natural dieback in young, naturally regenerated black locust stands, and the effects of the two silvicultural interventions on the early growth of this species in pure or mixed stands.

## REFERENCES


1. HUNTLEY JC 1990 *Robinia pseudoacacia* L. Black locust. *In*: Burns RM, Honkala BH (*techn. coord*.) Silvics of North America, Volume 2 Hardwoods. Agriculture Handbook 654, Forest Service, United States Department of Agriculture, Washington, DC, USA, pp 755-761
2. 2. KERESZTESI B 1988 Natural range of black locust and its distribution in other countries. *In*: Keresztesi B (*ed*) The black locust. Akadémiai Kiadó, Budapest, Hungary, pp 9-17
3. 3. LUNA RK 1996 *Robinia pseudoacacia* Linn. *In*: Plantation trees. International Book Distributions, Dehra Dun, India, pp 633-639
4. 4. DEMENE JM, MERZEAU D 2007 Black locust. History and biological characteristics (*in French*). *Forêt-entreprise* 177: 10-12
5. 5. ŞOFLETEA N, CURTU L 2007 Dendrology (*in Romanian*). Editura Universității „Transilvania", Brașov, Romania, 418 p
6. 6. TU B, GAVALAND A, DU K, LU X 2007 Black locust in China (*in French*). *Forêt-entreprise* 177: 50-53
7. 7. CIERJACKS A, KOWARIK I, JOSHI J, HEMPEL S, RISTOW M, VON DER LIPPE M, WEBER E 2013 Biological Flora of the British Isles: *Robinia pseudoacacia*. *J Ecol* 101 (6): 1623-1640. DOI: https://doi.org/10.1111/1365-2745.12162
8. 8. SAVILL P 2013 The silviculture of trees used in British forestry. 2nd edition. CAB International, Wallingford, UK, and Boston, USA, 280 p
9. 9. RÉDEI K 2013 The black locust (*Robinia pseudoacacia* L.) and its features. *In*: Rédei, K (*ed*) Black locust (*Robinia pseudoacacia* L.) growing in Hungary. Hungarian Forest Research Institute, Sárvár, Hungary, pp 7-11
10. 10. WOJDA T, KLISZ M, JASTRZĘBOWSKI S, MIONSKOWSKI M, SZYP-BOROWKA I, SZCZYGIEŁ K 2015 The geographical distribution of the black locust (*Robinia pseudoacacia* L.) in Poland and its role in non-forest land. *Papers on Global Change-IGBP* 22: 101-113. DOI: https://doi.org/10.1515/igbp-2015-0018
11. POSKIN A 1926 Handbook of Silviculture (*in French*). Jules Duculot, Gembloux, Librairie Agricole de la Maison Rustique, Paris, France, 439 p
12. NEGULESCU E, SĂVULESCU AL 1957 Dendrology (*in Romanian*). Editura Agro-Silvică de Stat, Bucharest, Romania, 457 p
13. HARALAMB AT 1967 Culture of tree species (*in Romanian*). Editura Agro-silvică, Bucharest, Romania, 755 p
14. MCALISTER RH 1971 Black locust (*Robinia pseudoacacia* L.). U.S. Department of Agriculture. Forest Service, American Woods-FS-24, Washington, D.C., USA, 6 p
15. STĂNESCU V 1979 Dendrology (*in Romanian*). Editura Didactică și Pedagogică, Bucharest, Romania, 470 p
16. HARLOW WM, HARRAR ES, WHITE FM 1986 Textbook of dendrology. 6th edition. McGraw-Hill Book Company, New York-Sydney-Tokyo-Toronto, 510 p
17. GILMAN EF, WATSON DG 1994 *Robinia pseudoacacia* Black locust. Fact Sheet ST-570. Environmental Horticulture Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida, USA, 4 p
18. CRPF 2007 The black locust (*in French*). Centre Régional de la Propriété Forestière de Poitou-Charentes, Smarves, France, 4 p
19. DINI-PAPANASTASI O, KOSTOPOULOU P, RADOGLOU K 2012 Effects of seed origin, growing medium and mini-plug density on early growth and quality of black locust (*Robinia pseudoacacia* L.) seedlings. *J For Sci* 58 (1): 8-20
20. ENESCU CM, DĂNESCU A 2013 Black locust (*Robinia pseudoacacia* L.) – an invasive neophyte in the conventional land reclamation flora in Romania. *Bulletin of the Transilvania University of Brașov, Series II: Forestry • Wood Industry • Agricultural Food Engineering* 6 (55): 23-30
21. SITZIA T, CIERJACKS A, DE RIGO D, CAUDULLO G 2016 *Robinia pseudoacacia* in Europe: distribution, habitat, usage and threats. *In*: San-Miguel-Ayanz J, de Rigo D, Caudullo G, Houston Durrant T, Mauri A (*eds*) A European Atlas of Forest Tree Species. Publications Office of the European Union, Luxembourg, pp 166-167

22. PEDROL N, PUIG CG, LÓPEZ-NOGEUEIRA A, PARDO-MURAS M, GONZÁLES L, SOUZA-ALONSO P 2017 Optimal and synchronized germination of *Robinia pseudoacacia*, *Acacia dealbata* and other woody Fabaceae using a handheld rotary tool: concomitant reduction of physical and physiological seed dormancy. *J For Res* 29 (2): 283-290. DOI: https://doi.org/10.1007/s1167
23. BÎRLĂNESCU E, BELU C 1968 Culture of black locust, focusing on black locust culture in Oltenia. *In*: Bakoș V (*ed*) Culture of fast growing tree species (*in Romanian*). Editura agrosilvică, Bucharest, Romania, pp 332-346
24. STĂNESCU V, ȘOFLETEA N, POPESCU O 1997 Wooden forest flora of Romania (*in Romanian*). Editura Ceres, Bucharest, Romania 451 p
25. BRUS R 2016 Current occurrence of non-native tree species in European forest. Presentation to the Joint WG Meeting of COST Action Non-native tree species for European forests – experiences, risks and opportunities (NNEXT), Lisbon, Portugal, 4th of October 2016
26. DRĂCEA MD 1919 When and on what pathway the black locust came to us? (*in Romanian*). *Economia forestieră* 3-4: 71-75
27. CRĂCIUNESCU G 1904 Afforestation of flying sands from the Piscu-Tunari and Ciuperceni State estates, Doljiu County (*in Romanian*). *Revista pădurilor* XVIII(II): 202-210
28. CIORTUZ I, PĂCURAR VD 2004 Land improvement (*in Romanian*). Editura Lux Libris, Brașov, Romania, 232 p
29. TÂRZIU DR 2008 General and forestry soils (*in Romanian*). Editura Universității „Transilvania", Brașov, Romania, 272 p
30. DRĂCEA M 1928 Contribution to the knowledge of black locust in Romania, with special emphasis on its culture on sandy soils of Oltenia (*in German*). Tipografia „Lucia", Bucharest, Romania 112 p
31. NICOLESCU VN, HERNEA C, BAKTI B, KESERÜ Z, ANTAL B, RÉDEI K 2018 Black locust (*Robinia pseudoacacia* L.) as a multi-purpose tree species in Hungary and Romania: a review. *J For Res* 29 (6) 1449-1463. DOI: https://doi.org/10.1007/s11676-018-0626-5
32. OLSON DF 1974 *Robinia* L. Locust. *In*: Schopmeyer, CS (*techn. coord*.) Seeds of woody plants in the United States. Agriculture Handbook No. 450, Forest Service, U.S. Department of Agriculture, Washington, D.C., USA, pp 728-731
33. RÉDEI K 2013 Stand establishment. *In*: Rédei, K (*ed*) Black locust (*Robinia pseudoacacia* L.) growing in Hungary. Hungarian Forest Research Institute, Sárvár, Hungary, pp 27-34
34. BORDE B 2011 Black locust in Bourgogne (*in French*). Centre Régional de la Propriété Forestière de Bourgogne, Chalons sur Saône, France, 19 p
35. CARBONNIÈRE T., DEBENNE JN, MERZEAU D, RAULT M 2007 Black locust in Aquitaine (*in French*). *Forêt-entreprise* 177: 13-17
36. MAPPM 2000a Technical norms on species compositions, planting schemes and forest regeneration technologies and afforestation of degraded lands 1 (*in Romanian*). Ministerul Apelor, Pădurilor și Protecției Mediului, Bucharest, Romania, 272 p
37. RÉDEI K, OSVATH-BUJTAS Z, VEPERDI I 2008 Black Locust (*Robinia pseudoacacia* L.) Improvement in Hungary: a Review. *Acta Silvatica and Lignaria Hungarica* 4: 127-132
38. RÉDEI K, CSIHA I, KESERŰ Z, KAMANDINÉ VÉGH A, GYÖRI J 2011 The Silviculture of Black Locust (*Robinia pseudoacacia* L.) in Hungary: a Review. *South-east Eur for* 2 (2): 101-107. DOI: https://doi.org/10.15177/seefor.11-11
39. DEBENNE JN 1988 Black locust, a short rotation species indispensable in the rural areas (*in French*). *Forêts de France* 314: 29-31
40. MAPPM 2000 Technical norms on tending operations 2 (*in Romanian*). Ministerul Apelor, Pădurilor și Protecției Mediului, Bucharest, Romania 163 p
41. COSTEA A, LĂZĂRESCU C, BÎRLĂNESCU E, IVANSCHI T, ARMĂȘESCU S, TRANTESCU GR, LATIȘ L, PÎRVU E 1969 Recommendations on black locust *Robinia pseudacacia* L. culture (*in Romanian*). ICSPS, Bucharest, Romania, 38 p
42. HALUPA L, RÉDEI K 1988 Forest tending. *In:* Keresztesi, B (*ed*) The black locust. Akadémiai Kiadó, Budapest, Hungary, pp 115-125
43. 43. CONSTANTINESCU N 1976 Tending of forest stands (*in Romanian*). Vol. II. Editura Ceres, Bucharest, Romania, 402 p
44. SPÂRCHEZ Z, I. RĂSMERIȚĂ I, RIȚIU A 1962 Afforestation of sandy lands from the north-west of the country (*in Romanian*). Ministerul Agriculturii, Editura Agro-Silvică, Bucharest, Romania, 117 p
45. TÂRZIU DR, SPÂRCHEZ GH 2013 Forest soils and sites (*in Romanian*). Editura Universității Transilvania, Brașov, Romania, 257 p
46. RIȚIU A, NICOLESCU L, NICOLESCU N 1988 Some considerations on windfalls and windbreaks in black locust forests in the north-west of the country (*in Romanian with English summary*). *Revista pădurilor* 3: 131-133
47. ICAS 2008 Forest management plan of IV Working Circle Valea lui Mihai (*in Romanian*). Institutul de Cercetări și Amenajări Silvice, Stațiunea Oradea, Romania, 302 p
48. RÉDEI K 2013 Tending and yield of black locust stands. *In*: Rédei, K (*ed*) Black locust (*Robinia pseudoacacia* L.) growing in Hungary. Hungarian Forest Research Institute, Sárvár, Hungary, pp 35-46
49. STATSOFT, INC. 2004 STATISTICA (data analysis software system), version 7. www.statsoft.com
50. LOCKOW KW, LOCKOW J 2015 Yield table for black locust (*Robinia pseudoacacia* L.) *(in German)*. Ed. Gesellschaft zur Förderung schnellwachsender Baumarten, Eutin, Germany, 80 p
51. PORYAZOV Y, TONCHEV T, DOBRICHOV I 2004 Handbook of forest measurements (*in Bulgarian*). Bulvark, Sofia, Bulgaria, 419 p

SEEFOR SOUTH-EAST EUROPEAN FORESTRY
OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

ORIGINAL SCIENTIFIC PAPER

DOI: https://doi.org/10.15177/seefor.19-16

# New Silvicultural Treatments for Conifer Peri-Urban Forests Having Broadleaves in the Understory - The First Application in the Peri-Urban of Xanthi in Northeastern Greece

**Elias Milios[1]*, Kyriaki Kitikidou[1], Kalliopi Radoglou[1]**

**(1)** Democritus University of Thrace, Department of Forestry and Management of the Environment and Natural Resources, Pantazidou 193, GR-68200 Orestiada, Greece

* **Correspondence:** e-mail: emilios@fmenr.duth.gr

**Citation:** MILIOS E, KITIKIDOU K, RADOGLOU K 2019 New Silvicultural Treatments for Conifer Peri-Urban Forests Having Broadleaves in the Understory - The First Application in the Peri-Urban of Xanthi in Northeastern Greece. *South-east Eur for* 10 (2): 107-116. DOI: https://doi.org/10.15177/seefor.19-16

**Received:** 15 Jun 2019; **Revised:** 28 Aug 2019; **Accepted:** 11 Sep 2019; **Published online:** 31 Oct 2019

## ABSTRACT

**Background and Purpose:** In Greece, forest practice did not develop special silvicultural treatments for planted conifer peri-urban forests where broadleaf trees appear as natural regeneration in the understory. The aims of this study are: a) to analyze the new proposed selective silvicultural treatments for the planted peri-urban forest of Xanthi and for analogous planted conifer forests, where broadleaf trees are naturally established in the understory b) to check the research hypothesis that the new selective silvicultural treatments exhibited higher intensity in terms of the basal area of cut trees, compared to that of traditional treatments in the studied peri-urban forest.

**Materials and Methods:** In the traditional treatments, in the pine overstory cuttings, apart from the dead trees, mainly the malformed, damaged, suppressed and intermediate trees were cut. In the lower stories, the goal of the thinning was the more or less uniform distribution of broadleaf trees. In the proposed selective treatments, the main aim of pine cuttings is to release the broadleaf formations growing in the lower stories, while the treatments of the broadleaf trees will be a form of "positive selection" thinning. Plots were established in areas where the two types of treatments were going to be applied. In each plot, tree measurements and a classification of living trees into crown classes took place. After the application of the treatments the characteristics of cut trees were recorded.

**Results:** In the established plots, before the cuttings (and thinning), total basal area was not statistically significantly different between the two types of treatments. In selective treatments, the basal area of all cut trees was statistically significantly higher than that of the results of traditional treatments. In the broadleaf cut trees there were statistical differences in the ratios of dominant, intermediate and suppressed trees between the two silvicultural approaches.

**Conclusions:** The research hypothesis was verified. The intensity of treatments in terms of the basal area of cut trees was higher in the selective approach, compared to the traditional treatments in the Xanthi peri-urban forest. However, the overstory cutting intensity of the selective treatments depends on the spatial distributions and densities of broadleaved and conifer trees. In the broadleaf trees, the different objectives of the two types of treatments resulted in thinning with different qualitative characteristics. The proposed silvicultural treatments will accelerate the conversion of peri-urban conifer forests having an understory of broadleaf trees into broadleaved forests, or into mixed forests of conifers and broadleaf trees.

**Keywords:** peri-urban forests, silvicultural treatments, conversion, positive selection

## INTRODUCTION

In the peri-urban forests of Greece, conifers were artificially established in very dense spacings (1×1 m) for the protection of forest soils in areas around cities and towns, as well as for the protection of the health and property of urban settlement residents [1].

In the north of Greece, within many peri-urban forests broadleaf trees were gradually established as natural regeneration under the canopy of conifers. This process resulted in formations where conifers (mainly pines) form the overstory, while broadleaf trees appear in the understory (and in some cases in the middlestory). As the planted conifer trees became older, exhibiting larger dimensions, and the density of broadleaf trees increased as a result of a continuous establishment, the competition among trees increased. Moreover, the available organic fuels became gradually higher, leading to a higher risk of wildfire. A wildfire in a peri-urban forest can have catastrophic results in many aspects. Apart from the destruction of the peri-urban forest, urban infrastructures may be destroyed. The most significant issue is that such fires may have huge costs in human lives (like in Attica in 2018). At the present, the component of broadleaf trees exhibits various densities, ages, dimensions and species compositions.

Another concern that the Forest practice has to incorporate in its design is their usage for recreation, regarding the manipulation-treatment of stand structure of peri-urban forests.

Areas with broadleaf trees are less vulnerable to forest fires, and broadleaf trees can react through sprouting against disturbances, such as wildfires or anything that can kill the aboveground part of trees [2-5]. As a result, the fast conversion of pine reforestations into broadleaved forest or to mixed conifer-broadleaf forest will contribute greatly to the reduction of forest fire risk, and also to the improvement of ecosystem resilience. A forest fire event can release a great amount of $CO_2$ in the atmosphere, depending on the volume of the burned organic matter. That conversion will contribute to the reduction of the $CO_2$ release risk and thus, it will act against the climate change process. Moreover, the ability of broadleaf trees to resprout after a forest fire will reduce – eliminate the costs of the vegetation re-establishment after the fire. Sprouts and sprouting ability can be used for the preservation of forest ecosystems during climate change period [6-8].

In Greece, forest practice did not develop special silvicultural treatments for planted conifer peri-urban forests in general, and in particular in peri-urban forests, where broadleaf trees appear as natural regeneration in the understory. The up to now applied silvicultural treatments are usually characterized by light intensity, while there are cases with medium to high intensity treatments. The cutting of dead trees and pruning are the common characteristics of treatments in peri-urban forests.

In the context of The FoResMit Project (LIFE14 CCM/IT/905 "Recovery of degraded coniferous Forests for environmental sustainability Restoration and climate change Mitigation"), new selective silvicultural treatments were developed in Monte Morello peri-urban forest in Italy and in the peri-urban forest of Xanthi in Greece and were applied together with the traditional silvicultural approaches [9, 10]. In Xanthi, the proposed silvicultural treatments target in the fast conversion of the peri-urban forest in a broadleaf forest or in a mixed conifer-broadleaf forest, and thus are expected to exhibit high intensity.

The aims of this study are: a) to analyze the new proposed selective silvicultural treatments for the planted peri-urban forest of Xanthi, and for analogous planted conifer forests, where broadleaf trees are naturally established in the understory and b) to check the research hypothesis that the new selective silvicultural treatments exhibited higher intensity in terms of the basal area of cut trees compared to that of traditional treatments in the peri-urban forest of Xanthi. Moreover, the characteristics of the first application of selective treatments in comparison to those of the traditional treatments, are given and discussed.

## MATERIALS AND METHODS

### Study Area

The peri-urban forest of Xanthi (41°09′27.3′′N, 24°54′09.8′′E) is located on the slopes around the town of Xanthi in northeastern Greece. It covers an area of about 2400 ha, in an elevation range of 100 to 630 m. In the peri–urban forest there are reforestations - plantations that began in 1936 and lasted up to 2007. However, most of them were established before 1973 [9, 10]. The reforestations cover a great part of the peri-urban forest. They were established mainly in degraded areas which were under grazing pressure. In those areas bare land alternated by areas of very sparse vegetation consisted of *Carpinus orientalis* L., *Quercus coccifera* L., *Fraxinus ornus* L., *Quercus frainetto* Ten., *Quercus pubescens* Willd., *Quercus petraea* Liebl. subsp. *polycarpa* (Schur) Soo etc. plants. In some cases, reforestations were established in agricultural lands with very small areas. The main species used in the reforestations was *Pinus brutia* Ten. [11], while some other species were also used. The main of them were *Pinus maritima* Mill., *Robinia pseudoacacia* L., *Cupressus sempervirens* L., and *Pinus nigra* J.F. Arnold. In the lower stories (mainly understory) there are naturally established broadleaved species like *Carpinus orientalis*, *Quercus coccifera*, *Fraxinus ornus, Quercus frainetto, Quercus pubescens, Quercus petraea* etc. In very few cases the tallest broadleaved trees had analogous height of their adjacent pine trees that were usually intermediate or codominant trees. In some areas, individuals of *Robinia pseudoacacia* L. have been naturally established under the pine overstory.

The deadwood in the reforestations of the peri-urban forest of Xanthi is 9.21 $m^3 \cdot ha^{-1}$ [12].

The mean annual precipitation in the area of Xanthi is 675 mm while the mean annual temperature is 15.5°C [13]. In the areas where the treatments that are analyzed in this study were applied, the soil texture is sandy clay to sandy clay loam [10]. The treatments were applied in a part of reforestations that was established (mainly) in the decade of 1950 (Figure 1).

**FIGURE 1.** Reforestations of Xanthi peri-urban forest where broadleaf trees were established as natural regeneration.

## Silvicultural Treatments in the Peri-Urban Forest in Xanthi

### *Traditional Treatments*

In Xanthi, in the overstory cuttings of the traditional treatments (Figure 2), apart from the dead, mainly the badly formed, damaged, suppressed and intermediate trees were cut. The first priority was the cutting of the badly formed and damaged trees. The intensity of the cuttings depended mainly on the density of the conifer overstory, and usually it was light. However, in some cases, in areas with rather dense overstory, where there were many badly formed trees, the intensity of the cuttings was much higher. In the lower stories, the goal of the thinning was the more or less uniform (if possible) distribution of broadleaf trees. In most cases, in the broadleaf tree thinning, the robust trees, as well as the trees with good form, were not cut. On the other hand, mainly trees with lower competitive abilities were removed. The intensity of the thinning in the lower stories was, almost in all cases, low.

**FIGURE 2.** Area where traditional treatments were applied.

### *Selective Treatments*

In the following text Dafis [14], Oliver and Larson [15] and Smith *et al.* [16] were used as a theoretical base in order to develop the new proposed silvicultural treatments.

The so-called selective treatments include rather intense cuttings in the overstory of pines (conifers) and thinning in the broadleaf component of the lower stories.

The objective of the selective treatments is the fast conversion of the peri-urban forest in a forest where broadleaf trees will be the dominant element, and in later time in a broadleaved forest (at least in the better sites). Only in the worst sites *Pinus brutia* (conifers) will be the dominant component of the stands, since the most broadleaf trees are more site sensitive than pines [17-19].

The main aim of the overstory cuttings is the release of the broadleaf formations (thickets or groups) growing under pines (Figure 3). In the overstory cuttings, except for the dead, the badly formed and damaged trees will be cut. The first priority is the removal of the trees having large dimensions and bad form (if there is a sufficient ground cover by broadleaf trees or their regeneration). The trees having the best form will be retained. Those pines are expected to exhibit high growth rates. The intensity of the overstory cuttings will be higher in areas with dense (or rather dense) formations of broadleaf trees, or where there is rich regeneration of broadleaf trees. In this context, if after the removal of the badly formed and damaged trees, a tree (or trees) with rather good or even best form must be cut, in order for a broadleaf formation to be sufficiently released, then that tree (or those trees) has to be cut. As mentioned above, the main target, which must determine and guide the scheme of cuttings, is the release of the broadleaf component of the stand. In areas totally covered by dense or rather dense formations of broadleaf trees, all the overstory pines have to be removed, if possible, in one cutting application, if it is ensured that there will be no serious damages in the broadleaf stories.

The proposed selective silvicultural treatments will be applicable in peri-urban forest(s) having various spatial distributions and densities of broadleaved and conifer trees resulting in different needs of overstory cutting intensities.

Generally, the intensity of the pine overstory cuttings will vary depending on the density of the overstory trees, as well as on the density of the broadleaf trees of the lower stories (and in the regeneration level) and the necessity for their release.

In the new proposed selective silvicultural treatments, the thinning of the broadleaf trees will be a form of "positive selection" thinning. In the thinning, the main competitors of the selected best broadleaved trees will be cut. In each thinning application, in almost all cases, one (the primary) competitor of each selected to be favored tree must be cut [14]. As the best trees will be considered the trees (or saplings) having strong growth vigor, symmetric and large or rather large crown and, if it is possible, a good (straight, having circular cross section, without deficiencies) bole form. An essential feature, that all the selected best trees that are going to be favored must have, is a vertical stance. The thinning will provide more growing space to the most dynamic and promising broadleaved trees. The individuals that are going to be favored through that “positive selection” thinning must be distributed in the total stand area, if it is possible, since they are going to be the robust dominant having large dimensions trees that will give strength and stability in the stand in the future. In the locations where there are no broadleaf trees with the aforementioned desirable features, the comparatively (to the adjacent) better trees will be favored [14]. In areas where the best trees do not confront rather significant competition, no trees will be cut.

The production of quality wood must be considered as a secondary service in a peri-urban forest [1]. That is why, even though the good bole form is considered as a feature of the best trees, it is not a necessary one. The "positive selection" thinning of the broadleaf trees has to start when the best trees with the aforementioned features are easily identified.

In the broadleaf component when there are groups of sprouts, these must be gradually thinned so as the best sprouts, having a vertical stance, finally remain. In this gradual thinning, at first the sprouts having the worst form will be cut.

**FIGURE 3.** Broadleaf trees that were released from conifer competition in the context of selective silvicultural treatments (arrows aim at the stumps of the cut pines).

The conversion of a conifer dominated peri-urban forest to a broadleaf dominated forest and finally to a forest of broadleaf trees have to be implemented through a series of cutting and thinning treatments, which gradually will redistribute the growing space. The specific characteristics of the treatments, the time period between treatments, and their intensity will be assigned according to the conditions that exist each time.

In areas where the density of broadleaf trees is low and the density of pine overstory is high, the transition to the broadleaf species' dominance will delay, while in areas with a high density of broadleaf trees and a sparse pine overstory the transition will be immediate.

A significant issue that must be decisive in the selection of appropriate silvicultural treatments that are going to be applied in each case, is the protection of forest soil against erosion. In this context, especially in areas with a high inclination, the vegetation density and ground coverage maintained by the tree crown projections have to be high, if possible.

The next step in the areas of broadleaf forest, or in the areas where the broadleaf trees will dominate, is to design the future silvicultural treatment approach. This approach has to incorporate services such soil protection and forest recreation.

In areas with a low inclination, silvicultural treatments must have as objective to create formations where the density of broadleaf trees in some cases will be low, and trees with large dimensions and crowns have to be grown. In general, in recreational forests the tree spacings must vary [1].

On the other hand, in areas with high inclination, the creation of dense formations of broadleaf trees for the protection of soils must be the objective. In cases of low productivity areas (worst sites) with high inclination, it is preferable a dense stratum of shrub form broadleaf trees with a very sparse overstory of conifer trees (if applicable).

## Application of the Two Different Silvicultural Approaches in the Peri-Urban Forest of Xanthi

Each type of silvicultural treatments was applied in three replicates of about 1.5 ha in the peri - urban forest of Xanthi (Figure 4). In each replicate, two fixed area circular plots having a radius of 13 m (area of 531 m$^2$) were randomly established in 2016. In each plot the breast height diameter and total height of all trees (dead and living) of the plot having a breast height diameter of 3 cm and above were measured and registered. The most broadleaved trees were in the understory. Very few of the tallest broadleaved trees had an analogous height to their adjacent pine trees that in most cases were intermediate or codominant trees. In the present study (and analyses), the pines are considered to grow in the overstory and the broadleaf trees are considered to belong to lower stories. Moreover, in each plot, each measured living tree was classified according to its crown class to dominant, codominant, intermediate or suppressed following the classification of Kraft [15, 16]. This classification was made separately in regard to the pine trees and for the broadleaved trees. In the understory, apart from the broadleaf trees, in a plot of traditional treatments there is a small *Juniperus oxycedrus* L. tree. In the following analyses (crown class classification, basal area calculation, etc.) this tree was included in the broadleaved component of the plots.

In September of 2016, overstory pine cuttings and thinning of the broadleaf trees in the lower stories took


**FIGURE 4.** The three replicates where the traditional and the selective treatments were applied (source: Imagery ©2019, CNES / Airbus, European Space Imaging, Maxar Technologies).

place in the three replicates of each of the two types of silvicultural treatments. In each plot the characteristics of cut trees were recorded.

In the results section basal area data of all trees (dead and living) and crown class data of living trees are analyzed. This happened since the aim of result analysis was to highlight the different approaches of the two types of treatments as these are reflected in the amount of the removed basal area of both dead and living trees and in the crown class of cut living trees. The crown class distribution of trees provides information that contributes to a better management of forest stands [20]. Moreover, since both types of treatments aim at the removal of dead trees, the incorporation of dead trees in the basal area analysis provides a better insight into the intensity of each silvicultural approach. However, before the cuttings and thinning, only 9 dead trees (five pines and four broadleaf trees) were found in the plots where the two different types of treatments were applied.

In the plots where the traditional and the selective treatments were applied, the ratio (proportion) of cut pines or broadleaf trees belonging in a crown class is calculated when the number of cut trees of the specific crown class is divided by the total number of cut trees. In the comparisons between ratios, the Z test was used [21], while in the comparisons between basal areas the t test was used.

## RESULTS

In the following section, the basal area data are referred to both dead and living trees.

In the six plots of traditional treatments the total basal area, from 12.41 $m^2$ (38.96 $m^2 \cdot ha^{-1}$), before the cuttings (and thinning) became 9.85 $m^2$ (30.93 $m^2 \cdot ha^{-1}$) after the cuttings (and thinning). The basal area of pine overstory of 11.96 $m^2$ (37.54 $m^2 \cdot ha^{-1}$) became 9.44 $m^2$ (29.64 $m^2 \cdot ha^{-1}$), exhibiting a reduction of 21.05%, while the basal area of broadleaf trees of 0.45 $m^2$ (1.42 $m^2 \cdot ha^{-1}$) became 0.41 $m^2$ (1.29 $m^2 \cdot ha^{-1}$), exhibiting a reduction of 8.93% (Figure 5). On the other hand, in the six plots of selective treatments the total basal area of 12.51 $m^2$ (39.27 $m^2 \cdot ha^{-1}$), before the cuttings (and thinning) became 7.58 $m^2$ (23.81 $m^2 \cdot ha^{-1}$) after the cuttings (and thinning). The basal area of pine overstory from 11.45 $m^2$ (35.93 $m^2 \cdot ha^{-1}$) became 6.69 $m^2$ (20.99 $m^2 \cdot ha^{-1}$), exhibiting a reduction of 41.57%, while the basal area of broadleaf trees of 1.06 $m^2$ (3.34 $m^2 \cdot ha^{-1}$) became 0.90 $m^2$ (2.82 $m^2 \cdot ha^{-1}$), exhibiting a reduction of 15.77% (Figure 5). In the established plots, before cuttings (and thinning), total basal area was not statistically significantly different ($p>0.05$) between the two types of silvicultural treatments (t-test, $t=-0.087$ and $p=0.933$). After cuttings (and thinning), the plots of selective treatments had statistically significantly lower ($p<0.05$) total basal area than those of traditional treatments (t-test, $t=2.611$ and $p=0.027$). In addition, in the plots of selective treatments, basal area of all cut trees was statistically significantly greater ($p<0.05$) than that of the plots of traditional treatments (t-test, $t=-3.997$ and $p=0.003$).

In the Figures 6 and 7, the number of living trees in the different crown classes before and after the cuttings (and thinning), in the plots where traditional and selective treatments were applied, is presented. There were no differences ($p>0.05$) in the ratios (proportions) of cut pine trees in each of the three crown classes (dominant, codominant and intermediate trees) between the two different types of silvicultural treatments, in the measured plots. There were no suppressed pine trees in the plots were the traditional treatments were applied (Table 1). In the case of broadleaf trees, the ratios (proportions) of cut trees belonging in the dominant and suppressed trees in the selective treatments were higher, compared to the corresponding ratios in the traditional treatments. In the traditional treatments the ratio (proportion) of cut intermediate trees was higher ($p<0.05$) than that of selective treatments, while there was no difference ($p>0.05$) in the ratios of cut codominant trees in the plots of the two different types of treatments (Table 1).

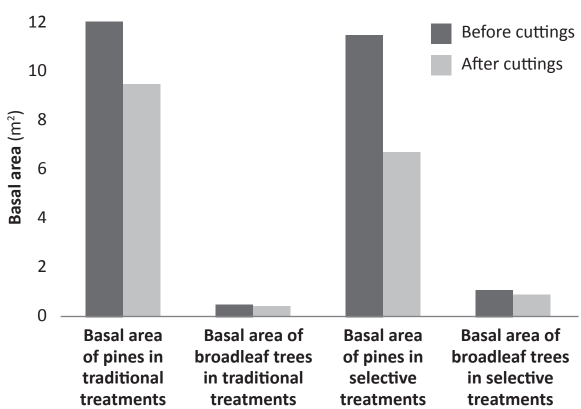


**FIGURE 5.** Basal area of pines and broadleaf trees before and after the cuttings (and thinning), in the plots where traditional and selective treatments were applied.

**TABLE 1.** Ratios (proportions) of living pines and broadleaf trees of different crown classes that were cut (out of the total number of trees that were cut) in the plots where traditional and selective treatments were applied.

| Ratios | | Comparison of the ratios | |
|---|---|---|---|
| | | Z | p |
| Dominant pine trees that were cut in the traditional treatments | Dominant pine trees that were cut in the selective treatments | | |
| 0.49 | 0.53 | -0.391 | 0.698 |
| Codominant pine trees that were cut in the traditional treatments | Codominant pine trees that were cut in the selective treatments | | |
| 0.14 | 0.25 | -1.166 | 0.252 |
| Intermediate pine trees that were cut in the traditional treatments | Intermediate pine trees that were cut in the selective treatments | | |
| 0.37 | 0.23 | 1.476 | 0.149 |
| Dominant broadleaf trees that were cut in the traditional treatments | Dominant broadleaf trees that were cut in the selective treatments | | |
| 0.00 | 0.20 | -2.371 | 0.027 |
| Codominant broadleaf trees that were cut in the traditional treatments | Codominant broadleaf trees that were cut in the selective treatments | | |
| 0.29 | 0.15 | 1.468 | 0.156 |
| Intermediate broadleaf trees that were cut in the traditional treatments | Intermediate broadleaf trees that were cut in the selective treatments | | |
| 0.67 | 0.28 | 3.358 | 0.003 |
| Suppressed broadleaf trees that were cut in the traditional treatments | Suppressed broadleaf trees that were cut in the selective treatments | | |
| 0.04 | 0.37 | -3.051 | 0.006 |

In the comparisons between ratios, the Z test was used. In the plots were the traditional and the selective treatments were applied, the ratio of cut pines or broadleaf trees belonging in a crown class is calculated when the number of cut trees of the specific crown class is divided by the total number of cut trees.

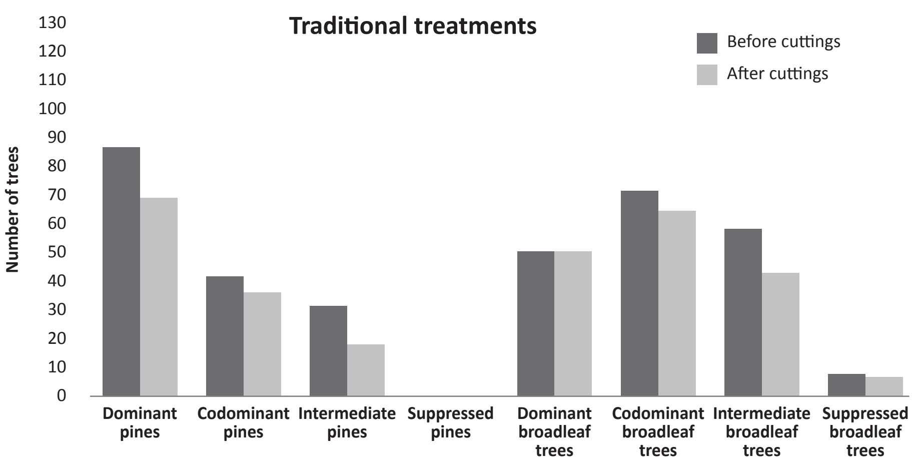


**FIGURE 6.** Number of pines and broadleaf trees in the different crown classes before and after the cuttings (and thinning), in the plots where the traditional treatments were applied.

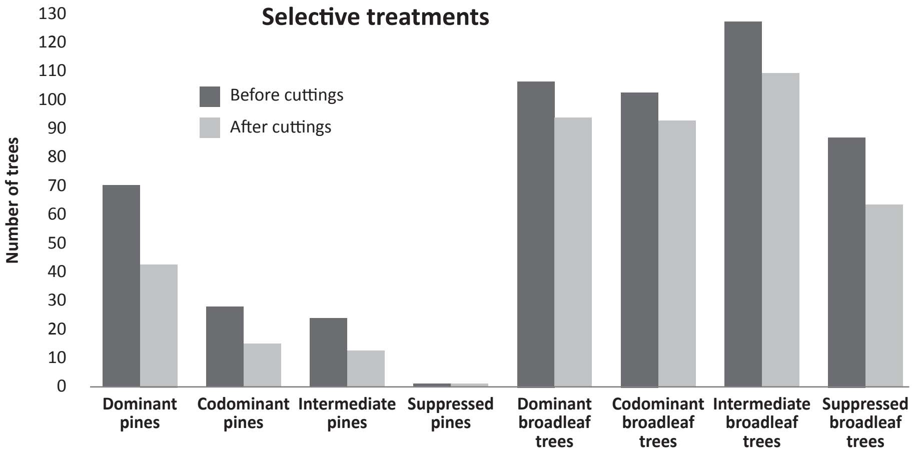


**FIGURE 7.** Number of pines and broadleaf trees in the different crown classes before and after the cuttings (and thinning), in the plots where the selective treatments were applied.

## DISCUSSION

The intensity of treatments was higher in terms of the basal area of cut trees in the selective silvicultural approach, compared to the traditional treatments in the peri-urban forest of Xanthi. In selective treatments all cut trees had greater (p<0.05) basal area compared to that of traditional treatments. Moreover, it must be mentioned that before the application of treatments there was no difference (p>0.05) in the total basal area between the plots where the two different types of treatments were applied. The higher amount of basal area of cut trees in the selective treatments is related to the need for the release of the broadleaved formations from the overstory pine competition, that results in more intense overstory pine cuttings in areas with dense (or rather dense) formations of broadleaf trees. However, as mentioned in the description of the selective treatments, their overstory cutting intensity depends on the spatial distributions and densities of broadleaved and conifer trees.

Thinning can be a satisfactory method for the restoration of hardwood species under conifer plantations [22, 23]. In a *Criptomeria japonica* plantation of 20 years old, Seiwa *et al.* [24] applied thinning treatments of two intensities. In intensive thinning the 60.5% of the tree volume was cut, while in the week thinning the 28.3% of the tree volume was cut. They found that a mixed at the level of canopy conifer – hardwood forest is more possible to be developed and occur more quickly after the intensive thinning, compared to the week thinning. Harmer *et al.* [25], after a study in a *Pinus nigra* – *Pinus sylvestris* plantation, they mentioned that in the conversion of pine plantations in a woodland of broadleaf trees, an extensive reduction of canopy may be applied. However, they referred that this treatment is the proper approach in areas where the ground flora species can have a negative effect on regeneration, while fast growing species is likely to be naturally established quickly. Mercurio and Spinelly [26] recommend the creation of gaps for the natural regeneration establishment of native species under the Mediterranean softwood plantations. They also refer that the size of the gap depends on the species and the management goals. On the other hand, Alday *et al.* [27] mentioned that for the conversion of *Pinus radiata* plantations to native forest using natural regeneration clear cutting treatments can be used.

There were not differences (p>0.05) in the ratios (proportions) of the three crown classes (dominant, codominant and intermediate) of cut pine trees between the two different types of treatments. The main difference in the overstory cuttings between the two silvicultural approaches is the release of the lower stories of broadleaf trees, aimed in the selective treatments, while in the traditional treatments the first priority is the gradual removal of the badly formed tress and damaged trees. Badly formed trees and damaged trees are not connected to a particular crown class, and they can also have great dimensions. As a result, the ratios (proportions) of the removed pine trees that belonged in dominant, codominant and intermediate crown classes were not different in the two types of treatments.

In the broadleaf trees, the different objectives of the two types of treatments resulted in thinning with different qualitative characteristics. In selective treatments, more dominant trees (p<0.05) were proportionally cut (higher ratio) than in the traditional treatments. In fact, in traditional treatments no dominant trees were cut. This was predictable since, as it is referred above, in the traditional treatments, in most cases, in the thinning of broadleaf trees the robust trees were not cut, while mainly trees with lower competitive ability were removed. In this context, in the thinning of traditional treatments more intermediate trees (p<0.05) were proportionally cut, compared to selective treatments. However, in the selective treatments, more suppressed trees (p<0.05) were proportionally cut, compared to the traditional treatments. In this case, this was the result of the existence of groups of sprouts, in the plots where the selective treatments were applied. In the present treatments, in these groups, badly formed sprouts that were in parallel characterized as suppressed, since they had a curved form, were cut, leading in the high number of suppressed trees that removed in the plots where the selective treatments were applied.

A high intensity of the thinning of broadleaf trees in the selective treatments is not an inherent feature. The intensity of thinning of the broadleaf trees in the selective treatments depends on the competition imposed in the best trees, and secondarily on the density of formations of broadleaf trees.

In the proposed selective silvicultural treatments, there is a fast conversion of the peri-urban forest in a broadleaved forest (at least in the better sites) through the fast releasement of broadleaf trees, and only in the worst sites, conifers will be the dominant component of the stands. Moreover, in the thinning of the broadleaf trees in the lower stories, the best trees that are going to be favored are going to be the robust dominant having large dimensions trees, which will give strength and stability in the stand in the future. In Great Britain, it is considered that the fast conversion of conifer plantation to woodlands of native broadleaved species through clear cutting treatments under certain ecological conditions can be more preferable compared to the gradual removal of plantation trees [25, 28, 29].

Regarding the traditional silvicultural treatments, there is no acceleration of forest dynamics in the direction of broadleaf species dominance, with all the advantages of this fast conversion. Cuttings are not targeted at the release of broadleaf species and only by chance, in the case of removal of one (or two proximate) badly formed pine tree having large dimensions, there will be a release of a group of broadleaf trees (if there were such a group under the pine tree that was cut). Moreover, in the traditional treatment, the broadleaf trees are not strengthened through the favoring of their most dynamic elements. The redistribution of the growing space does not give a significant advantage in a specific category of trees.

According to Doukalianou *et al.* [10], both types of silvicultural treatments reduced the potential of global warming. However, they mentioned that there is an indication that the selective treatments, which were high-intensity treatments, exhibit a high potential for the mitigation of global change.

The new proposed selective silvicultural treatments can be applied in peri-urban forests having a similar stand structure and analogous ecological conditions with the peri-urban forest of Xanthi.

## CONCLUSIONS

The research hypothesis was verified. The intensity of treatments was higher in terms of the basal area of cut trees in the selective silvicultural approach, compared to the traditional treatments in the peri-urban forest of Xanthi. However, the overstory cutting intensity of the selective treatments depends on the spatial distributions and densities of broadleaved and conifer trees.

There were not differences ($p>0.05$) in the ratios (proportions) of the three crown classes (dominant, codominant and intermediate) of cut pine trees between the two different types of treatments. In the broadleaf trees of the lower stories, the different objectives of the two types of treatments resulted in thinning with different qualitative characteristics.

The proposed selective silvicultural treatments will accelerate the conversion of the peri-urban forests having an understory of broadleaf trees into broadleaved forests or into mixed forests of conifers and broadleaf trees and will strengthen the most dynamic elements of broadleaf trees. Thus, in the future peri-urban forests, the risk of wildfires will be reduced, there will be an increased ability of the forest ecosystem to react after disturbances, and new abilities of stand structure manipulation in the direction of usage of peri-urban forests, for recreation and soil protection, will be created.

### Acknowledgments

Supported by the European FORESMIT Project (LIFE14 CCM/IT/000905) «FOrests for environmental sustainability, REStoration and climate change MITigation».

## REFERENCES

1. HATZISTATHIS A, ISPIKOUDIS I 1995 Protection of the Nature and Architecture of the Landscape. Giahoudi, Thessaloniki, Greece, 417 p
2. BOND W, MIDGLEY JJ 2001 Ecology of sprouting in woody plants; the persistence niche. *Trends Ecol Evol* 16 (1): 45-51. DOI: https://doi.org/10.1016/S0169-5347(00)02033-4
3. MILIOS E, PIPINIS E, KITIKIDOU K, BATZIOU M, CHATZAKIS S, AKRITIDOU S 2014 Are sprouts the dominant form of regeneration in a lowland *Quercus pubescens–Quercus frainetto* remnant forest in Northeastern Greece? A regeneration analysis in the context of grazing. *New Forest* 45 (2): 165-177. DOI: https://dx.doi.org/10.1007/s11056-013-9399-z
4. BATZIOU M, MILIOS E, KITIKIDOU K 2017 Is diameter at the base of the root collar a key characteristic of seedling sprouts in a *Quercus pubescens–Quercus frainetto* grazed forest in north-eastern Greece? A morphological analysis. *New Forest* 48 (1): 1-16. DOI: -https://doi.org/10.1007/s11056-016-9552-6
5. MILIOS E, KITIKIDOU K, ANDREADOU P 2017 Sprouting characteristics of *Quercus pubescens* Willd. and *Quercus frainetto* Ten. trees after a wildfire: to cut or not to cut the burned trees? *Eur J For Res* 136 (5-6): 971–979 DOI: https://doi.org/10.1007/s10342-017-1085-9
6. MILIOS E, AKRITIDOU S 2003 Sprout propagation – Biology – Ecology – Forest Practice (in Greek). *In*: Hellenic Forestry Society (*eds*) Forest Policy, Coppice Forests, Protection of Natural Environment, Proceedings of the 11th conference of Hellenic Forestry Society, Olympia, Greece, 30 September – 3 October 2003, Hellenic Forestry Society, Greece, pp 663-673

7. MILIOS E 2010 Facilitation process and sprouting ability as silvicultural tools in the frame of climate change. *In*: Ljubinko Rakonjac (*ed*) Forest Ecosystems and Climate Changes, Proceedings of Plenary Lectures of the International Scientific Conference: Forest Ecosystems and Climate Changes, Belgrade, Serbia 9-10 March 2010, Institute of Forestry Belgrade, Serbia, pp 137-142
8. SJOLUND MJ, JUMP AS 2013 The benefits and hazards of exploiting vegetative regeneration for forest conservation management in a warming world. *Forestry* 86 (5): 503-513. DOI: https://doi.org/10.1093/forestry/cpt030
9. MAZZA G, ANGELLI AE, CANTIANI P, CHIAVETTA U, DOUKALIANOU F, KITIKIDOU K, MILIOS E, ORFANOUDAKIS M, RADOGLOU K, LAGOMARSINO A 2019 Short-term effects of thinning on soil CO2, N2O and CH4 fluxes in Mediterranean forest ecosystems. *Sci Total Environ* 651: 713-724. DOI: https://doi.org/10.1016/j.scitotenv.2018.09.241
10. DOUKALIANOU F, RADOGLOU K, ANGELLI AE, KITIKIDOU K, MILIOS E, ORFANOUDAKIS M, LAGOMARSINO A 2019 Annual Greenhouse-Gas Emissions from Forest Soil of a Peri-Urban Conifer Forest in Greece under Different Thinning Intensities and Their Climate-Change Mitigation Potential. *Forest Sci* 65 (4): 387-400. DOI: https://doi.org/10.1093/forsci/fxy069
11. KITIKIDOU K, MILIOS E, RADOGLOU K 2017 Single-entry volume table for *Pinus brutia* in a planted peri-urban forest. *Annals of Silvicultural Research* 41 (2): 74-79. DOI: https://doi.org/10.12899/asr-1437
12. DE MEO I, ANGELLI AE, GRAZIANI A, KITIKIDOU K, LAGOMARSINO A, MILIOS E, RADOGLOU K, PALETTO A 2017 Deadwood volume assessment in Calabrian pine (*Pinus brutia* Ten.) peri-urban forests: Comparison between two sampling methods. *J Sustain Forest* 37 (7): 666-686. DOI: https://doi.org/10.1080/10549811.2017.1345685
13. PAPAIOANNOU G 2008 The torrential environment of river Kosynthos (*in Greek with English summary*). MSc. thesis, Democritus University of Thrace, Department of Forestry and Management of the Environment and Natural Resources, Nea Orestiada, Greece, 118 p
14. DAFIS S 1992 Applied Silviculture (*in Greek*). Giahoudi - Giapouli, Thessaloniki, Greece, 258 p
15. OLIVER CD, LARSON BC 1996 Forest Stand Dynamics. John Wiley & Sons, Inc. New York, USA, 520 p
16. SMITH DM, LARSON BC, KELTY MJ, ASHTON PMS 1997 The practice of silviculture: applied forest ecology. John Wiley & Sons, Inc. New York, USA, 537 p
17. ATHANASIADIS N 1986 Forest botany, Part II (*in Greek*). Giahoudi - Giapouli, Thessaloniki, Greece, 309 p
18. DAFIS S 1986 Forest ecology (*in Greek*). Giahoudi - Giapouli, Thessaloniki, Greece, 443 p
19. KORAKIS G 2015 Forest botany (e-book) (*in Greek*). Association of Greek Academic Libraries, Athens, Greece, 619 p. URL: http://hdl.handle.net/11419/742
20. BOUNTIS D, MILIOS E 2017 Does crown class classification improve the initiation and development analysis of post-fire *Pinus brutia* stands? *CERNE* 23 (1): 61-68. DOI: https://-doi.org/10.1590/01047760201723012260
21. COX DR 2006 Principles of Statistical Inference. Cambridge University Press, New York, USA, 236 p
22. UTSUGI E, KANNO H, UENO N, TOMITA M, SAITOH T, KIMURA M, KANOU K, SEIWA K 2006 Hardwood recruitment into conifer plantations in Japan: Effects of thinning and distance from neighboring hardwood forests. *Forest Ecol Manag 237 (1-3): 15-28.* DOI: https://doi.org/10.1016/j.foreco.2006.09.011
23. KITAGAWA R, UENO M, MASAKI T 2018 Initial effects of thinning and concomitant disturbance on the understory woody Community in Japanese cedar plantation. *J Forest Res-JPN* 23 (2): 120-128. DOI: https://doi.org/10.1080/13416979.2018.1430653
24. SEIWA K, ETOH Y, HISITA M, MASAKA K, IMAJI A, UENO N, HASEGAWA Y, KONNO M, KANNO H, KIMURA M 2012 Roles of thinning intensity in hardwood recruitment and diversity in a conifer, *Criptomeria japonica* plantation: A 5-year demographic study. *Forest Ecol Manag 269: 177-187.* DOI: https://doi.org/10.1016/j.foreco.2011.12.014
25. HARMER R, KIEWITT A, MORGAN G 2012 Effects of overstorey retention on ash regeneration and bramble growth during conversion of a pine plantation to native broadleaved woodland. *Eur J For Res* 131 (6): 1833-1843. DOI: https://doi.org/10.1007/s10342-012-0636-3
26. MERCURIO R, SPINELLI R 2012 Exploring the silvicultural and economic viability of gap cutting in Mediterranean softwood plantations. *For Stud China* 14 (1): 63-69. DOI: https://doi.org/10.1007/s11632-012-0103-8
27. ALDAY JG, EXTEBERRIA E, AMETZAGA I 2017 Conversion of *Pinus radiata* plantations to native forest after harvest operations: a north Iberian Peninsula case study. *Eur J For Res* 136 (5-6): 801-810. DOI: https://doi.org/10.1007/s10342-017-1071-2
28. HARMER R, MORGAN G 2009 Storm damage and the conversion of conifer plantations to native broadleaved woodland. *Forest Ecol Manag 258 (5): 879-886.* DOI: https://doi.org/10.1016/j.foreco.2009.03.023
29. HARMER R, MORGAN G, BEAUCHAMP K 2011 Restocking with broadleaved species during the conversion of *Tsuga heterophylla* plantations to native woodland using natural regeneration. *Eur J For Res* 136 (2): 161-171. DOI: https://doi.org/10.1007/s10342-010-0418-8

SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

ORIGINAL SCIENTIFIC PAPER

DOI: https://doi.org/10.15177/seefor.19-15

# Age-Related Changes of Some Chemical Components in the Leaves of Oriental Beech (*Fagus orientalis* Lipsky.)

**Nezahat Turfan[1]*, Sezgin Ayan[2]*, Esra Nurten Yer[2], Halil Barış Özel[3]**

**(1)** Kastamonu University, Faculty of Science and Literature, Biology Department, Kuzeykent Campus, TR-37150 Kastamonu, Turkey; **(2)** Kastamonu University, Faculty of Forestry, Silviculture Department, Kuzeykent Campus, TR-37100 Kuzeykent, Kastamonu, Turkey; **(3)** University of Bartın, Faculty of Forestry, Silviculture Department, TR-74100 Bartın, Turkey

* **Correspondence:** e-mail: nturfan@kastamonu.edu.tr

**Citation:** TURFAN N, AYAN S, YER EN, ÖZEL HB 2019 Age-Related Changes of Some Chemical Components in the Leaves of Oriental Beech (*Fagus orientalis* Lipsky.). *South-east Eur for* 10 (2): 117-124. DOI: https://doi.org/10.15177/seefor.19-15

**Received:** 26 Feb 2019; **Revised:** 25 Apr 2019, 11 Jul 2019; **Accepted:** 20 Aug 2019; **Published online:** 4 Nov 2019

## ABSTRACT

**Background and Purpose:** This study presents the analysis of photosynthetic pigments, proline, total soluble protein, total amino acids, glucose, sucrose, total soluble sugars, total amount of phenolic compounds and flavonoids, malondialdehyde (MDA) and hydrogen peroxide ($H_2O_2$) concentration in the leaf samples collected from oriental beech trees, which are naturally spread in Kastamonu Province, Turkey, with differing ages, enzyme activities of ascorbate peroxidase (APX), catalase (CAT) and superoxide dismutase (SOD).

**Material and Methods:** The research was carried out on oriental beech trees (*Fagus orientalis* L.) of different ages located at 1300 m high elevation in Ahlat Village of Kastamonu Province, Turkey. Oriental beech trees of different ages (≥25, ≥50, ≥100, ≥200 and ≥600 years-old) constituted the material of this study. In leaf samples taken from trees of different ages, photosynthetic pigments (chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoid), proline, total soluble protein, total amino acid, glucose, sucrose, total soluble sugars, the amount of total phenolic compounds and flavonoids, MDA, $H_2O_2$ concentration, enzyme activities of APX, CAT and SOD, as well as the relationship between the total content of C, N and H elements and the tree ages were studied.

**Results:** As a result of the research conducted, significant differences were determined in terms of chlorophyll, total phenolic compound, flavonoid, glucose, amounts of sucrose, nitrogenous compounds, proline, total soluble protein, MDA, $H_2O_2$ concentrations, and the activities of APX, CAT and SOD in the leaves of oriental beech trees with differing ages. The highest content of chlorophyll *a* was found to be in the youngest age group of ≥25 years. Total chlorophyll is low in young trees and high in middle-aged, old and very old trees. According to the results obtained, it was concluded that the MDA and $H_2O_2$ concentrations in the trees did not vary depending on the age of trees only, but also on the genotype, environmental conditions and metabolic activities. It was concluded that the fact that the total chlorophyll, phenolic compounds and sucrose content in oriental beech trees are high and that MDA content is low could have an influence on the long life of ≥600 years-old oriental beech trees.

**Conclusions:** The activity of photosynthesis is related to leaf characteristics more than the age of trees.

**Keywords:** Tree physiology, Oriental beech, Chemical content, Tree age, Enzyme activities.

## INTRODUCTION

In studies analysing the growth and development of trees, the balance between photosynthesis/respiratory rate [1], coordination between the above-ground and under-ground organs [2], metabolic processes [3] and the changes in environmental factors were found to be affecting the growth and development of trees [4, 5]. Approximately, 1/3 of daily photosynthesis gain of young trees was used for respiration [6]; this consumption increased in old trees even more with the change in the ratio of photosynthetic tissue/non-photosynthetic tissue [7-9]; deficiency in nutrient distribution and the respiratory activities were the determining factors that reflect the aging phenology; and when the tissues and organs completed their maturation period, the respiration slowed down, while the senescence accelerated [10]. The effect of irreversible deterioration, which started in the physical and chemical structure of chloroplasts, in the stimulation of senescence was very high. The accumulation of toxic substances in the tissues and cells such as reactive oxygen (ROS), malondialdehyde (MDA), and ketones increased and apoptotic deaths started afterwards [11]. The prediction of biological life of a tree, and thus the future of a forest, depends on the determination of its economic life and cause-effect relationships. Hence, many researchers reported that establishing the ecological characteristics of the forests and the individual growth and increment relationships of all the species forming those forests was an important step in forest planning [12, 13].

Oriental beech (*Fagus orientalis* Lipsky.) is an important species covering a total of 1,751,484 ha of spreading area including 1,373,245 ha of productive high forest lands and 378,239 ha of unproductive high forest lands in Turkey, and it takes the third place in terms of country-wide growing stock after Turkish pine (*Pinus brutia* Ten.) and Anatolian black pine (*Pinus nigra* Arnold) [14]. However, forest lands around the world have been decreasing due to silvicultural interventions, which were not conducted according to abiotic and biotic stress factors and techniques, and which is why the productivity in the forests of oriental beech, which is one of our fundamental tree species, has also been decreasing [15]. The fact that forests in Turkey have rich biological and genetic diversity depending on different habitat conditions is directly effective in determining the techniques to be applied in the rejuvenation and maintenance works to be carried out, and in the success of those works. For this reason, in forest lands, where silvicultural interventions are carried out, the growing conditions of oriental beech trees, stand establishment characteristics (pure or mixed stands, closure, density, etc.) and particularly the monitoring of age-related growth and development relationships have significant importance [16, 17]. In this study, the age-related changes in organic compounds such as photosynthetic metabolism, which takes part in growing and development processes of oriental beech trees of different ages, protein, proline, soluble sugars, damages occurring in cellular membranes and their effects on chemical content, antioxidant enzymes, total phenolic compounds and flavonoids were presented.

## MATERIAL AND METHODS

### Material

Oriental beech trees (*Fagus orientalis* L.) of different ages (≥25, ≥50, ≥100, ≥200 and ≥600 years-old) located at 1300 m high elevation (2º23'50" N, 33º46'50" E) (Figure 1) in Ahlat Village of Kastamonu Province constituted the material of this study. The age determination of the trees in the sampling area was performed by counting the annual rings on the increment corer taken by an increment borer from 3 trees in each age-group at the breast height ($d_{1.30}$ m). While determining the age of the tree with increment borer, attention was paid to ensure that the increment corer was in two perpendicular directions in order to prevent the error that may occur in measuring the annual ring and eccentric growth. The fresh leaves under the canopy of the trees belonging to each age group in the sampling area were collected from each direction of the tree in the second half of July [18].

### Methods

In leaf samples taken from trees of different ages, photosynthetic pigments (chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoid), proline, total soluble protein, total amino acid, glucose, sucrose, total soluble sugars, the amount of total phenolic compounds and flavonoids, malondialdehyde (MDA), hydrogen peroxide ($H_2O_2$) concentration, enzyme activities of ascorbate peroxidase (APX), catalase (CAT) and superoxide dismutase (SOD) as well as the relationship between the total content of C, N and H elements and the tree ages were studied.

The C, N and H content of the leaf samples was measured by the XRF device of SPECTRO brand and XEPOS model available at Kastamonu University Central Research Laboratory.

In order to determine the chlorophyll content, 0.5 g of fresh leaf tissue was thoroughly crushed inside liquid nitrogen and was homogenized by adding 5 ml of 80% acetone solution at 4°C [19, 20] The homogenate was centrifuged at 3000 rpm for 10 minutes and the spectrophotometric reading of the supernatants taken were performed in triplicate at the values of 450, 645, 663 nm. In determining the total chlorophyll content, the Arnon equation [21] was used, whilst the carotenoid content was determined based on the

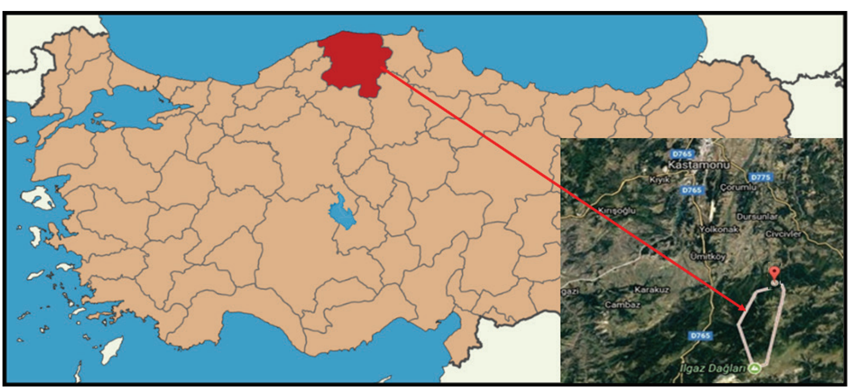


**FIGURE 1.** Research area

Jaspars formula [22]. The proline content in leaf samples was determined according to the Bates method [23], whilst the protein content was determined according to the Bradford method [24], MDA [25] and $H_2O_2$ extraction [26].

Total carbohydrate quantitation was carried out by using the Anthrone method [27]; 1 g of powder sample was homogenized in 80% ethanol. Absorbance of some of the homogenate was measured at 630 nm by a spectrophotometer, and glucose and total starch quantitation was performed. The remaining filtrate was extracted using 52% perchloric acid and its absorbance values were measured at 620 nm wavelength by a spectrophotometer, and were then used for sucrose and total soluble carbohydrate measurement. Total phenolic analysis was performed according to the spectrophotometric Folin-Ciocalteu method [28]. Total flavonoid quantitation was carried out spectrophotometrically (Shimadzu UV-260) [29].

While determining the enzyme activities of fresh leaf samples, 0.5 g of fresh leaf sample was crushed inside liquid nitrogen and then homogenized with 5 ml of 50 mM (pH=7.6) $KH_2PO_4$ (pH=7) buffered solution containing 0.1 mMNa-EDTA. The homogenized samples were centrifuged at 15000 g and 4°C for 15 minutes. Enzyme activities were measured in this supernatant. APX was determined spectrophotometrically according to the method applied by Nakano & Asada [30] by measuring the oxidation rate of ascorbate at 290 nm (E=2.8 mM cm-1), while CAT activity was determined spectrophotometrically according to Bergmeyer [31], and SOD enzyme activity according to the method applied by Cakmak [32].

### Statistical Analysis

Whether each parameter of the chemical compounds detected on the leaves differed significantly by age or not was presented through the F-test of the Analysis of Variance (ANOVA) using the SPSS program (Version 11). According to the ANOVA results (P≤0.05), to determine statistically significant differences between means Tukey test as a multiple range test was applied.

## RESULTS

### Changes in the Amount of Photosynthetic Pigment, Total Phenolic Compounds and Flavonoids

Changes in the amount of photosynthetic pigments, total phenolic compounds and flavonoids in the oriental beech leaves are given in Table 1. According to the variance analysis results, the amounts of chlorophyll *a*, *b*, chlorophyll *a/b*, total chlorophyll, total phenolic compound and flavonoids showed significant differences depending on tree age except total carotenoids (Table 1).

The pigment content changed significantly according to age groups of the trees (p<0.05). The highest content of chlorophyll *a* in eastern beech trees was detected in the youngest age group of ≥25 years-old trees (0.159 mg), while the content of chlorophyll *b* was found in older trees. The lowest content of chlorophyll *b* was found to be 0.128 mg in ≥25 years-old trees (Table 1).

The total chlorophyll content varied between 0.287 and 0.408 mg. While the youngest (≥25) oriental beech tree had the lowest chlorophyll content of 0.287 mg, the oldest (≥600) oriental beech tree within the research material had the highest chlorophyll content of 0.408 mg. In terms of chlorophyll *a/b*, ≥25 years-old age group was found to have the highest chlorophyll *a/b* value, while the ≥600 years-old group had the lowest. Chlorophyll *a/b* ratio of the youngest group was found to be approximately 2.3 times higher than the oldest group.

No significant change was detected between age groups of trees in terms of carotenoid content. In terms of total phenolic compounds content, the highest value was obtained from a tree older than 600 years, while in terms of flavonoids content, the highest value was obtained from a tree older than 200 years. The lowest total phenolic compound content was recorded in a tree older than 200 years, and the lowest flavonoid content was recorded in a beech tree older than 25 years (Table 1).

### Changes in the Amount of Glucose, Sucrose, Total Soluble Carbohydrate and Starch

While significant differences were detected in the glucose and sucrose contents of beech trees of different ages, no significant change was determined in total soluble carbohydrate and starch contents. In addition to this, the highest glucose, total soluble carbohydrate and starch contents were detected in beech trees older than 200 years, while the highest sucrose content was recorded in trees older than 600 years (Table 2).

### N, C and H Content Changes

In oriental beech tree leaves, the N content was found to be the highest in trees older than 200 and 100 years, and

**TABLE 1.** Results of variance analysis and Tukey test according to age groups for the amount of photosynthetic pigments (chlorophyll a, chlorophyll b, total chlorophyll and carotenoid), total phenolic compounds and flavonoids.

| Age group | Chlorophyll *a* (mg·g$^{-1}$) | Chlorophyll *b* (mg·g$^{-1}$) | Total Chlorophyll (mg·g$^{-1}$) | Chlorophyll *a/b* (mg·g$^{-1}$) | Total Carotenoid (mg·g$^{-1}$) | Total Phenolic Compound (µg·g$^{-1}$) | Flavonoid (µg·g$^{-1}$) |
|---|---|---|---|---|---|---|---|
| ≥25 | 0.159±0.002b | 0.128±0.020a | 0.287±0.02a | 1.301±0.214a | 9.41±0.014a | 17.16±0.18b | 8.89±0.19a |
| ≥50 | 0.147±0.002a | 0.239±0.020b | 0.386±0.02b | 0.626±0.063ab | 9.48±0.03a | 16.13±0.11ab | 9.07±0.09b |
| ≥100 | 0.147±0.001a | 0.260±0.002c | 0.406±0.01c | 0.566±0.003b | 9.42±0.03a | 16.23±0.12ab | 9.12±0.10b |
| ≥200 | 0.148±0.001a | 0.257±0.002c | 0.404±0.01c | 0.575±0.001b | 9.44±0.03a | 15.16±0.13a | 9.21±0.12b |
| ≥600 | 0.149±0.001a | 0.259±0.001c | 0.408±0.01c | 0.573±0.002b | 9.42±0.04a | 17.75±0.16b | 8.96±0.05a |
| F value | 17.216 | 21.488 | 20.691 | 10.392 | 1.018 | 5027.95 | 118.37 |
| Sig. Lev. | 0.000 | 0.000 | 0.000 | 0.001 | 0.443 | 0.000 | 0.000 |

the lowest in trees older than 50 years. Hydrogen content is the highest in beech trees older than 200 and 100 years and the lowest in young beech trees older than 25 years (Table 3).

### Changes in Proline, Total Soluble Protein, Total Amino Acid and MDA and H2O2 Concentration

Age-related change of nitrogenous compounds such as proline, total soluble protein, total amino acid and nitrogen (%) in oriental beech trees was found statistically significant. Also, MDA and $H_2O_2$ concentrations demonstrated significant age-related differences. $H_2O_2$ concentration varied between 80.88 µmol and 161.53 µmol (Table 4).

### Antioxidant activity changes

APX, CAT and SOD activities were affected by tree age at a significant level. The APX activity was found to be the lowest in a tree older than 600 years. CAT activity was 72.96% higher in trees older than 200 years compared to ≥600 years-old trees and 13.54% lower in trees older than 100 years. On the other hand, the SOD activity was found to be higher in ≥50 and ≥600 years-old beech trees (Table 5).

**TABLE 2.** Results of variance analysis and Tukey test according to age groups for glucose, sucrose, total soluble carbohydrate and starch contents.

| Age group | Glucose ($mg \cdot g^{-1}$) | Sucrose ($mg \cdot g^{-1}$) | Total Soluble Carbohydrate ($mg \cdot g^{-1}$) | Starch ($mg \cdot g^{-1}$) |
|---|---|---|---|---|
| ≥25 | 70.47±0.02a | 67.44±0.02a | 53.55±0.28a | 49.99±0.02a |
| ≥50 | 71.62±0.02a | 66.89±0.04a | 53.77±0.11a | 50.19±0.02a |
| ≥100 | 71.17±0.03a | 68.41±0.04b | 54.63±0.22a | 50.99±0.03a |
| ≥200 | 72.06±0.03b | 67.77±0.05a | 55.34±0.23a | 51.65±0.03a |
| ≥600 | 71.46±0.03a | 68.60±0.11b | 54.36±0.17a | 50.73±0.03a |
| F Value | 817.91 | 156.82 | 1160.51 | 1160.51 |
| Sig. Lev. | 0.000 | 0.000 | 0.000 | 0.000 |

**TABLE 3.** Results of variance analysis and Tukey test according to age groups for N, C and H content changes.

| Age Group | N% | C% | H% |
|---|---|---|---|
| ≥25 | 0.62±0.0002c | 14.91±0.0006b | 1.95±0.0006a |
| ≥50 | 0.57±0.0004a | 14.79±0.0004a | 1.98±0.0004b |
| ≥100 | 0.64±0.0006d | 15.00±0.0002d | 1.99±0.0004b |
| ≥200 | 0.68±0.0004e | 15.23±0.0004e | 2.04±0.0004c |
| ≥600 | 0.61±0.0006b | 14.92±0.0004c | 1.98±0.0004b |
| F Value | 8241.50 | 165248.99 | 5957.22 |
| Sig. Lev. | 0.000 | 0.000 | 0.000 |

**TABLE 4.** Results of variance analysis and Tukey test according to age groups for proline, total soluble protein, total amino acid, MDA and $H_2O_2$ contents.

| Age group | Proline ($\mu mol \cdot g^{-1}$) | Total Soluble Protein ($mg \cdot g^{-1}$) | Total Amino Acid ($\mu g \cdot g^{-1}$) | MDA ($\mu mol \cdot g^{-1}$) | $H_2O_2$ ($\mu mol \cdot g^{-1}$) |
|---|---|---|---|---|---|
| ≥25 | 56.22±0.02c | 11.52±0.10c | 29.81±0.05c | 15.97±0.13e | 80.77±0.19a |
| ≥50 | 50.69±0.20a | 8.41±0.16a | 20.69±0.03a | 6.86±0.20a | 92.58±0.24b |
| ≥100 | 60.82±0.04d | 15.12±0.06d | 32.38±0.10d | 9.84±0.16c | 131.58±0.19d |
| ≥200 | 69.32±0.11e | 21.18±0.10e | 40.22±0.05e | 12.05±0.16d | 161.53±0.22e |
| ≥600 | 53.86±0.03b | 10.16±0.10b | 27.03±0.02b | 7.78±0.15b | 110.86±0.34c |
| F Value | 52.371 | 2338.756 | 8257.961 | 53675.291 | 34087.214 |
| Sig. Lev. | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

**TABLE 5.** Results of variance analysis and Tukey test according to age groups for the amounts of APX, CAT and SOD activities.

| Age Group | APX | CAT | SOD |
|---|---|---|---|
| ≥25 | 0.271±0.001b | 0.164±0.002c | 48.49±0.23b |
| ≥50 | 0.284±0.001d | 0.168±0.001c | 56.53±0.08d |
| ≥100 | 0.289±0.001e | 0.133±0.002a | 51.26±0.13c |
| ≥200 | 0.276±0.001c | 0.266±0.002d | 39.28±0.19a |
| ≥600 | 0.258±0.002a | 0.154±0.003b | 55.5±0.19d |
| F Value | 26.531 | 2057.27 | 4358.07 |
| Sig. Lev. | 0.000 | 0.000 | 0.000 |

## DISCUSSION AND CONCLUSION

Chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids are photoreceptors functioning in photosynthesis. While chlorophyll *a* molecule plays an important role in the transmission of electrons, chlorophyll *a* and carotenoids are also effective in protecting the chloroplast membranes from getting photo oxidative damage as well as absorbing the light [33]. In the study, the highest chlorophyll *a* and the lowest chlorophyll *b* content were determined in the youngest oriental beech tree. Total chlorophyll was low in young trees, while it was high in middle-aged, old and very old trees. Total carotenoid did not demonstrate a significant change between trees (Table 1).

These results were in accordance with the results of the study conducted on the age-related changes in photosynthetic activity and the pigment content. The photosynthetic pigment content in herbal tissues varied according to parameters such as leaf anatomy, morphology and growth status, age, height and volume of the tree as well as light, drought and soil characteristics [34, 35]. The fact that the leaves of the tree older than 25 years have high chlorophyll *b* and total chlorophyll content and have low chlorophyll *a* content was associated with light conditions.

In fact, chlorophyll *b* content was high in plants growing in low light conditions or in shaded areas [36], while chlorophyll *a* content was decreasing; chlorophyll *a* and *b* molecules transformed to each other depending on the light conditions. $H_2O_2$ ratio increased in case the chlorophyll *b* content was high [37]. Contents of chlorophyll *b* and $H_2O_2$ in aged trees also confirmed this result (Table 1, 4). Since carotenoids, which protect the chloroplast membranes with their antioxidant characteristics, were more stable compounds compared to the chlorophyll molecule, they did not show a significant change among the trees [33].

Carbon is the most abundant element found in all living systems. Researchers reported that 45% of the plants' dry weight was made of carbon, and that the plants obtained carbon through photosynthesis and respiratory reactions [6]. Apart from photosynthesis-fixed carbon being added in the structure of primary and secondary metabolites, it is also stored in pools in order to be used in the future [38]. C accumulation in plant tissues is closely related to the balance between photosynthesis and respiratory rate [39]. The C content in beech trees of different ages did not show significant changes (Table 3). Glucose, total carbohydrate and starch contents are higher in trees older than 200 years, while sucrose content is higher in trees older than 600 years. Contrastingly, glucose, sucrose, total soluble carbohydrate and starch contents have at the lowest levels in the youngest beech trees (≥25) (Table 2). The fact that total carbon, total soluble carbohydrate and starch contents in beech trees of different age groups do not change significantly shows that the photosynthesis/respiration rate is equal during the day and that there is no problem in the distribution of assimilates and metabolites in trees [6].

Morphology, functions and biochemistry of cells, tissues and organs of the plants change during their developmental stages such as seedlings, juvenile, adult and senile stages [40]. Increase in tissue and organ deformation along with aging stimulates the accumulation of lipid peroxidation products such as MDA and ketonic compounds, and the ROS derivatives such as $H_2O_2$ and SOD anions in plant cells and tissues [41]. However, the plants can destroy these compounds, which reduce the cellular activity and stimulate oxidative stress in plants, by means of APX, CAT, peroxidases and enzymatic compounds such as SOD, carotenoids, phenolic compounds and non-enzymatic compounds such as proline [42]. Within the scope of this study, MDA concentration was found to be the highest in the youngest beech tree, whereas $H_2O_2$ concentration was low in young trees and high in middle-aged and mature trees (Table 4). Especially, the ≥100 years-old oriental beech tree has the highest $H_2O_2$ content. According to the results obtained, it was concluded that MDA and $H_2O_2$ concentrations of trees vary depending on genotype, environmental conditions, tree age and metabolic activities (Table 4). In the studies conducted, it was stated that MDA and $H_2O_2$ concentrations in plants increased during processes such as tissue and organ development, tracheal differentiation and senescence [43]. Deteriorations in the lipid structure and increase in the cell MDA and ROS derivatives were determined to be formed through leaf development [44], through the formation of tracheal elements in the leaf [45], and through aging of tissue and organs [46]. In this study, the changes in $H_2O_2$ concentration of oriental beech trees confirm this result. The fact that $H_2O_2$ content in trees older than 600 years decreases compared to trees older than 200 and 100 years was associated with the fact that young trees have larger leaf area compared to the old ones, and the fact that transmission bundle areas decrease with body deformations of the tree [45]. In addition, secondary cell walls activities in the old trees also work with $H_2O_2$ activity [46].

In this study, APX has the lowest activity in the oldest (≥600) beech trees, while CAT has the lowest activity in beech trees older than 100 years. SOD has the lowest activity in beech trees older than 200 years. In spite of this, APX activity is the highest in beech trees older than 100 years, CAT is the highest in trees older than 200 years and SOD in trees older than 50 years (Table 4). Not many studies of age-related enzyme changes could be found in the literature. However, the fact that morphological, physiological and biochemical changes in the developmental stages of the tree, especially age-related senescence events, stimulate the membrane functions and structure as well as the ROS production necessitate the synthesis of antioxidant compounds [10, 11]. As a matter of fact, high $H_2O_2$ damage in trees older than 200 years may be balanced with high CAT activities and with high APX activities in trees older than 200 years (Table 4) [47]. Both enzymes eliminate the impact of $H_2O_2$. In addition to this, high levels of SOD and APX activity in trees with low MDA content also refer to the inhibitory effects of these enzymes on lipid peroxidation [48].

Among the non-enzymatic compounds contributing in the elimination of ROS accumulation and lipid peroxidation damages, proline and total soluble proteins are particularly important [49]. In addition, phenolic compounds and flavonoids are also important non-enzymatic compounds affecting the growth and development of plants [50]. Besides, they play an important role in increasing tolerance to environmental changes through their functions such as cell wall activities, distribution of assimilates and osmotic regulation [51].

The highest proline, total soluble protein and total nitrogen contents of beech trees at different ages were detected in tree leaves older than 200 years. These compounds have the lowest values in beech trees older than 50 years (Table 5). The fact that proline and protein contents are the lowest in beech trees older than 50 and 600 years, where the nitrogen content is low, suggested that nitrogenous compounds were closely related to nitrogen available in tissues. The proline and protein contents in the tissues were related to the nitrogen pool [52].

As a matter of fact, this result arose due to the fact that the proline and protein values were the highest in oriental beech trees older than 200 years, which had also the highest N content. Furthermore, in a tree older than 100 years, where the total N content is the second highest, the aforementioned compounds are also the second highest (Table 3). In addition to this, the high content of chlorophyll pigments in these trees also indicates the adaptation to source/pool balancing [53]. Moreover, the high nitrogen content in trees older than 100 and 200 years may be a physiological response to the increase in hydrolytic resistance of these trees [54]. $H_2O_2$-stimulated proline synthesis stimulated the wall resistance, thus increasing tolerance to stress in plants [55].

Phenolic compounds are secondary metabolite derivatives which are involved in physiological processes such as being the compounds of cell wall elements, regulating the wall elasticity and plasticity, and ensuring resistance to photoprotectant and pathogen attacks against the UV light [56]. The content of total phenolic compound is the highest in the oldest and youngest oriental beech trees, while it is the lowest in a tree older than 200 years. The flavonoid content did not demonstrate significant changes among the trees, but the highest flavonoid content was detected in a tree older than 200 years (Table 5). Total phenolic compounds and flavonoid values indicate that there are no significant changes to cause stress in the environment where the oriental beech trees grow [50].

Amino acid, proline, H, glucose, sucrose and total soluble carbohydrate contents in trees older than 100 and 200 years indicate that the respiratory activities are high [57]. In trees older than 600 years, glucose and sucrose contents coincide with pigment values. This result indicates that photosynthetic activity is more associated with leaf characteristics rather than the tree age. Many researchers state that the photosynthetic activity of the leaf changes depending on the developmental status of the leaf, the leaf's position on the plant and its light-receiving capacity [53-58].

## REFERENCES


1. KROMER S 1995 Respiration during photosynthesis. *Ann Rev Plant Physiol Plant Mol Biol* 46: 45-70. DOI: https://doi.org/10.1146/annurev.pp.46.060195.000401
2. PEICHL M, ARAIN MA 2006 Above and below ground ecosystem biomass and carbon pools in an age-sequence of temperate pine plantation forests. *Ag Forest Meteorol* 140: 51-63. DOI: https://doi.org/10.1016/j.agrformet.2006.08.004
3. BOND BJ 2000 Age-related changes in photosynthesis of woody plants. *Trends Plant Sci* 5 (8): 349-353. DOI: https://doi.org/10.1016/S1360-1385(00)01691-5
4. LOUIS J, MEYER S, MAUNOURY-DANGER F, FRESNEAU C, MEUDEC E, CEROVIC ZG 2009 Seasonally changes in optically assessed epidermal phenolic compounds and chlorophyll contents in leaves of sessile oak (*Quercus petraea*): towards signatures of phenological stage. *Functional Plant Biology* 36: 732-741. DOI: https://doi.org/10.1071/FP09010
5. KRESLAVSKI VD, LOS DA, ALLAKHVERDIEV SI, KUZNETSOV V 2012 Signalling role of reactive oxygen species in plants under stress. *Russ J Plant Physiol* 59: 141-154. DOI: https://doi.org/10.1146/annurev-arplant-042817-040322
6. DELUCIA EH, DRAKE JE, THOMAS RB, GONZALEZ-MELER M 2007 Forest carbon use efficiency: is respiration a constant fraction of gross primary production? *Glob Change Biol* 13:1157-1167. DOI: https://doi.org/10.1111/j.1365-2486.2007.01365.x
7. POETHIG R 2013 Vegetative phase change and shoot maturation in plants. *Curr Top Dev Biol* 105: 125-152. DOI: https://doi.org/10.1016/B978-0-12-396968-2.00005-1
8. LIM OP, NAM GH 2007 Aging and senescence of the leaf organ. *J of Plant Biol* 50 (3): 291-300. DOI: https://doi.org/10.1007/BF03030657
9. RYAN MG, YODER BJ 1997 Hydraulic limits to tree height and tree growth. *BioScience* 47: 235-242. DOI: https://doi.org/10.2307/1313077

10. CASWELL H, SALGUERO-GÓMEZ R 2013 Age, stage and senescence in plants. *J Ecol* 101: 585-595. DOI: https://doi.org/10.1111/1365-2745.12088
11. THOMAS H 2013 Senescence, ageing and death of the whole plant. *New Phytol* 197: 696-711. DOI: https://doi.org/10.1111/nph.12047
12. BETTINGER P, CHUNG W 2004 The key literature of, and trends in, forest-level management planning in North America, 1950-2001. *Int For Rev* 6 (1): 40-50. DOI: https://doi.org/10.1505/ifor.6.1.40.32061
13. BURKHART HE 1995 Modelling forest growth. Encyclopedia of Environmental Biology, 2: 535-543. DOI: https://doi.org/10.1007/978-90-481-3170-9
14. ANONYMOUS 2006 Forest presence. Ministry of Environment and Forestry, General Directorate of Forestry, Ankara, Turkey, 152 p
15. TUNCTANER K, OZEL HB 2008 Regeneration problems of oriental beech (*Fagus orientalis* Lipsky.) forests in Western Black Sea Region. *Journal of Bartın Forestry Faculty* 10 (13): 57-65
16. ÖZEL HB 2007 Stand structures and the factors affecting the success of group natural regeneration practices in Bartın and Devrek Oriental beech (*Fagus orientalis* Lipsky.) forests. PhD Thesis, Zonguldak Karaelmas Üniversitesi, Fen Bilimleri Enstitüsü, Bartın, Turkey, 272 p
17. ODABAŞI T, BOZKUS HF, CALISKAN A 2004 Silviculture Technique. Istanbul University, Faculty of Forestry, IU Publication Nu: 4459, FF Publication Nu: 475, Istanbul, Turkey, 314 p
18. SUMANGALA HP, ASWATH C, LAXMAN RH, NAMRATHA MR 2018 Evaluation of air pollution tolerance index (ATPI) of selected ornamental tree species of Bengaluru, India. *Int J Pure App Biosci* 6 (3): 366-373. DOI: http://dx.doi.org/10.18782/2320-7051.6382
19. LICHTENTHALER H, WELLBURN AR 1985 Determinations of total carotenoids and chlorophylls a and b of leaf extracts in different solvents. *Biochem Soc T* 11 (5): 591-592. DOI: https://doi.org/10.1042/bst0110591
20. WITHAM, FH, DF BLAYDES, RM DEVLIN 1971 Experiments in plant physiology. Nostrand Reinhold Co., New York, USA, 245 p. URL: https://lib.ugent.be/catalog/rug01:001190680
21. ARNON DI 1949 Copper enzymes in isolated chloroplasts. Polyphenol oxidase in *Beta vulgaris*. *Plant Physiol* 24: 1-15. DOI: https://doi.org/10.1104/pp.24.1.1
22. LICHTENTHALLER HK 1987 Chlorophylls and carotenoids, pigments of photosynthetic biomembranes. *Method Enzym* 148: 350-382. DOI: https://doi.org/10.1016/0076-6879(87)48036-1
23. BATES L, WALDERN RP, TEARE ID 1973 Rapid determination of free proline for water-stress studies. *Plant Soil* 39: 205-207. DOI: https://doi.org/10.1007/BF00018060
24. BRADFORD MMA 1976 Rapid sensitive method for the quantitation of micro program quantities of protein utilizing the principle of protein-dye binding. *Anal Biochem* 72: 248-254. DOI: https://doi.org/10.1006/abio.1976.9999
25. LUTTS S, KINET JM, BOUHARMONT J 1996 NaCl-induced senescence in leaves of rice (*Oryza sativa* L.) cultivars differing in salinity resistance. *Ann Bot-London* 78: 389- 398. DOI: https://doi.org/10.1006/anbo.1996.0134
26. VELIKOVA V, YORDANOV I, EDRAVA A 2000 Oxidative stress and some antioxidant systems in acid rain-treated bean plants. *Plant Sci* 151: 59-66. DOI: https://doi.org/10.1016/S0168-9452(99)00197-1
27. PEARSON D, MELON H, RONALD S 1976 Chemical analysis of food. 8th edition, Churchill Livingstone, pp 5-63. DOI: https://doi.org/10.4236/jep.2014.513122 3,924
28. SINGLETON VL, ORTHOFER R, LAMUELA-RAVENTÓS RM 1999 Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. *Method Enzym* 299: 152-178. DOI: https://doi.org/10.1016/S0076-6879(99)99017-1
29. KUMARAN A, KARUNAKARAN RJ 2006 Antioxidant and free radical scavenging activity of an aqueous extract of *Coleus aromaticus*. *Food Chem* 97: 109-114. DOI: https://doi.org/10.1016/j.foodchem.2005.03.032
30. NAKANO Y, ASADA K 1981 Hydrogen peroxide is scavenged by ascorbate-spesific peroxidase in spinach chloroplasts. *Plant Cell Physiol* 22 (5): 867-880. DOI: https://doi.org/10.1093/oxfordjournals.pcp.a076232
31. BERGMEYER HU 1975 Methods of Enzymatic Analysis. Academic Press, New York, USA. DOI: https://doi.org/10.1002/star.19630150713
32. CAKMAK I, MARSCHNER H 1992 Magnesium deficiency and highlight intensity enhance activities of superoxide dismutase, ascorbate peroxidase and glutathione reductase in bean leaves. *Plant Physiol* 98: 1222-1226. DOI: https://doi.org/10.1104/pp.98.4.1222
33. ANDERSSON B, BARBER J 1996 Mechanisms of photodamage and protein degradation during photoinhibition of photosystem II. *In*: Baker NR (*eds*) Photosynthesis and the Environment. Advances in Photosynthesis and Respiration, vol 5. Springer, Dordrecht. DOI: https://doi.org/10.1007/0-306-48135-9_4
34. POORTER H, NIINEMETS U, POORTER L, WRIGHT IJ, VILLAR R 2009 Causes and on sequence of variation in leaf mass per area (LMA): a meta-analysis. *New Phytol* 182: 565-588. DOI: https://doi.org/10.1111/j.1469-8137.2009.02830.x
35. ENGLAND JR, ATTIWILL PM 2006 Changes in leaf morphology and anatomy with tree age and height in the broad leaved evergreen species, *Eucalyptus regnans* F. Muell. *Trees* 20: 79-90. DOI: https://doi.org/10.1007/s00468-005-0015-5
36. HORIE Y, ITO H, KUSABA M, TANAKA R, TANAKA A 2009 Participation of chlorophyll b reductase in the initial step of the degradation of light harvesting chlorophyll a/b-protein complexes in *Arabidopsis*. *J Biol Chem* 284: 17449-17456. DOI: https://doi.org/10.1074/jbc.M109.008912
37. SAKURABA Y, TANAKA A, YOKONO M, AKIMOTO S, TANAKA R 2010 Deregulated Chlorophyll b Synthesis Reduces the Energy Transfer Rate between Photosynthetic Pigments and Induces Photo damage in *Arabidopsis thaliana*. *Plant Cell Physiol* 51 (6): 1055-1065. DOI: https://doi.org/10.1093/pcp/pcq050
38. LEMOINE R, LACAMERA S, ATANASSOVA R, DÉDALDÉCHAMP F, ALLARIO T, POURTAU N, BONNEMAIN JL, LALOI M, COUTOS-THÉVENOT P, MAUROUSSET L, FAUCHER M, GIROUSSE C, LEMONNIER P, PARRILLA J, DURAND M 2013 Source-to-sink transport of sugar and regulation by environmental factors. *Front Plant Sci* 4 (272): 1-20. DOI: https://doi.org/10.3389/fpls.2013.00272
39. DAMESIN C 2003 Respiration and photosynthesis characteristics of current-year stems of *Fagus sylvatica*: from the seasonal pattern to an annual balance. *New Phytol* 158: 465-475. DOI: https://doi.org/10.1046/j.1469-8137.2003.00756.x
40. HACKETT WP 1985 Juvenility, maturation and rejuvenation in woody plants. *Hort Rev* 7: 109-155. DOI: https://doi.org/10.1002/9781118060735.ch3
41. KOUSSEVITZKY S, NOTT A, MOCKLER TC, HONG F, SACHETTO-MARTINS G, SURPIN M, LIM IJ, MITTLER R, CHORY J 2007 Signals from chloroplasts converge to regulate nuclear gene expression. *Science* 316: 715-719. DOI: https://doi.org/10.1126/science.1140516
42. SZABADOS L, SAVOURE A 2009 Proline: A multifunctional amino acid. *Trends Plant Sci* 2: 89-97. DOI: https://doi.org/10.1016/j.tplants.2009.11.009
43. STEFFENS B, KOVALEV A, GORB SN, SAUTER M 2012 Emerging roots alter epidermal cell fate through mechanical and reactive oxygen species signalling. *Plan Cell* 24 (8): 3296-3306. DOI: https://doi.org/10.1105/tpc.112.101790
44. SINHA N 1999 Leaf development in angiosperms. *Annu Rev Plant Physiol Plant Mol Biol* 50: 419-446. DOI: https://doi.org/10.1146/annurev.arplant.50.1.419

45. NELSON T, DENGLER N 1997 Leaf vascular pattern formation. *The Plant Cell* 9: 1121-1135. DOI: https://doi.org/10.1105/tpc.9.7.1121
46. KNOWLES NR, KNOWLES LO 1990 Changes in fatty acid composition of phospholipids from different ages of potato seed-tubers during sprouting. *Ann Bot* 65: 217-223. DOI: https://doi.org/10.1093/oxfordjournals.aob.a087927
47. DEHON L, MACHEIX JJ, DURAND M 2002 Involvement of peroxidases in the formation of the brown coloration of heartwood in *Juglans nigra*. *J Exp Bot* 53: 303-311. DOI: https://doi.org/10.1093/jexbot/53.367.303
48. FOYER CH, NOCTOR G 2005 Redox homeostasis and antioxidant signalling: a metabolic interface between stress perception and physiological responses. *Plant Cell* 17: 1866-1875. DOI: https://doi.org/10.1105/tpc.105.033589
49. MATTIOLI R, COSTANTINO P, TROVATO M 2009 Proline accumulation in plants-Not only stress. *Plant Sig Behav* 4 :1016-1018. DOI: https://doi.org/10.4161/psb.4.11.9797
50. HARBORNE JB 1980 In Secondary plant products. Encyclopaedia of Plant Physiology, Springer-Verlag, Berlin-Heidelberg, pp 329-402. DOI: https://doi.org/10.1371/journal.pone.0045345
51. BERNHARDT C, TIERNEY ML 2000 Expression of AtPRP3, a proline-rich structural cell wall protein from *Arabidopsis*, is regulated by cell-type-specific developmental pathways involved in root hair formation. *Plant Physiol* 122: 705-714. DOI: https://doi.org/10.1104/pp.122.3.705
52. MALAGUTI D, MILLARD P, WENDLER R, HEPBURN A, TAGLIAVINI M 2001 Translocation of amino acids in the xylem of apple (*Malus domestica* Borkh.) trees in spring as a consequence of both N remobilization and root uptake. *J Exp Bot* 52: 1665-1671. DOI: https://doi.org/10.1093/jxb/52.361.1665
53. NIINEMETS U 2007 Photosynthesis and resource distribution through plant canopies. *Plant Cell Environ* 30: 1052-1071. DOI: https://doi.org/10.1111/j.1365-3040.2007.01683.x
54. WOODRUFF DR, BOND BJ, MEINZER FC 2004 Does turgor limit growth in tall trees? *Plant Cell Envir* 27: 229-236. DOI: https://doi.org/10.1111/j.1365-3040.2003.01141.x
55. YANG SL, LAN SS, GONG M 2009 Hydrogen peroxide-induced proline and metabolic pathway of its accumulation in maize seedlings. *J Plant Physiol* 166: 1694-1699. DOI: https://doi.org/10.1016/j.jplph.2009.04.006
56. BENNET N, WALLSGROVE RM 1994 Secondary metabolism in plant defence mechanisms. *New Phytol* 127: 617-633. DOI: https://doi.org/10.1111/j.1469-8137.1994.tb02968.x
57. ROLLAND F, WINDERICKX J, THEVELEIN JM 2002 Glucose-sensing and -signalling mechanisms in yeast. *FEMS Yeast Res* 2: 183-201. DOI: https://doi.org/10.1128/EC.00028-08
58. LUSK CH, REICH PB 2000 Relationships of dark respiration with light environment and tissue nitrogen content in juveniles of 11 cold-temperate tree species. *Oecol* 123: 318-329. DOI: https://doi.org/10.1007/s004420051018

SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

ORIGINAL SCIENTIFIC PAPER

DOI: https://doi.org/10.15177/seefor.19-17

# Modelling Bark Thickness of Norway Spruce (*Picea abies* Karst)

**Jusuf Musić[1], Ahmet Lojo[1], Besim Balić[1], Aida Ibrahimspahić[1*], Admir Avdagić[1], Jelena Knežević[1], Velid Halilović[1]**

**(1)** University of Sarajevo, Faculty of Forestry, Zagrebačka 20, BA-71000 Sarajevo, Bosnia and Herzegovina

* **Correspondence:** e-mail: a.ibrahimspahic@sfsa.unsa.ba

**Citation:** MUSIĆ J, LOJO A, BALIĆ B, IBRAHIMSPAHIĆ A, AVDAGIĆ A, KNEŽEVIĆ J, HALILOVIĆ V 2019 Modelling Bark Thickness of Norway Spruce (*Picea abies* Karst). *South-east Eur for* 10 (2): 125-135. DOI: https://doi.org/10.15177/seefor.19-17

**Received:** 4 May 2019; **Revised:** 6 Sep 2019; **Accepted:** 11 Sep 2019; **Published online:** 3 Nov 2019

## ABSTRACT

**Background and Purpose:** Bark thickness and its share in the volume of roundwood are the most important characteristics of the bark, particularly in the process of timber harvesting, and during scaling of processed logs. Therefore it is very important to have at disposal relatively accurate data regarding these characteristics of bark for particular tree species. The main goal of this paper is to investigate the thickness of the bark and its share in the volume of roundwood of Norway spruce.

**Materials and Methods:** The research was carried out in the area of the Canton 10 of the Federation of Bosnia and Herzegovina and it encompassed 393 trees of Norway spruce from 10 cm to 115 cm of thickness at breast height. Measuring of the mean diameter and double thickness of bark was conducted by section method. In total, 4,647 diameters and bark thicknesses were measured in different relative lengths of stems or in average 10.6 measurements per one stem.

**Results:** As an optimal model for the evaluation of double thickness of the bark of Norway spruce depending on mean diameter of roundwood the function with designated determination coefficient of 0.7142 was selected.

The obtained results have confirmed the previously defined relations of investigate characteristics, which are as following: a) with the increase of mean diameter of roundwood (section) double bark thickness is increased from 9.26 mm (thickness class 12.5 cm) to 31.65 mm (thickness class 92.5 cm); b) with the increase of mean diameter of roundwood the share of bark in its volume decreased from 14.26% (thickness class 12.5 cm) to 6.73% (thickness class 92.5 cm).

**Conclusions:** By the actual method of estimating bark thickness or the share of bark in the volume of roundwood of Norway spruce in the forestry of the Federation of Bosnia and Herzegovina a significant error was created which increases with the increase of mean diameter. The obtained results point to the necessity of investigation of these bark characteristics in Bosnia and Herzegovina and represent an inevitable starting point for making adequate tables of bark thickness and its percentage share in the volume of roundwood of Norway spruce.

**Keywords:** bark thickness, bark share, mean diameter, roundwood, relative length

## INTRODUCTION

Bark is the layer of tree consisted of an external and internal part. External bark (lub) consists of the dead protection layer of the bark, and it spreads from internal bark to the peripheral layer of the tree. Internal bark (floem) includes the living part of the bark which performs physiological and protection functions, and spreads from cambial ring to the internal zone of dead bark. The importance of bark as the external layer of the trunk consists of several important aspects: (1) it provides protection for trunk growth, (2) it can be used as the source of energy or in production of special products (malch, tannin, dye, pharmaceutical products, etc.), and (3) it has impact on the realized income since technical roundwood is, as standard, delivered and sold based on volume without bark. Therefore, knowledge regarding bark thickness and the possibility of most accurate assessment of its share in the trunk and timber assortments is extremely important in the present wood trade. Inaccurate assessments may, for the forest owner, result in loss of value even up to 11% [1]. Studies on bark thickness and its percentage share in the volume of the trunk or roundwood were conducted for the needs of forest management and exploitation, and, among other things, were inspired by the progress of the commercial importance of bark from unwanted residue to important fuel and a source of bio-material of high value [2].

First studies on bark thickness and bark volume were conducted by Flurry in Switzerland at the end of the 19th century. The goal was to identify factors for the conversion of the volume of the trunk with bark into volume without bark, and it represented the beginning of some still accurate studies of bark of different tree species in many parts of the world [3]. Previous studies were mainly focused on the assessment of bark thickness at the breast height [4-6] since total volume of the trunk bark can be calculated approximately based on its thickness at breast height. However, recently researchers have more dealt with the impact of other factors on the thicknes of the bark, such as relative height of the trunk, quality of the habitat, altitude above the sea level, age, etc. [7-12].

The first comprehensive studies were conducted by Altherr *et al.* [13] in Baden-Württemberg. The sample covered a surface of 35.752 km$^2$ and a very wide scope of habitat and stand conditions. Data collected from 7.712 trees resulted in identification of functional dependence of bark thickness (mm) and percentage share of bark (%) in the trunk volume for 33 tree species. Implementation of these results is recommended by Pollanschütz for Austria as well [14]. However, for the region of Tyrol, Kirschner made tables for bark thickness and its share for main tree species in Tyrol, while Güde made tables for thickness and its share of bark of spruce which can be implemented in Forstdirektion Mayr-Melnhof Frohnleiten [14].

In the area of former Yugoslavia, research on bark thickness was first conducted on deciduous tree species [4, 5, 15]. Namely, regulations on methods of measuring and identification of quantities, and regulations on methods of delivering roundwood of deciduous species have caused reasonable and justified interest for the most accurate identification of bark thickness and the percentage share in the volume of the trunk or roundwood. Studies on coniferous trees' bark were mainly devoted to fir [16, 17]. Bark thicknes of spruce was researched in Slovenia by Turk and Lipoglavšek [18], and also by Rebula [19]. Rebula [19] obtained slightly larger values of bark thickness than Turk and Lipoglavšek [18], noting that the results should be checked by a larger sample and in locations where spruce is a more significant tree species (Alpine area). Also, Rebula [19] stated that the bark of spruce in Slovenia is thinner for 1-2 mm compared to Upper Schwabia (Germany), and that these differences are particularly expressed in thicker trees in upper parts of the trunk.

By analyzing different sources of losses in volume for roundwood of spruce due to the prescribed method of measuring in Croatia, Poršinsky and Vujeva [20] identified the deduction of double thickness of bark (from 16.9 vol. % to 5.8 vol. %) to be the source of highest loss.

For numerous coniferous species it was identified that bark thickness can be well described by the following variables: diameter with bark, total height of the trunk and measuring height [21]. For spruce it was identified that bark thickness depends on diameter with bark and relative height of the trunk, and that it is also conditioned by the age of the tree, its height and shape [9].

All studies so far have identified some generally accepted facts [22]:

- bark thickness is directly proportional to diameter of the trunk or roundwood,
- bark thickness decreases from the stump towards the top of the trunk,
- bark thickness increases with the thickness of roundwood, and its relative share in the volume decreases.

Assortment tables which are used in Bosnia and Herzegovina for the most important tree species, apart from numerous wood assortments, also contain the category "waste". From practical point of view this category can be divided to real waste and losses. Real waste in that sense consists of several unprocessed parts of large wood and sawdust, while losses are made due to prescribed methods of measuring of dimensions and identification of quantities and deducted double thickness of bark. According to the above-mentioned, it is extremely important for forest enterprises that such losses are as low as possible, or that they have at disposal the most accurate data on bark thickness of particular tree species. Evident differences in thickness of spruce bark between particular countries, even between different regions in the same country, which were identified by some authors, impose the need to research this characteristic in Bosnia and Herzegovina as well. In Sweden, for example, according to the instructions of Timber Measurement Council [23], it is recommended to use of as many as 11 different functions for the calculation of bark thickness for spruce, depending on geographical origin of the tree. This was one of the crucial motives for this research.

## MATERIALS AND METHODS

Spruce (*Picea abies* Karst) is, from the economic and ecological aspect, one of the most important coniferous tree species in Europe. In optimal conditions it can reach the height of over 40 m and diameter of over 1 m. The bark is relatively thin and greyish. At the beginning, on young branches and young trunk the bark is smooth, and later on older trees it peels and falls off in the form of round scales and is coloured dark-reddish. Large area (Figure 1) has caused the occurrence of numerous forms variable per habitat, including branch forming, needles and cones [24]. Spruce wood is valuable construction timber, and it is also used for the production of premium veneers, different types of wood plates, in the production of cellulose, paper and other. It is also popular as a Christmas tree, and especially valuable is as resonance spruce wood for making musical instruments.

Spruce is one of the most significant forest tree species in Bosnia and Herzegovina. According to the preliminary results of the Second National Forest Inventory in Bosnia and Herzegovina, the total surface of available high forests of production character where spruce is grown amounts to 589,700 ha, where its share in the total wood stock is 16.1%. This makes it the third most important tree species in our forests (after beech and fir).

The present research was conducted in the area of Canton 10 (Figure 2), and it was financed by the Federal Ministry of Education and Science within the project "Making of bark thickness tables for fir, spruce and beech".

For the purpose of objective research on impacts of different factors on which bark thickness depends only normaly formed trees were selected for the sample, or the trees without visible deformations on the trunk. On every trunk several diameters were measured, starting from the stump to the top. Distance of the diameter from the stump was expressed in relative units from total height of the trunk, or the length of the cut trunk.

In every place on the trunk (section) the following were measured:

- mean diameter outside the bark (in the middle of the section) in centimeters with accuracy down to millimeter and crossed (biggest and smallest),
- bark thickness down to millimeter accuracy, on points where diameter measuring device touches the trunk (two measurements).

During the measuring of the bark the so-called notch was made vertically to the trunk on the wood, so that bark thickness can be clearly seen and precisely measured (Figure 3). The measuring itself was performed by movable measuring device (vernier calipers). Namely, measuring by Swedish bark gauge in general overestimates its thickness since during the measurement it partially penetrates into wood, while it is also sensitive to the season of sampling

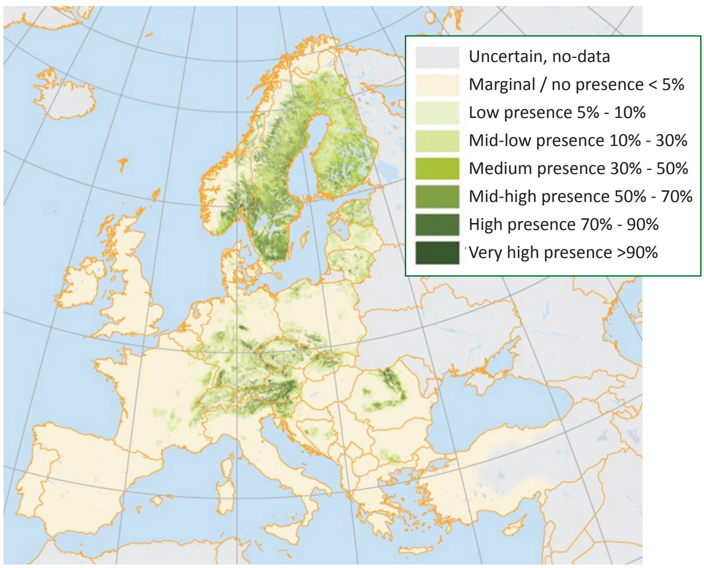


**FIGURE 1.** Distribution map of Norway spruce (*Picea abies*) in Europe with estimation of the relative probability of presence [25].

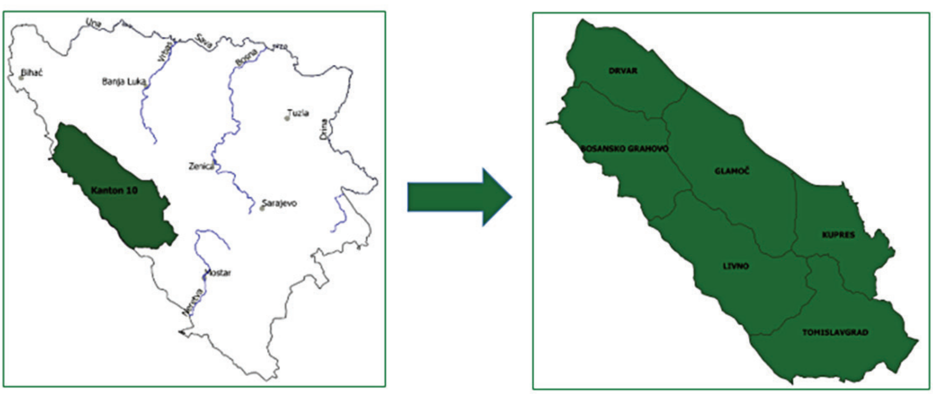


**FIGURE 2.** Research area – Canton 10 of the Federation of Bosnia and Herzegovina.

[26]. Along with that, it is severely dependent on subjective feeling of the measuring technician [27] since it requires huge skill for such method of determination of bark thickness in order to be able to recognize the moment when the blade is starting to penetrate into wood [11]. Due to these reasons, which were confirmed in our trial work with this instrument, it was decided that the measurement shall be done in the described way.

Despite the importance of certain parameters, such as the method of measuring bark thickness, sample size and its distribution on the researched area, these parameters were not given adequate attention in previous literature as well [28]. Husch *et al.* [29] as a general rule mentioned that for the determination of factors of bark at the breast height it is necessary to provide a sample of 20 to 50 trees. Studies which research models of conical characteristics, which may include measurements of the diameter with or without bark are extremely variable. Kozak [30], for example, has analyzed the sample of over 100,000 trees and 16 tree species, while Jiang *et al.* [31] have covered by analysis only 18 trees of one tree species. It is of critical importance that the sample should cover variations of bark thickness in the research area with lowest possible costs [28].

**FIGURE 3.** Notch on the stem.

The sample of this research consisted of 393 spruce trees on which 4,647 diameters and bark thicknesses were measured, or in average 11.8 measurements per one tree. In the sample trees of different sizes were selected, from 10 to 115 cm of thickness at breast height (1.30 m) and of different quality classes, according to silvicultural and technical classification [32, 33]. Trees in the area were selected in a way that their number in the sample was proportional to the total surface of forests of this tree species in Canton 10 per particular municipalities. After measuring, logical analysis of the collected data was conducted. One part of the collected data was excluded from further processing due to illogically small or large value, or in cases when measurement was not completed (some data were missing).

To express dependence of bark thickness on influential factors the method of simple and multiple regression analysis was implemented by Generalized linear models (GLM) method. The result of GLM analysis is a complex regression equation which contains parameters with particular category variables or cases within category variables. In the processing of data and interpretation of results statistical program STATGRAPHICS Centurion XVII was used.

For the calculation of percentage share of bark in the volume of the section (part of the trunk) Mayer [34] template was used. Mayer presumed that the form factor of trunks with bark is equal to form factor of trunks without bark. Based on that assumption he made the following equation for the calculation of percentage share of bark:

$$p_k = \left(1 - \frac{d^2}{D^2}\right) \cdot 100\ [\%]$$

where $p_k$ is the share of bark in the volume of the section of the trunk; d is the diameter inside Bark, and D is the diameter outside bark.

## RESULTS AND DISCUSSION

### Bark Thickness

According to the results of conducted studies on factors which have impact on bark thickness it was presumed that bark thickness, apart from the diameter of roundwood, depends also on the point of measuring on the trunk, or on distance from the stump towards its top. This hypothesis was checked by statistical analysis of data by using GLM analysis. In the analysis the dependent variable was the double thickness of bark ($D_{bark}$ in milimeters), while as independent variables the following were taken:

- mean diameter of the section (part of the trunk) – Dm section (cm) as continuous variable, and
- relative distance of diameter of the section from the stump – $PART_{trunk}$ as a category variable.

Each trunk was divided in 5 sections of equal relative lengths ($PART_{trunk}$). The first section (1) included the lower fifth of the total length of the trunk (from stump), the second section (2) included the next fifth, etc. The fifth section (5) included the upper fifth of the length of the trunk (the thinnest).

First, by statistical analysis the normality of independent variable ($D_m$ section) by potential transformations [35] was checked. It was identified that the distribution of original data deviates from normal, and therefore for its optimal transformation the exponent of 0.256 was designated (Figure 4).

The same procedure was conducted also for the dependent variable. It was identified that for achieving approximately normal distribution the value of double thickness of bark ($D_{bark}$) also has to implement potential transformation, with the exponent of 0.4026 (Figure 5).

After conducted transformations the following regression model with coefficient of multiple determination of 0.7631 was identified:

$$BoxCox(D_{bark})=-17.317-1.782\cdot I1(1)-1.98071\cdot I1(2)-0.952788\cdot I1(3)+1.08855\cdot I1(4)+18.605\cdot Dmsection^{0.256}$$

where:

$$BoxCox\,(D_{bark})=\frac{D_{bark}^{\,0.402646}-1}{0.40264\cdot 14.9581^{0.597354}}$$

I1(1) = 1 if $PART_{trunk}$ = 1, -1 if $PART_{trunk}$ = 5,0 in other case;
I1(2) = 1 if $PART_{trunk}$ = 2, -1 if $PART_{trunk}$ = 5,0 in other case;
I1(3) = 1 if $PART_{trunk}$ = 3, -1 if $PART_{trunk}$ = 5,0 in other case;
I1(4) = 1 if $PART_{trunk}$ = 4, -1 if $PART_{trunk}$ = 5,0 in other case.

Table 1 shows the variance of the model (explained part of varying) of residual deviation (error of the model) and total variance of data on bark thickness. According to the factor F - the relation of the middle of the square in explained and unexplained part of varying (variances) it can be concluded that the selected independent variables

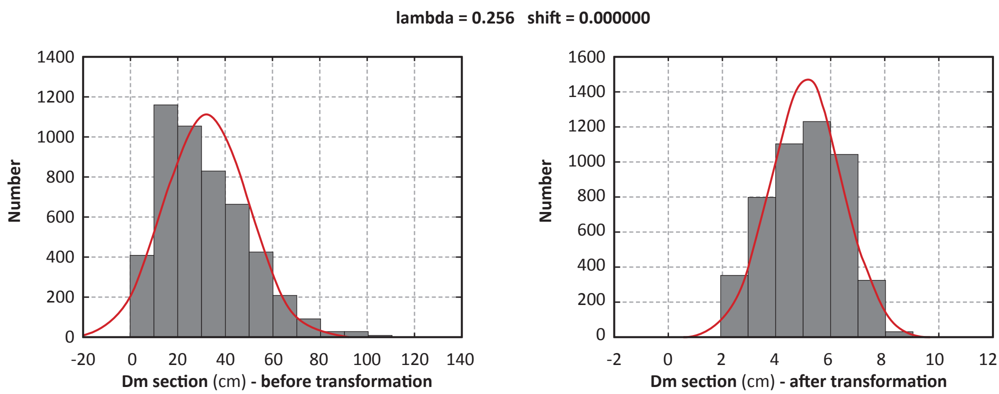


**FIGURE 4.** Distribution of data for independent variable before and after transformation.

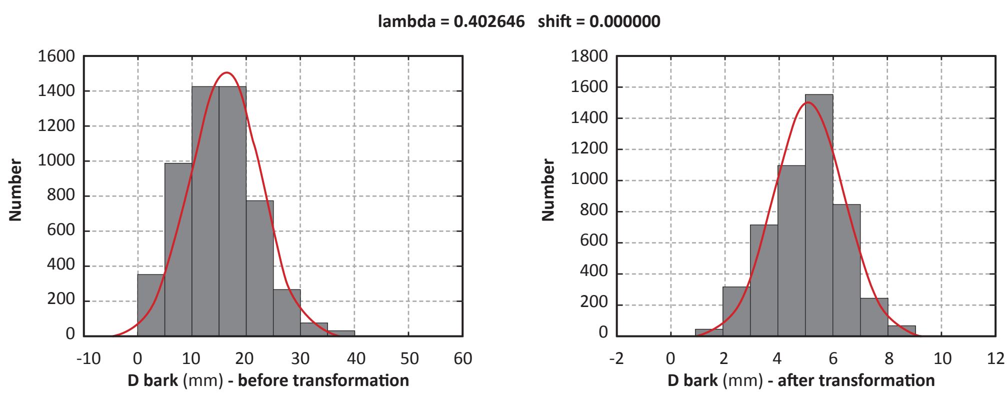


**FIGURE 5.** Distribution of data for dependent variable before and after transformation.

have statistically high impact on the change of the value of dependent variable. According to the identified value of F-test, which is larger than critical according to F-distribution (Fisher-Snedecor distribution), and p-value, which is smaller than 0.05, the difference between variances is, with usual safety of conclusion of 95%, statistically important [36, 37].

Based on the results of the analysis of the source of varying and *F*-relation of variances presented in Table 2 it can be concluded that the highest impact on bark thickness has the diameter of the section of the trunk ($D_m$ section), which was expected. Also, it can be concluded also that the variable $PART_{trunk}$ (part of the trunk) has very high impact on bark thickness. That means that bark thickness at the same diameter of the section (part of the trunk) on different relative heights of the trunk is not equal.

Figure 6 shows mean thicknesses of bark for different parts of the trunk and lowest significant differences (LSD intervals) at the probability of 95%. It is visible that bark thickness is increasing from bottom towards the top of the trunk (further from the stump). That means that pieces of wood of the same diameter have thicker bark if they are closer to the top of the trunk. An exception from that rule is the first section (1) which has slightly thicker bark than the next section (2), but that difference is not significant. It can be more clearly seen from data in Table 3.

Identified impact of the variable $PART_{trunk}$ on bark thickness is very interesting, but in principle logical. In available literature this impact was researched only by Bojanin [15] for ash, but he did not identify significant difference. The results found by this research were caused primarily by laws of thickness increment of the trunk and characteristics of the spruce bark. Namely, thickness increment along the trunk of trees is different from increment at breast height. Thickness increment is the smallest at certain height of the trunk, below or above the breast height. Height of the smallest thickness increment depends on age, or thickness of the trunk and quality of the conditions of the habitat. Towards the top and towards the foot of the tree from that place (height) thickness increment increases, and it is the biggest at the top of the trunk [38]. The fact that the increase of thickness

**TABLE 1.** The analysis of variance for the thickness of bark ($D_{bark}$) of the regression model.

| Source of variability | Sum of squares | Deg. of freedom | Variance | F-ratio | "P" probability |
|---|---|---|---|---|---|
| Model | 137066 | 5 | 27413.3 | 2960.43 | 0.0000 |
| Residual | 42975.1 | 4641 | 9.25989 | | |
| Total (Corr.) | 180042 | 4646 | | | |

**TABLE 2.** GLM analysis of the influence of independent variables on the dependent variable in the regression model.

| Source of variability | Sum of squares | Deg. of freedom | Variance | F-ratio | "P" probability |
|---|---|---|---|---|---|
| $PART_{trunk}$ | 8469.63 | 4 | 2117.41 | 228.66 | 0.0000 |
| $D_m$ section$^{0.256}$ | 107763 | 1 | 107763 | 11637.56 | 0.0000 |
| Residual | 42975.1 | 4641 | 9.25989 | | |
| Total (Corr.) | 180042 | 4646 | | | |

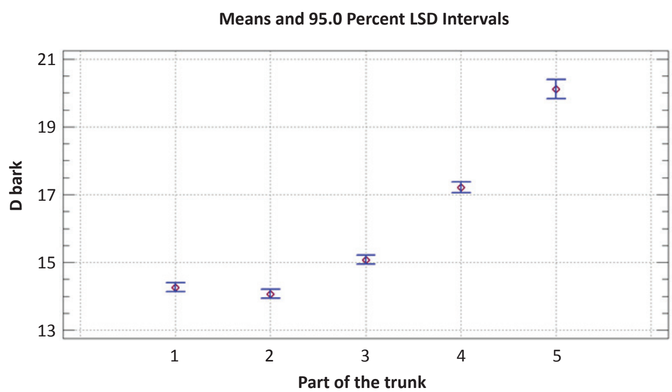


**FIGURE 6.** Average values of bark thickness and Fisher LSD interval of particular sections of the same diameter at the point of measuring.

**TABLE 3.** Average bark thickness of particular sections of the same diameter at the point of measuring, lowest significant difference (LSD Fisher test) and formed homogeneous groups with the probability of 95%.

| Part of the trunk | Count | LS Mean | LS Sigma | Homogeneous Groups | | | |
|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 |
| 2 | 1033 | 14.0662 | 0.097412 | X | | | |
| 1 | 1159 | 14.2585 | 0.098931 | X | | | |
| 3 | 1038 | 15.0780 | 0.094452 | | X | | |
| 4 | 1000 | 17.2131 | 0.103564 | | | X | |
| 5 | 417 | 20.1072 | 0.169758 | | | | X |

increment is also followed by the increase of bark thickness is in favor of the obtained results. Additionally, spruce bark on older trees or older parts of trees is peeling and falling off, which also results in smaller thickness.

The identified mathematical model, unfortunately, has only scientific significance and is not applicable in practice. Namely, when it comes to practical implementation of this model for the assessment of bark thickness (in measuring sizes and delivering roundwood from stock yard) most often it is unknown from which part of the trunk particular pieces are taken. Therefore, the identified model is currently not applicable in operational work withouth changes in rules and regulations for identification and marking of roundwood.

Therefore the model for the assessment of double thickness of bark was created based on only one independent variable - diameter of the part of the trunk with bark ($D_m$ section), which in forestry practice of Bosnia and Herzegovina, with length measuring , is used as the basis for the identification of the volume of roundwood. As in the previously described procedure, the independent variable ($D_m$ section) was used in its transformed form. For identification of optimal model of the assessment of double bark thickness depending on diameter of the section of the trunk (with bark) in the same statistical program several regression models were checked. As an optimal model, which is obtained with the transformation of dependent variable per BoxCox procedure, the following linear function was selected:

$$BoxCox(D_{bark}) = -10.7807+15.4065 \cdot Dm\ section^{0.256}$$

where:

$$BoxCox(D_{bark}) = \frac{D_{bark}^{0.422} - 1}{0.40264 \cdot 14.9581^{0.578}}$$

The unique mathematical expression of the model is:

$$D_{bark}=[(1.3612 \cdot Dm^{0.256})-0.0441]^{2.3697}$$

Coefficient of correlation for this model is R=0.8451, or the coefficient of determination $R^2$=0.7142. According to this, by not including the impact factor $PART_{trunk}$ about 5% of explanation of variability of bark thickness was lost. The values of statistical indicators of significance (*t*-values), free member and parameter with independent variable, which are much higher than the critical size and *p*-value, which is much smaller than 0.05 of high statistical significance of parameters of the model were identified (Table 4).

Based on the selected model the assessed values for each input data for thickness of the section were calculated. After that real deviations (residuals) were calculated, and based on it the standard deviation of the model (SD=3.22 mm) and standard error of estimate (SEE=0.036 mm) were calculated. The relation of real values of bark thickness ($D_{bark}$) and assessed bark thickness per this regression model is presented in Figure 7.

**TABLE 4.** Parameters of the double bark thickness estimation function and their statistical indicators.

| Parameter | Estimate | Standard Error | t-Statistic | P-value |
|---|---|---|---|---|
| Intercept | -10.7807 | 0.341968 | -31.5254 | 0.0000 |
| Slope | 15.4065 | 0.142989 | 107.746 | 0.0000 |

**TABLE 5.** Variance analysis.

| Source of variability | Sum of squares | Deg. of freedom | Mean Square | F-ratio | P-value |
|---|---|---|---|---|---|
| Model | 128554 | 1 | 128554 | 11609.16 | 0.0000 |
| Residual | 51436.4 | 4645 | 11.0735 | | |
| Total (Corr.) | 179990 | 4646 | | | |

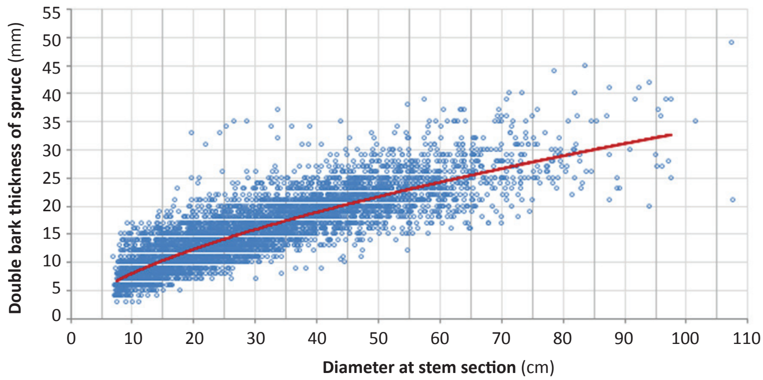


**FIGURE 7.** Double bark thickness of spruce depending on diameter at stem section.

Analysis of residuals shows that there is no systematic deviation of it in any part of the domain of empirical data (Figure 8).

By modeling the thickness of spruce bark in Germany, with similar goal to the goal in this paper, Stängle *et al.* [39] have used in the analysis three independent variables (diameter at breast height, relative height and diameter of the section) and obtained the model with determination coefficient of 0.76.To show the dependence of spruce bark thickness on diameter of the section (log) in Slovenia, Rebula [19] identified linear dependence with determination coefficient of 0.65. By modeling bark thickness in even-aged spruce stands depending on diameter at breast height Laasasenaho *et al.* [9] obtained determination coefficient of 0.66. Apart from the diameter, they also used the height and age of the tree (in logarithmic form), so determination coefficient increased to 0.77. In the analysis of fir bark thickness depending on diameter at breast height, Božić *et al.* [10] used variables in logarithmic form and obtained adjusted determination coefficient of 0.67%. By introducing additional variables (height, age, altitude above the sea level) the same authors identified a model with slightly larger determination coefficient of 0.7037. By studying fir bark thickness depending on mean diameter of the section Lojo *et al.* [12] obtained for the selected optimal model of levelling determination a coefficient of 0.758. Prka [8] obtained by modeling beech bark thickness depending on mean diameter of the piece (section) models with determination coefficient from 0.355 to 0.783, depending on the type of felling, or 0.65 for all felling together.

Based on conducted comparations with results of other authors who dealt with modeling of connection between bark thickness and diameter, it can be concluded that the selected model in this research is very good, and that its statistical parameters and assessed values of double bark thickness depending on mean diameter of the section, presented in Table 6, are very reliable.

## Bark Share in the Volume of Roundwood

Bark share in the volume of the trunk or part of the trunk is also a value usable in forestry practice, since, among other things, one of the standardized ways of the reduction of volume with bark is implementation of adequate tables of the percentage of bark share in the volume. Therefore in this paper the percentage of spruce bark share in the volume of the section was calculated depending on mean diameter outside bark by using Mayer formula (Table 6). Diameters inside bark were obtained by deduction of double thickness of bark calculated by the identified mathematical model.

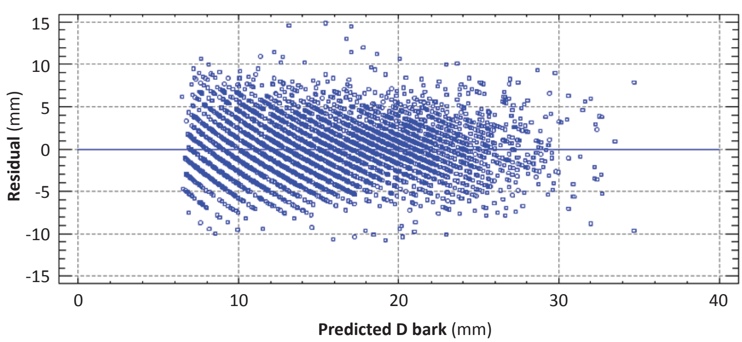


**FIGURE 8.** Residual deviations from the double bark thickness estimation model.

Data show a decrease of percentage of bark share with the increase of mean diameter, while the same relation was identified also by other authors who studied this characteristic [11, 12, 15, 17, 19]. The first reason for this relation is the fact that the increment of wood mass is higher than the increment of bark, and that the trunks (logs) of larger diameters have in percentage lower share of bark in the volume compared to thinner trunks [8].

**TABLE 6.** Double bark thickness and the share of spruce bark depending on mean diameter of the section.

| **Mean diameter of the section** (cm) | **Double bark thickness** (mm) | **Share of bark in section volume** (%) |
|---|---|---|
| 12.5 | 9.26 | 14.26 |
| 17.5 | 11.39 | 12.59 |
| 22.5 | 13.29 | 11.47 |
| 27.5 | 15.04 | 10.64 |
| 32.5 | 16.66 | 9.99 |
| 37.5 | 18.20 | 9.47 |
| 42.5 | 19.65 | 9.03 |
| 47.5 | 21.04 | 8.66 |
| 52.5 | 22.37 | 8.34 |
| 57.5 | 23.65 | 8.06 |
| 62.5 | 24.89 | 7.81 |
| 67.5 | 26.09 | 7.58 |
| 72.5 | 27.26 | 7.38 |
| 77.5 | 28.40 | 7.19 |
| 82.5 | 29.51 | 7.03 |
| 87.5 | 30.59 | 6.87 |
| 92.5 | 31.65 | 6.73 |

By analyzing the results presented in Table 6 it can be seen that they are logical and that they cofirm previously established relations regarding the observed characteristics. In order to see the whole picture, the results of this paper were compared with the results of other authors. Figure 9 shows a comparative presentation of double bark thickness of spruce depending on mean diameters of the section for roundwood.

The highest values of spruce bark thickness were identified by Kirschner [14], and the lowest by Rebula [19]. Rebula [19] emphasized that his sample was too small (186 sections) and that it is not sufficient for identification of certain laws, while the results of Kirchner [14] are very indicative because this author within his research obtained thicker bark for spruce compared to fir, which is a unique case. The results of this research to a large extent correlate with the results of Altherr *et al.* [13] and Güde [14], noting that by these studies slightly higher bark thickness in lower and lower thickness in higher thickness classes were obtained as compared to the mentioned authors.

Regarding the percentage of bark share in the volume of the part of the trunk (section), as it has already been emphasized, it decreases with the increase of mean diameter. A comparative presentation of the obtained values by the author who researched this characteristic is given in Figure 10. It is important to mention that, having in mind the method of calculation of the percentage of bark share (Mayer formula), the results are as accurate as the accuracy of assessed bark thickness.

Reduction of the percentage of bark share with the increase of mean diameter of the section of roundwood is visible in the results of all analyzed authors, but it is most emphasized in Kirschner [14], who obtained the highest values of this characteristic. Values obtained in this research are in the same relation with the results by Altherr *et al.* [13] and Güde [14] for bark thickness as well (as it has been previously described).

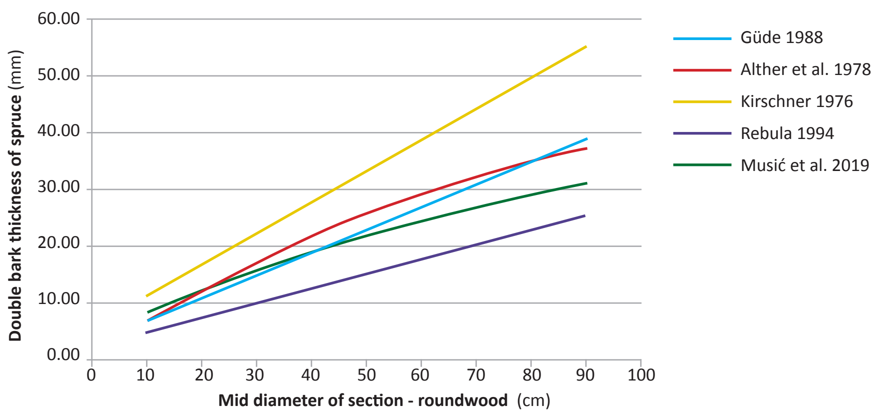


**FIGURE 9.** Comparasion of double bark thicknesses with results of other authors.

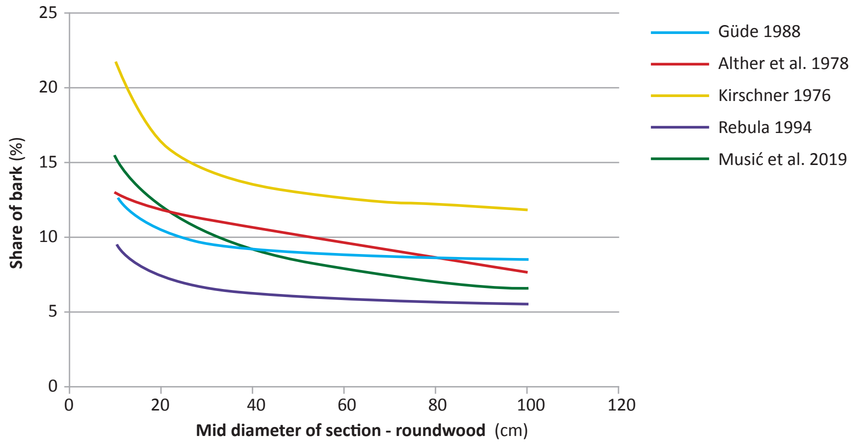


**FIGURE 10.** Comparasion of the share of bark in the volume of roundwood with results of other authors.

The conducted studies on thickness and the percentage share of spruce bark per its scope of the sample size have been the most comprehensive so far in scientific work in Bosnia and Herzegovina. The obtained results clearly point to all lacks of the usual practice of deduction of bark in operational forestry of the Federation of Bosnia and Herzegovina. Namely, in forestry practice there are no rules or tables for the deduction of bark based on adequate scientific or expert research, but it has been, unfortunately, based on lump assessments and/or alleged experience of empolyees duing measuring and delivery. Such method of deduction of bark has multiple negative effects on business operations of forest enterprises, and it also puts certain buyers in a more favorable position than others and vice versa [12].

## CONCLUSIONS

Based on the obtained results of the conducted research and discussion the following important conclusions can be drawn:

- The highest impact on bark thickness has the diameter of the section of the trunk ($D_m$ section). Also, the variable $PART_{trunk}$ (part of the trunk) has very high impact on bark thickness, and, respectively, bark thickness at the same diameter of the section (part of the trunk) on different relative heights of the trunk is not equal.
- The obtained results on spruce bark thickness and its percentage share in the volume of the part of the trunk depending on mean diameter confirm the previously established relations, and evident differences point to the need to research these characteristics in Bosnia and Herzegovina.
- Bark thickness of spruce increases with the increase of mean diameter of roundwood (section) from 9.26 mm (thickness class 10-15 cm) to 33.65 mm (thickness class 90-95 cm). Determination coefficient of 71.42% and standard error of estimation of 0.036 mm of the selected model show that the estimated values of bark thickness are very reliable.
- Percentage share of bark in the volume of roundwood (section) of spruce decreases with the increase of mean diameter of 14.26% (thickness class 10-15 cm) to 6.73% (thickness class 90-95 cm).
- By actual method of estimating bark thickness or the share of volume of bark in the volume of roundwood of spruce a significant error is created which increases with the increase of mean diameter.
- In forestry as a branch of economy which belongs to the category of so-called mass-production the law of large numbers is present where on multi-million exampes huge losses can appear due to inappropriately prescribed method of measuring dimensions of roundwood including the deduction of double thickness of bark. Therefore it is very important that the measurements or estimations of bark thickness are conducted with as high accuracy and reliability as possible. Related to that, the obtained results represent an inevitable starting point for making adequate tables for bark thickness and its percentage share in the volume of roundwood of spruce.


## Acknowledgements

The research was financed by the Ministry of Education and Science of the Federation of Bosnia and Herzegovina and on this occasion we sincerely express our gratitude to them. The authors are grateful to all employees of FMC "Hercegbosanske šume" Ltd. Kupres for unselfish assistance during the measuring of trees and the collecting of necessary data.

## REFERENCES


1. MARSHALL HD, MURPHY GE, LACHENBRUCH B 2006 Effects of bark thickness estimates on optimal log merchandising. *For Prod J* 56 (11/12): 87-92
2. DORUSKA PF, PATTERSON D, HARTLEY J, HURD M, HART T 2009 Newer technologies and bioenergy bring focus back to bark factor equations. *J For* 107 (1): 38-43. DOI: https://doi.org/10.1093/jof/107.1.38
3. STÄNGLE SM, SAUTER UH, DORMANN CF 2017 Comparison of models for estimating bark thickness of *Picea abies* in southwest Germany: the role of tree, stand, and environmental factors. *Ann For Sci* 74: 16. DOI: https://doi.org/10.1007/s13595-016-0601-2
4. KLEPAC D 1957 Research about bark thickness in forests of sessile oak and pedunculate oak (*in Croatian with English summary*). *Šum list* 81 (3-4): 90-106
5. KLEPAC D 1958 The relationship between the diameter over bark and the bark thickness for our most important hardwood species (*in Croatian with English summary*). *Šum list* 82 (7-9): 251-267
6. MONSERUD RA 1979 Relations between inside and outside bark diameter at breast height for Douglas-fir in Northern Idaho. USDA Forest Service Research Note INT-266. DOI: https://doi.org/10.5962/bhl.title.79427
7. WILHELMSSON L, ARLINGER J, SPÅNGBERG K, LUNDQVIST S-O, GRAHN T, HADENBERG Ö, OLSSON L 2002 Models for Predicting Wood Properties in Stems of Picea abies and Pinus sylvestris in Sweden. *Scand J For Res* 17 (4): 330-350. DOI: https://doi.org/10.1080/02827580260138080
8. PRKA M 2004 Bark Thickness of Common Beech (*Fagus sylvatica* L.) in cutting areas of Bilogora near Bjelovar. *Šum list* 128 (7-8): 391-403
9. LAASASENAHO J, MELKAS T, ALDÉN S 2005 Modelling bark thickness of Picea abies with taper curves. *For Ecol Manag* 206 (1-3): 35-47. DOI: https://doi.org/10.1016/j.foreco.2004.10.058
10. BOŽIĆ M, ČAVLOVIĆ J, VEDRIŠ M, JAZBEC M 2007 Modeling bark thickness of silver fir trees (*Abies alba* Mill.). *Šum list* 131 (1-2): 3-12
11. STANKIĆ I, KOVAČ S, PORŠINSKY T 2010 Bark Features of Black Alder from Podravina. *Nova mehanizacija šumarstva* 31: 27-36
12. LOJO A, MUSIĆ J, BALIĆ B, AVDAGIĆ A, HALILOVIĆ V, IBRAHIMSPAHIĆ A, KNEŽEVIĆ J 2019 Thickness and share of bark in the volume of fir roundwood (*Abies alba* Mill.) (*in Bosnian with English summary*). *Naše šume* 54-55 (in print)
13. ALTHERR E, UNFRIED P, HRADETZKY J, HRADETZKY V 1978 Statistische Rindenbeziehungen als Hilfsmittel zur Ausformung und Aufmessung unentrindeten Stammholzes. Mitteilungen der Forstlichen Versuchs - und Forschungsanstalt, Baden – Württemberg , Freiburg i. Breisgau
14. RÖSSLER G 2018 Estimation of bark proportion - but how? BFW - Austrian Research Centre for Forests. URL: https://bfw.ac.at/100/pdf/Vortrag_Rindenabzug_kl.pdf (4 March 2019)
15. BOJANIN S 1972 Bark thickness and percentage of the narrow-leaved ash (*Fraxinus angustifolia* Wahl.) roundwood (*in Croatian with English summary*). *Šum list* 96 (7-8): 267-277
16. BOJANIN S 1966 The thickness of the bark at different height above the ground for fir tree (*in Croatian with English summary*). *Drvna industrija* 17 (4-5): 76-85
17. KLEPAC D 1972 Research of the thickness and volume of bark for fir in various phytocenoses (*in Croatian with French summary*). *Glasnik za šumske pokuse* 16: 105-122
18. TURK Z, LIPOGLAVŠEK M 1972 The volume and weight of bark in relation to the diameter of fir, spruce and beech in certain regions of Slovenia (*in Slovenian with German summary*). Institute of Forest and Wood Economy of Slovenia, Ljubljana, Slovenia, 68 p
19. REBULA E 1994 Uncertainty of Determining the Volume of Coniferous Round Timber with Proposal for a Measurment Procedure. *Mehanizacija šumarstva* 19 (2): 87-110
20. PORŠINSKY T, VUJEVA J 2007 Volume losses of processed spruce roundwood due to prescribed method of scaling. *Nova mehanizacija šumarstva* 28 (1): 37-47.
21. LI R, WEISKITTEL AR 2011 Estimating and predicting bark thickness for seven conifer species in the Acadian Region of North America using a mixed-effects modeling approach: comparison of model forms and subsampling strategies. *Eur J For Res* 130 (2): 219-233. https://doi.org/10.1007/s10342-010-0423-y
22. KRPAN APB 1986 Bark of the beech from the standpoint of forest exploitation. Miscellanea of Coloquy about the beech – The Conference of the assistents section, Velika, Hrvatska, 22-24 November 1984. Forestry Faculty of University Zagreb, Zagreb, Croatia, pp 77-88
23. SWEDICH TIMBER MEASUREMENT COUNCIL 1999 Regulations for measuring of roundwood. VMR 1-99
24. JOVANOVIĆ B 1985 Dendrology. University of Belgrade, Faculty of Forestry, Belgrade, Serbia, 557 p
25. EUFORGEN 2013 Distribution map of norway spruce (*Picea abies*). URL: http://forest.jrc.ec.europa.eu/media/atlas/Picea_abies.pdf (26 March 2019)
26. ALTHEN FW 1964 Accuracy of the Swedish bark measuring gauge. *For Chron* 40 (2): 257-258. DOI: https://doi.org/10.5558/tfc40257-2
27. MESAVAGE C 1969 Measuring bark thickness. *J For* 67 (10): 753-754. DOI: https://doi.org/10.1093/jof/67.10.753
28. STÄNGLE SM, WEISKITTEL AR, DORMANN CF, BRÜCHERT F 2016 Measurement and prediction of bark thickness in Picea abies: assessment of accuracy, precision, and sample size requirements. *Can J For Res* 46 (1): 39-47. DOI: https://doi.org/10.1139/cjfr-2015-0263
29. HUSCH B, BEERS TW, KERSHAW JA 2003 Forest Mensuration. 4th Ed., John Wiley & Sons, Hoboken, New Jersey, USA, 443 p
30. KOZAK A 2004 My last words on taper equations. *For Chron* 80 (4): 507-515. DOI: https://doi.org/10.5558/tfc80507-4
31. JIANG L, BROOKS JR, WANG J 2005 Compatible taper and volume equations for yellow - poplar in West Virginia. *For Ecol Manag* 213 (1): 399-409. DOI: https://doi.org/10.1016/j.foreco.2005.04.006
32. MATIĆ V 1964 Method of the Forest Inventory on large areas – part I and II (Manuscript). Institute for Forestry of the Faculty of Forestry in Sarajevo, Bosnia and Herzegovina
33. LOJO A, BEUS V, MEKIĆ F, KOPRIVICA M, MUSIĆ J, TREŠTIĆ T, BALIĆ B, ČABARAVDIĆ A, HOČEVAR M 2008 Method of the Second Forest Inventory on large areas in Bosnia and Herzegovina (*in Bosnian with English summary*). *Works of the Faculty of Forestry University of Sarajevo* 20 (1): 1-156
34. MEYER H 1946 Bark volume determination in trees. *J For* 44 (12):1067-1070. DOI: https://doi.org/10.1093/jof/44.12.1067
35. BOX GEP, COX DR 1964 An Analysis of Transformations. *J Roy Stat Soc B Met* 26 (2): 211-252. DOI: https://doi.org/10.1111/j.2517-6161.1964.tb00553.x
36. HADŽIVUKOVIĆ S 1973 Statistical methods. Forum, Novi Sad, Serbia
37. SNEDECOR GW, COCHRAN WG 1971 Statistical methods (*in Serbian*). Vuk Karadžić, Beograd, Serbia, 511 p
38. MATIĆ V 1980 Forest growth and yeild. University of Sarajevo, Faculty of Forestry, Bosnia and Hezegovina, 351 p
39. STÄNGLE SM, NAKOI A, BRÜCHERT F, SAUTER UH, KOHNLE U 2014 Modeling Bark Thickness of Norway Spruce. Sustaining Forests, Sustaining People: The Role of Research, Abstracts of XXIV IUFRO World Congress, 5-11 October 2014, Salt Lake City, USA, 427 p

SEEFOR SOUTH-EAST EUROPEAN FORESTRY
OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

ORIGINAL SCIENTIFIC PAPER

DOI: https://doi.org/10.15177/seefor.19-21

# Modelling Stand Variables of Beech Coppice Forest Using Spectral Sentinel-2A Data and the Machine Learning Approach

**Azra Čabaravdić[1*], Besim Balić[1]**

**(1)** University of Sarajevo, Faculty of Forestry, Zagrebačka 20, BA-71000 Sarajevo, Bosnia and Herzegovina

* **Correspondence:** e-mail: azrac2012@gmail.com

**Citation:** ČABARAVDIĆ A, BALIĆ B 2019 Modelling Stand Variables of Beech Coppice Forest Using Spectral Sentinel-2A Data and the Machine Learning Approach. *South-east Eur for* 10 (2): 137-144. DOI: https://doi.org/10.15177/seefor.19-21

**Received:** 16 Jul 2019; **Revised:** 24 Sep 2019; **Accepted:** 3 Oct 2019; **Published online:** 3 Nov 2019

## ABSTRACT

**Background and Purpose:** Coppice forests have a particular socio-economic and ecological role in forestry and environmental management. Their production sustainability and spatial stability become imperative for forestry sector as well as for local and global communities. Recently, integrated forest inventory and remotely sensed data analysed with non-parametrical statistical methods have enabled more detailed insight into forest structural characteristics. The aim of this research was to estimate forest attributes of beech coppice forest stands in the Sarajevo Canton through the integration of inventory and Sentinel S2A satellite data using machine learning methods.

**Materials and Methods:** Basal area, mean stand diameter, growing stock and total volume data were determined from the forest inventory designed for represented stands of coppice forests. Spectral data were collected from bands of Sentinel S2A satellite image, vegetation indices (difference, normalized difference and ratio vegetation index) and biophysical variables (fraction of absorbed photosynthetically active radiation, leaf area index, fraction of vegetation cover, chlorophyll content in the leaf and canopy water content). Machine learning rule-based M5 model tree (M5P) and random forest (RF) methods were used for forest attribute estimation. Predictor subset selection was based on wrapping assuming M5P and RF learning schemes. Models were developed on training data subsets (402 sample plots) and evaluations were performed on validation data subsets (207 sample plots). Performance of the models was evaluated by the percentage of the root mean squared error over the mean value (rRMSE) and the square of the correlation coefficient between the observed and estimated stand variables.

**Results and Conclusions:** Predictor subset selection resulted in a varied number of predictors for forest attributes and methods with their larger contribution in RF (between 8 and 11). Spectral biophysical variables dominated in subsets. The RF resulted in smaller errors for training sets for all attributes than M5P, while both methods delivered very high errors for validation sets (rRMSE above 50%). The lowest rRMSE of 50% was obtained for stand basal area. The observed variability explained by the M5P and RF models in training subsets was about 30% and 95% respectively, but those values were lower in test subsets (below 12%) but still significant. Differences of the sample and modelled forest attribute means were not significant, while modelled variability for all forest attributes was significantly lower ($p<0.01$). It seems that additional information is needed to increase prediction accuracy, so stand information (management classes, site class, soil type, canopy closure and others), new sampling strategy and new spectral products could be integrated and examined in further more complex modelling of forest attributes.

**Keywords:** Coppice Forest, Inventory Data, Spectral Biophysical Variables, M5 Model Tree, Random Forest Regression

## INTRODUCTION

Coppice forests have multiple roles related to their production in forest management, as well as their social, ecological and economic importance for local communities. Their contribution is recognized and emphasized in rural livelihoods, low-carbon bio-economy, in protective functions, sharing economy, provision and enrichment [1].

Several studies were conducted analyzing structure, functions, silvicultural measures and other aspects in coppice forests in Europe and the Balkan region [1-8]. Authors [3-8] from South Eastern Europe (SEE) concluded that degradation and inappropriate treatments in high forests in the 20th century resulted in degradation and appearance of coppice forests on larger areas. Stajić *et al.* [3] described past and recent coppice forest management in some regions of SEE in relation to their characteristics. Višnjić *et al.* [8] investigated ecological and silvicultural characteristics of coppice forests in Bosnia and Herzegovina (B&H). In B&H coppice forests occupy around 23% of the forested area according to data from the second national forest inventory. Different silvicultural treatments (conversion, thinning, reforestation and others) for the improvement of their production and other forest functions were examined and analyzed [9, 10]. Recent intensive studies of coppice forests were conducted in the Sarajevo Canton [11-14]. Balić [11] presented the research on productivity, structural characteristics and models of growth and increment of coppice beech forests based on forest inventory data using statistical parametrical approach in the Sarajevo Canton.

For management planning purposes it is important to estimate stand productivity variables (basal area, stand diameter, wood volume, growing stock and others) and their spatial distributions, especially where different management regimes are recommended. Therefore, apart from forest inventory data, forest management planning should consider all available information about the forest status and stand conditions. Available remote sensing data from different satellite programs compiled with forest inventory have been used as a source for additional research about forest characteristics since the middle of the 20th century. Landsat and Sentinel satellite images have been used most frequently for forest type classification [15-17], as well as for the estimation of forest productivity attributes [18, 19]. Rapid information technology development resulted in continuous improvements of remote sensing capabilities (satellite and aerial imagery, lidar), offering innovative possibilities of research on forest vegetation [19-21]. Then statistical classification and estimation methods supported with information technology development become more efficient and promising in spatial characterization of forest attributes on the forested area [22-24]. Recently, high forests and artificial stands were analyzed frequently using machine learning rule-based approach. Therefore research focus was re-directed on coppice forests where wide interest for further coppice forest characterization was obtained.

The aim of this paper is to evaluate beech coppice forest stand variable estimates based on machine learning rule-based methods: M5 model tree and random forest regression using inventory and Sentinel S2A spectral data.

## MATERIALS AND METHODS

### Study Area

The study was conducted in the Sarajevo Canton (about 1277 km$^2$), which is bounded by the southern geographical latitudes 43°53' - 43°47' and the eastern geographical longitudes 18°16'-18°27’ in central Bosnia and Herzegovina (Figure 1). Forest stands of state-owned beech (*Fagus silvatica* L.) coppice forests surrounding the capital city of Sarajevo were selected as study areas. The selected beech coppice stands are situated on plane and hilly positions at altitude range of 550 to 1700 meters, but mostly below 1000 meters (about 60%). About 80% of forest stands are situated on humid expositions with deeper and moist soils. More than 65% of forest stands are located on a position with an inclination above 20°, while less than 15% is on planes. The study area is influenced by moderate continental climate with subalpine character at higher altitudes.

### Field Data

Field measurements were acquired for geo-referenced field plots located at the intersection of 200×200 m grid. Trees with diameter of the breast height of 7 cm were selected in circular plots with different radii based on the probability proportional to size [25]. The most important forest stand attributes including the basal area, stand mean diameter, total volume and growing stock were calculated and used in this research (Table 1). Tree volume for individual trees was calculated using regression models [26] and then scaled to a per unit area basis (m$^3$·ha$^{-1}$). In this research 609 sample plots in 185 stands were used for modelling. Descriptive statistics of forest attributes and rank correlations with predictor variables were calculated for the sample dataset.

### Sentinel S2A Data

One cloud-free Sentinel-2 scene acquired on 17th October 2018 was used in this study. The spectral data were obtained from the Copernicus Open Access Hub [27] as Level-1C data with Top of Atmosphere (TOA) reflectance. Characteristics of the spectral bands of Sentinel-2 MSI (Multi-Spectral Instrument) sensor and subset of used bands are presented in Table 2 [28]. The atmospheric correction of Level-1C input data was performed using the Sen2Cor plug-in for Sentinel-2 Toolbox and SNAP software provided by ESA (version 6.0.0, Brockmann Consult, Geesthacht, Germany). Corrected data were resampled on 20 m resolution, and vegetation indices and biophysical variables were calculated.

Then, three spectral vegetation indices were calculated: difference vegetation index (DVI), ratio vegetation index (RVI) [29], and normalized difference vegetation index (NDVI) [30]. In addition, the biophysical variables were calculated in SNAP from its biophysical processor, which uses a neural network algorithm based on the PROSPECT+SAIL (PROSAIL) radiative transfer model [31]. Five biophysical variables were determined: fraction of absorbed photosynthetically active radiation (fapar), leaf area index (LAI), fraction of vegetation cover (FCOVER), chlorophyll content in the leaf (CHC), and canopy water content (CWC).


**FIGURE 1.** Position of the study area in B&H and Sarajevo Canton.

**TABLE 1.** Descriptive statistics of dataset of forest attributes (n=609).

| Statistic | Basal area ($m^2 \cdot ha^{-1}$) | Stand diameter (cm) | Total volume ($m^3 \cdot ha^{-1}$) | Growing stock ($m^3 \cdot ha^{-1}$) |
|---|---|---|---|---|
| Mean | 20.0 | 18.7 | 203.9 | 149.0 |
| Standard Deviation | 9.8 | 10.1 | 116.9 | 95.4 |
| Minimum | 1.6 | 2.2 | 18.4 | 0.00 |
| Maximum | 50.2 | 52.8 | 566.9 | 437.2 |

**TABLE 2.** Spectral bands of Sentinel-2 MSI sensor.

| Band | λ (nm) | Δλ (nm) | Resolution (m) | Feature set |
|---|---|---|---|---|
| B1 | 433 | 20 | 60 | - |
| B2 | 490 | 65 | 10 | + |
| B3 | 560 | 35 | 10 | + |
| B4 | 665 | 30 | 10 | + |
| B5 | 705 | 15 | 20 | + |
| B6 | 740 | 15 | 20 | + |
| B7 | 783 | 20 | 20 | + |
| B8 | 842 | 115 | 10 | + |
| B8A | 865 | 20 | 20 | + |
| B9 | 945 | 20 | 60 | - |
| B0 | 1375 | 30 | 60 | - |
| B11 | 1610 | 90 | 20 | + |
| B12 | 2190 | 180 | 20 | + |

## Machine Learning Algorithms

Machine learning approach refers to analytical model building automatically learning from data itself. Here two different machine learning-based rules algorithms for regression were applied: M5P and RF. M5P is a machine learning technique introduced as reconstruction of Quinlan's M5 algorithm for tree-based regression modelling [32]. It creates decision tree with linear regression function at the nodes using splitting criterion that minimizes the intra-subset variation. The RF regression model is an ensemble of tree predictors constructed from bootstrapping training data. For both algorithms parameters tuning is related to the number of regression trees and the number of features (explanatory variables). Here default rules for the number of trees in Weka software were applied [33]. Important influence on the results of the applied rule-based algorithms has the feature selection. Here the ”wrapper method was used, which selects a set of features most suitable for a particular algorithm. Datasets were separated in reference (66%) and validation (33%) subsets randomly. Accuracy assessment was evaluated using the mean square error (MAE), root mean square error (RMSE) and relative RMSE (RMSE%) calculated using the following equations:

$$MAE = \frac{\sum_i (\hat{y}_i - y_i)}{n} \quad (1)$$

$$RMSE = \sqrt{\frac{\sum_i (\hat{y}_i - y_i)^2}{n}} \quad (2)$$

$$RMSE\% = \frac{RMSE}{\bar{y}} \times 100 \quad (3)$$

where $y_i$ is observed forest attribute of the data i, $\hat{y}_i$ is estimated forest attribute of i, n is the number of validation data and $\bar{y}$ is the mean of the observed forest attribute. Then, determination was used to examine relationships between observed and estimated values.

The finalized machine learning models were used to make predictions for measured and non-measured geo-positions on pixel level in the study area. Input data were extracted from raster layers for each pixel geo-positioned on determined *x* and *y* coordinates.

Described method was applied for forest attributes estimates based on inventory and Sentinel S2A spectral data in similar studies [19, 22, 23].

## RESULTS AND DISCUSSION

### Correlations

Spearman's rank correlation between forest attributes, spectral data, vegetation indices, biophysical variables and altitude is shown in Table 3. All forest attributes are correlated significantly to the most auxiliary variables. All forest variables are correlated significantly to B2 (blue), B3 (green), B5, B6, B7 (three vegetation red edges), B8 (near infrared), B8A (narrow near-infrared band), all vegetation indices (DVI, NDVI and RVI) and a set of four biophysical variables (LAI, fapar, FCOVER and CWC). Shortwave infra-red bands B11 and B12 have low but significant correlation with the total volume and growing stock only.

Growing stock was correlated significantly to all auxiliary variables achieving highest correlation with vegetation red edge B6 (-0.24). All correlations were very low, pointing out to weak correlations in general. Astola *et al.* [18] reported higher correlations between $V_0$, $D_g$, BA in boreal broadleaved forests and Sentinel S2A digital numbers (-0.74, -0.75 and -0.69, respectively).

### Feature Selection

Predictor selection based on wrapping method resulted in subsets presented in Figure 2. The number of selected predictors varied between four and ten per forest attributes. Vegetation indices and biophysical variables were selected more frequently then the original spectral data.

Original spectral bands participated in smaller numbers than in similar research related to regression tree modelling for boreal broadleaved forests [19].

### Model Evaluation

The differences of sample and modelled forest attribute means were not significant, while modelled variability for all forest attributes was significantly lower ($p<0.01$). Model evaluations for reference and validation subsets are presented in Table 4. Relative RMSEs for M5P in reference sets ranged from 47.4% for G to 63.1% for GS, while values for RF varied from 17.9% to 23.6% for the same forest attributes respectively. Higher relative RMSEs for both algorithms were obtained for validations sets and ranged between 51% and 68% approximately. Higher relative RMSEs related to regression tree modelling were found for G, $D_g$ and $V_0$ in boreal broadleaved forests [19].

The RF performed better in a reference set for all forest attributes related to correlations between the observed and predicted values, while correlations in validation subsets were higher for M5P for all attributes (Figure 2).

The presence of systematic errors was obtained for both algorithms for all attributes in a consistent way. Figure 3 presents the relationships between the observed and predicted values in reference and validation sets for basal area that are similar for other forest attributes. The better performance of RF predictions is visible for RF in the reference set, while predictions in validation sets were biased and weak

**TABLE 3.** Feature selection.

| Forest Attribute | BA | | $D_g$ | | $V_0$ | | V7 | |
|---|---|---|---|---|---|---|---|---|
| Algorithm | M5P | RF | M5P | RF | M5P | RF | M5P | RF |
| B2 | + | | | | + | | + | |
| B3 | + | | | | + | | | |
| B4 | | | | | + | | | |
| B5 | + | | | + | | | | |
| B6 | | | | | + | + | | + |
| B7 | + | | | + | | | | |
| B8 | | | | + | | | + | |
| B8A | | + | | | | | + | |
| B11 | | | | + | | + | | + |
| B12 | + | | | + | | | | + |
| DVI | | | | | | | + | |
| NDVI | | + | + | + | | | + | |
| RVI | + | | + | | + | | + | + |
| LAI | + | + | | | | + | + | + |
| fapar | | | | | + | | | + |
| FCOVER | | | + | + | | | | |
| CHC | + | | | + | | | | + |
| CWC | | + | | + | | + | | |
| Altitude | + | + | + | + | | + | | + |

**TABLE 4.** Evaluation results (MAE, RMSE, RMSE%).

| Forest Variable | Data Set | Method | MAE | RMSE | RMSE% |
|---|---|---|---|---|---|
| G | RS | M5P | 7.2 | 9.1 | 47.4 |
| | | RF | 2.7 | 3.4 | 17.9 |
| | VS | M5P | 7.8 | 9.8 | 51.2 |
| | | RF | 8.2 | 10.4 | 54.1 |
| $D_g$ | RS | M5P | 7.8 | 10.0 | 54.4 |
| | | RF | 3.0 | 3.9 | 21.0 |
| | VS | M5P | 7.4 | 9.6 | 52.0 |
| | | RF | 7.3 | 9.5 | 51.6 |
| V | RS | M5P | 87.8 | 111.4 | 56.8 |
| | | RF | 33.0 | 42.1 | 21.5 |
| | VS | M5P | 87.8 | 112.5 | 57.4 |
| | | RF | 96.0 | 122.0 | 62.2 |
| GS | RS | M5P | 72.0 | 89.6 | 63.1 |
| | | RF | 26.7 | 33.5 | 23.6 |
| | VS | M5P | 73.3 | 92.8 | 65.3 |
| | | RF | 75.3 | 95.6 | 67.3 |

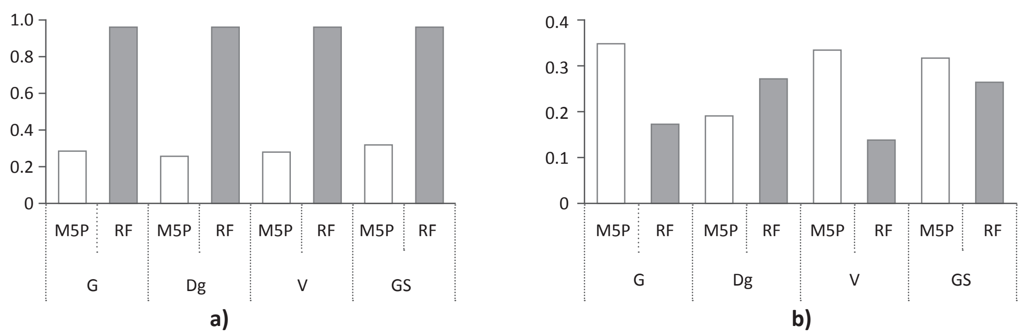


**FIGURE 2.** Correlations in reference **(a)** and validation **(b)** subsets for different forest attributes and machine learning algorithms.

for both algorithms in the range of observed basal area values.

The over-fitting in reference sets was obtained in all models with weak adjustment in validation sets. The RF predictions on the measured location achieved reliable values, while surrounding pixel-based estimates deviated from ground truth. It seems that the chosen feature selection method and the algorithm's specifications express low performances in validation sets, so further research related to reliable estimates on the pixel-level is needed.

## Mapping of Basal Area for Beech Coppice Stands

The mapping of forest attributes has become a contributing part for forest management on all forested areas [23, 34]. Recent research of coppice forests [12-14, 35] pointed out the importance of spatial distribution of forest production attributes for the planning of ameliorative measures (restoration, reforestation) especially in beech stands.

We found that the applied machine learning-based estimation mapping could give insight into spatial distribution of forest attributes with better preservation of ranges of ground and RF estimated values.

Here is a visualized spatial distribution modelled by RF for basal area as an example and two details with stands from Google Satellite (above) and estimated basal area (below) (Figure 4).

Estimate of spatial distribution of highly correlated forest attributes is consistent over the forested area. This consistency could contribute to the coppice forests' function analysis considering their productive and protective roles. Related to productivity, RF spatial estimates better indicate areas with low values of forest attributes pointing out to the adequacy of stand potentials usage. Also, machine learning-based estimates near stand boundaries indicate forest quantity coverage related to the preservation of forest soil and protection from erosion and drying. We found that these indications could contribute to forest planning considering management and silvicultural measures aiming to improve coppice forest quantity and quality potentials.

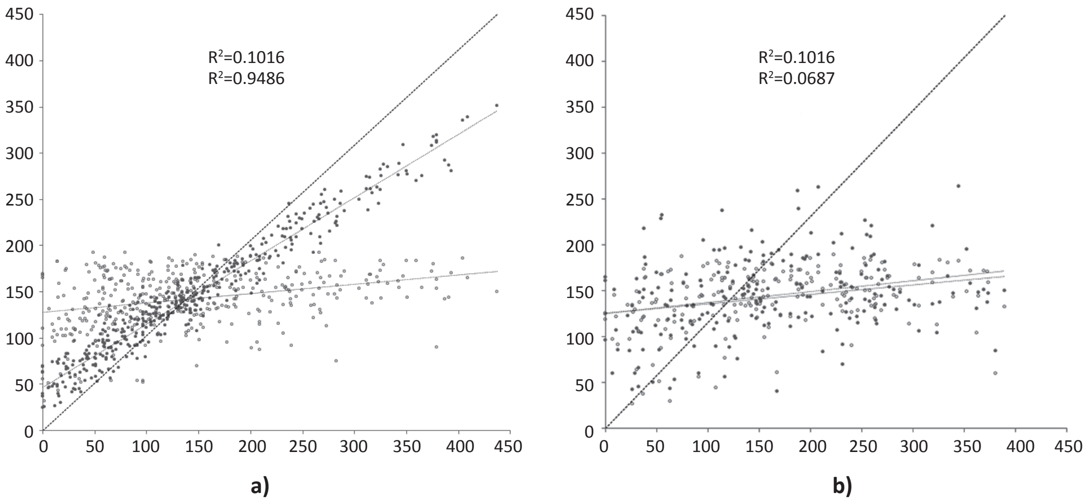


**FIGURE 3.** Relationship between the observed and estimated values for growing stock in **(a)** the reference dataset and **(b)** the validation dataset.

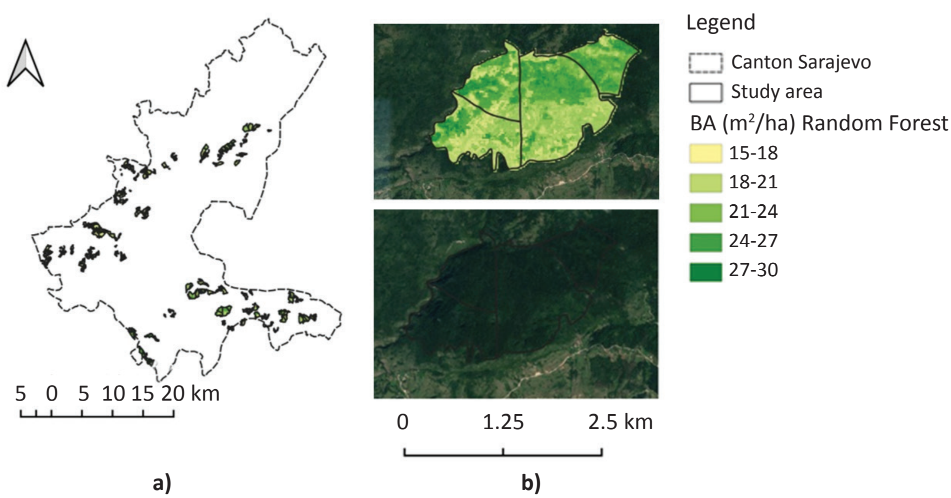


**FIGURE 4.** Thematic maps of estimated spatial distribution for basal area in coppice stands **(a)** RF; **(b)** stands on Google - above, stands with basal area RF estimates - bellow).

## CONCLUSIONS

Conclusions that can be drawn from this study are:

- There are significant rank correlations between spectral Sentinel S2A data, vegetation indices, biophysical variables, altitude and the main beech coppice forest attributes (G, $D_g$, $V_0$, GS).
- NDVI, LAI and altitude participated most frequently in selected variable subsets.
- Machine learning modelling based on M5P and RF resulted in different efficiency for all forest attributes. RF estimates in reference sets (RMSE% below 24%) were better than M5P estimates (RMSE% below 63%). In both modelling processes over fitting in reference sets were obtained, while estimates achieved high relative RMSEs in validation sets.
- The machine learning approach compiled with Sentinel S2A spectral data is promising for the estimation and mapping of spatial distribution of forest attributes in beech coppice stands.

Further research is needed related to machine learning algorithm specifications, more intensive and representative ground sample, spatial correlations and other scientific and technical possibilities.

## REFERENCES


1. UNRAU A, BECKER G, SPINELLI R, LADZINA D, MAGAGNOTTI N, NICOLESCU VN, BUCKLEY P, BARTLETT D, KOFMAN PD (eds) 2018 Coppice forest in Europe. Albert Ludwing University of Freiburg, Freiburg, Germany
2. MAIROTA P, MANETTI MC, AMORINI E, PELLERI F, TERRADURA M, FRATTEGIANI M, SAVINI P, GROHMANN F, MORI P, TERZUOLO PG, PIUSSI P 2016 Opportunities for coppice management at the landscape level: the Italian experience. *iForest* (9): 775-782. DOI: https://doi.org/10.3832/ifor1865-009
3. STAJIĆ B, ZLATANOV T, VELICHKOV I, DUBRAVAC T, TRAJKOV P 2009 Past and recent coppice forest management in some regions of South eastern Europe. *Silva Balcanica* 10 (1): 9-19
4. ZENELI G, KOLA H 2017 Coppice Forests: Can Traditional Coppice Forest Managament Help the Western Balkan Region? *Forest Research* 6 (3). DOI: https://doi.org/10.4172/2168-9776.1000212
5. DEKANIĆ S, LEXER M J, STAJIĆ B, ZLATANOV T, TRAJKOV P 2009 European forest types for coppice forests in Croatia. *Silva Balcanica* 10 (1): 47-62
6. PANTIĆ D, KRSTIĆ M, DANILOVIĆ M, MATOVIĆ B, MARKOVIĆ N 2003 Tree development and productivity of beech coppice stands in the Crni Vrh region (*in Serbian with English summary*). *Glasnik Šumarskog fakulteta* 87: 175-186. DOI: https://doi.org/10.2298/GSF0387175P
7. STOJANOVIĆ LJ, KRSTIĆ M, RADOVANOVIĆ T 2004 Proposition of optimal silvicultural operations in coppice beech forests on mt. Ozren (*in Serbian with English summary*). *Časopis za šumarstvo, preradu drveta, pejsažnu arhitekturu, i zaštitu od erozija* 3: 105-238
8. VIŠNJIĆ Ć, MEKIĆ F, VOJNIKOVIĆ S, BALIĆ B, BALLIAN D, IVOJEVIĆ S 2010 Ecological and silvicultural characteristics of beech coppice forests in Bosnia and Herzegovina (*in Bosnian with English summary*). Monograph, Faculty Forestry University Sarajevo, Bosnia and Herzegovina, 154 p
9. PINTARIĆ K 2002 Problem of the conversion of beech coppices into high forests of beech (*in Croatian with English summary*). *Šumar list* 126 (3-4): 119-128
10. KORIČIĆ Š 2005 Biološki, ekološki i ekonomski pokazatelji uspješnosti proreda u panjačama bukve *(in Bosnian with English summary*). PhD thesis, University of Sarajevo, Faculty of Forestry, Sarajevo, Bosnia and Herzegovina, 220 p
11. BALIĆ B 2013 Productivity, structural caracteristics and models of growth and increment coppice beech forest in the Sarajevo Canton *(in Bosnian with English summary*). PhD thesis, University of Sarajevo, Faculty of Forestry, Sarajevo, Bosnia and Herzegovina, 215 p
12. BALIĆ B, VIŠNJIĆ Ć, VOJNIKOVIĆ S, IBRAHIMSPAHIĆ A, LOJO A, AVDAGIĆ A 2016 Ecological, productive and silvicultural categorisation of coppice beech stands in the area of Sarajevo Canton. *Works of the Faculty of Forestry University of Sarajevo* 45 (2): 83-99
13. VIŠNJIĆ Ć, BALIĆ B, VOJNIKOVIĆ S, MEKIĆ F 2017 Ameliorative categorsiation of beech coppice forests at the territory of Canton Sarajevo (*in Bosnian with English summary*). Monograph, Faculty Forestry University Sarajevo, Bosnia and Herzegovina, 115 p
14. LOJO A, MUSIĆ J, BALIĆ B, BAJRIĆ M, SOKOLOVIĆ DŽ, IBRAHIMSPAHIĆ A, AVDAGIĆ A 2017 Analise of the current state and long-term projection of use and conversion of stateowned coppice forests in order to improve of wood production and state of forest in the Sarajevo Canton (*in Bosnian with English summary*). *Naše šume* (46-47): 12-29
15. IMMITZER M, VUOLO F, ATZBERGER C 2016 First Experience with Sentinel-2 Data for Crop and Tree Species Classifications in Central Europe. *Remote Sens* 8 (3): 166. DOI: https://doi.org/10.3390/rs8030166
16. BERTA A 2018 Tree species classification in forests of Central Croatia using Sentinel 2 data and data mining. Conference: Natural Resources, Green Technology&Sustainable Developement /3, Zagreb, Croatia
17. GAŠPAROVIĆ M, ZRINJSKI M, GUDELJ M 2019 Automatic cost-effective method for land cover classification (ALCC). *Computers, Environment and Urban Systems* 76: 1-10. DOI: https://doi.org/10.1016/j.compenvurbsys.2019.03.001
18. ASTOLA H, HÄME T, SIRRO L, MOLINIER M, KILPI J 2019 Comparison of Sentinel-2 and Landsat 8 imagery for forest variable prediction in boreal region. *Remote Sens Environ* 223: 257-273. DOI: https://doi.org/10.1016/j.rse.2019.01.019
19. WITTKE S, YUA X, KARJALAINENA M, HYYPPAA J, PUTTONENA E 2019 Comparison of two-dimensional multitemporal Sentinel-2 data with threedimensional remote sensing data sources for forest inventory parameter estimation over a boreal forest. *Int J Appl Earth Obs* 76: 167-178. DOI: https://doi.org/10.1016/j.jag.2018.11.009
20. CHEN L, REN C, ZHANG B, WANG Z, XI Y 2018 Estimation of Forest Above-Ground Biomass by Geographically Weighted Regression and Machine Learning with Sentinel Imagery. *Forests 9* (10): 528-582. DOI: https://doi.org/10.3390/f9100582
21. BALENOVIĆ I, ALBERTI G, MARJANOVIĆ H 2013 Airborne Laser Scanning - the Status and Perspectives for the Application in the South-East European Forestry. *South-east Eur for* 4 (2): 59-79. DOI: https://doi.org/10.15177/seefor.13-07
22. SAFARI A, SOHRABI H, POWELL SL 2018. Comparison of satelitte-based estimates of aboveground biomass in coppice oak forests using parametric, semiparametric and non-parametric modeling methods. *Journal of Apllied Remote Sensing* 12 (4), 046026 . DOI: https://doi.org/10.1117/1.JRS.12.046026
23. CHEN L, WANG Y, REN C, ZHANG B, WANG Z 2019 Optimal combination of predictors and algorithms for forest above-ground biomass mapping from Sentinel and SRTM data. *Remote Sens* 11 (4): 414. DOI: https://doi.org/10.3390/rs11040414
24. NOI PT, KAPPAS M 2018 Comparison of Random Forest, k-Nearest Neighbor, and Support Vector Machine Classifiers for Land Cover Classification Using Sentinel-2 Imagery. *Sensors* 18 (1): 18. DOI: https://doi.org/10.3390/s18010018
25. STOJANOVIĆ O, DRINIĆ P 1974 Istraživanje veličine koncentričnih kružnih površina za taksacionu procjenu šuma (*in Bosnian with English summary*). *Works of the Faculty of Forestry and Institute of Forestry Sarajevo* 34 p
26. BALIĆ B, MUSIĆ J, LOJO A, ČABARAVDIĆ A, IBRAHIMSPAHIĆ A 2010 Creation of volume and sortiment tables for beech coopice forests as scientific base for management planning for beech coppice forests in Federation B&H (*In Bosnian with English summary*). Federal Ministry of Agriculture, Foresty and Water Management, Sarajevo, 80 p
27. EUROPEAN SPACE AGENCY 2019 Copernicus Open Acces Hub. URL: https://scihub.copernicus.eu/dhus/#/home (12 February 2019)
28. EUROPEAN SPACE AGENCY 2019 Sentinel-2 Spectral Response Functions (S2-SRF). URL: https://sentinel.esa.int/web/sentinel/document-library/content/-/article/sentinel-2a-spectral-responses (23 July 2019)
29. RICHARDSON AJ, WIEGAND CL 1977 Distinguishing Vegetation From Soil Background Information. *Photogramm Eng Rem S* 43 (12): 1541-1552
30. ROUSE JWJ R, HAAS RH, DEERING DW, SCHELL JA, HARLAN JC 1974 Monitoring the Vernal Advancement and Retrogradation (Green Wave Effect) of Natural Vegetation, NASA/GSFC Type III Final Report, Greenbelt, MD, USA, 371 p

31. JACQUEMOUD S, VERHOEF W, BARET F, BACOUR C, ZARCO-TEJADA PJ, ASNER GP, FRANÇOIS C, USTIN SL 2009 PROSPECT + SAIL models: A review of use for vegetation characterization. *Remote Sens Environ* 113: 56-66. DOI: https://doi.org/10.1016/j.rse.2008.01.026
32. QUINLAN RJ 1991 Learning with Continuous Classes. *In:* Australian Joint Conference of Artificial Intelligence, World Scientific, Singapore, pp 343-348
33. HALL M, FRANK E, HOLMES G, PFAHRINGER B, REUTEMANN, WITTEN IH 2009 The WEKA data mining software: an update. SIGKDD Explorations 11 (1). URL: https://www.cs.waikato.ac.nz/ml/weka/ (23 Sepember 2019)
34. CORONA P 2010 Integration of forest mapping and inventory to support forest management. *iForest* 3 (3): 59-64. DOI: https://doi.org/10.3832/ifor0531-003
35. CHIRICI G, GIULIARELLI D, BISCONTINI, TONTI D, MATTIOLI W, MARCHETTI M, CORONA P 2011 Large-scale monitoring of coppice forest clearcut by multitemporal very high resolution satellite imagery. Case study from central Italy. *Remote Sens Environ* 115 (4): 1025-1033. DOI: https://doi.org/10.1016/j.rse.2010.12.007

SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

ORIGINAL SCIENTIFIC PAPER

DOI: https://doi.org/10.15177/seefor.19-19

# Widespread Distribution of the Sycamore Seed Bug *Belonochilus numenius* (Hemiptera: Heteroptera: Lygaeidae) Throughout the Republic of North Macedonia

**Katerina Srebrova[1], Sterja Nacheski[1], Kiril Sotirovski[1]***

**(1)** "Ss. Cyril and Methodius" University, Faculty of Forestry, Aleksandar Makedonski bb, MK-1000 Skopje, Republic of North Macedonia

* **Correspondence:** e-mail: kirils@sf.ukim.edu.mk

**Citation:** SREBROVA K, NACHESKI S, SOTIROVSKI K 2019 Widespread Distribution of the Sycamore Seed Bug *Belonochilus numenius* (Hemiptera: Heteroptera: Lygaeidae) Throughout the Republic of North Macedonia. *South-east Eur for* 10 (2): 145-149. DOI: https://doi.org/10.15177/seefor.19-19

**Received:** 11 Sep 2019; **Revised:** 4 Oct 2019; **Accepted:** 5 Oct 2019; **Published online:** 1 Nov 2019

## ABSTRACT

**Background and Purpose:** The sycamore seed bug, *Belonochilus numenius* (Say, 1831), was recorded for the first time in Europe in 2008, with finds in that same year in two separate locations in Spain and two in France. Since then, it has been reported to be present in 17 European countries. Once it reached Europe, the fast spread and establishment of this species was facilitated both by the increased plant trade and the relative frequency of plane trees (*Platanus* x *acerifolia, P. orientalis* and *P. occidentalis*) planted on a wide scale across the continent due to their popularity as urban and peri-urban trees.

**Materials and Methods:** In the summer of 2019 we inspected urban, peri-urban and natural populations and groups of plane trees throughout North Macedonia, on a total of 44 sites, looking for presence of nymphs and adults of this insect on seed balls. We collected specimens and related data and made identification based on specific external characteristics typical of *B. numenius*.

**Results:** We report the first record of *B. numenius* in the Republic of North Macedonia from July 2019, from *P.* x *acerifolia* in Skopje. Furthermore, after inspecting plane trees throughout the country we report the presence of this insect in 29 cities and towns, 3 peri-urban and in 1 natural population of *P. orientalis.*

**Conclusions:** From the widespread distribution of this insect species, we conclude that it has entered the territory of North Macedonia many years prior, very likely soon after first records in Serbia in 2011 and Bulgaria in 2012, but has since been overlooked.

**Keywords**: alien insect species, Nearctic, plane trees, invasive

## INTRODUCTION

*Belonochilus numenius* (Say, 1831), referred to as the sycamore seed bug or American sycamore seed bug, is naturally widely distributed in the USA and Mexico [1], between latitudes 15°-45° N, as per Ashlock (1967) [2], and in Canada in Ontario [3]. In 2011 it was recorded for the first time in the western state of British Columbia in Canada [4]. The main host plant species in North America are *Platanus occidentalis* and *P.* x *acerifolia*, but other species also mentioned as hosts by the early American investigators are *P. racemosa* and *P. wrighti*, as well as *Ambrosia trifida*, *Celtis occidentalis* and *Salix* sp. [1].

This Nearctic species has recently entered and established itself in Europe, and has become invasive for the continent. The first record in 2008 was published in France by Matocq (2008), on finds of the species on the island of Corsica and the region of Languedoc [2, 5], and soon after in Spain on an earlier find from the region of Catalonia [2]. However, the earliest record in Europe is now considered to be the one from the islands of Palma de Mallorca in July of 2008 [5-7]. The first records, including those from Italy

[8], all came from coastal regions of the Mediterranean, but this insect species quickly spread beyond and has been recorded in many countries and regions of the continent. Until to date, records of the presence of the species have been published in the following European countries – Spain and France in 2008; in 2010 Italy [8], Monaco [9] and Austria [10]; Czech Republic [11], Slovakia [12] and Serbia [13] in 2011; Switzerland [9], Hungary [14], Germany [15] and Bulgaria [13] in 2012; Madeira Islands of Portugal in 2014 [16]; Slovenia in 2015 [6]; Bosnia and Herzegovina in 2016 [17]; Albania in 2017 [18], and the latest first record coming from Greece in 2018 [19] with a sighting of a single individual adult specimen and no further finds despite active search after the first record. Additionally to these reports, detailed records of the spread and distribution of *B. numenius* have been published in Spain, France, Austria and Germany [5, 7, 9, 20, 21], where it is considered to be widely present.

It is worth mentioning that a find of a single specimen on the Azores (Portugal) determined as *B. numenius* (published by Ribes in 2010) is in fact a matter of misidentification of *Orsillus depressus* [7] and should therefore not be considered.

In early works in the USA, Heidemann (1902) and Van Duzee (1914) established that this species completes its life cycle on seed balls of *P. occidentalis* [1, 22]. The insect is not considered as a threat to *Platanus* trees [7] and is not listed on either A1 or A2 list of the European and Mediterranean Plant Protection Organization for regulation of quarantine pests. However, it was officially declared as an urban pest for the first time in Badalona in Spain in 2011, and in 2015 it was declared as public nuisance in Barcelona, El Prat de Llobregat and Blanes [7]. This status was warranted because insects disturbed citizens due to their high numbers and amassing in houses, balconies, restaurants and the similar during outbreaks.

Plane trees are amongst the most common tree species used in urban greenery in North Macedonia, mainly *P. orientlalis*, but also *P.* x *acerifolia*, which has lately gained in popularity, and to a lesser extent *P. occidentalis* (Sotirovski, unpublished). The capital Skopje alone counts at least 3537 (incomplete tree census data for 2018; http://gis.skopje.gov.mk/zk/) and likely thousands more (Sotirovski, unpublished). On the other hand, there are only two towns (Delchevo and Pehchevo) which do not have at least a few plane trees incorporated in their urban landscape. Even in Krushevo, which is considered to be the town at the highest altitude in the Balkans at 1350 m a.s.l., there is an established oriental plane tree positioned in a prominent place of the town. Taking into consideration that there are also natural populations of *P. orientalis* along the Vardar river and several of its tributaries south of Skopje, around Ohrid and Dojran lakes, and in the footer of Belasica mountain [23], the numbers and distribution of plane trees in North Macedonia is such that the aerial distance of the most isolated and furthest subpopulation of plane trees (in Debar) to the nearest other subpopulation (Kichevo) in North Macedonia is less than 36 km (Sotirovski, unpublished). Furthermore, for the Debar plane tree subpopulation, we suspect that it might be positioned at a shorter distance from plane trees in Albania than from the ones in Kichevo. This, as well as imports and internal trade of plane trees for landscaping purposes, makes plane trees a perfect niche for the establishment and fast spread of *B. numenius* in North Macedonia.

Because of the wide dissemination and fast spread of this insect species in Europe and recent reports of its presence in neighboring countries, and after recording the first find in North Macedonia, we set to establish a snapshot of its current dissemination throughout the country.

## MATERIAL AND METHODS

Our survey by visual inspection of host tree species and collection of specimens was conducted in the period between 10th July 2019 (first record of *B. numenius* in North Macedonia) and 10th September 2019. Survey and collection expeditions were completed throughout North Macedonia on plane trees (*P. orientalis*, *P.* x *acerifolia*, and *P. occidentalis*) in urban settings in 34 cities and towns, 3 natural populations of *P. orientalis*, and 7 groups or isolated individual trees, or trees in peri-urban areas (Figure 1).

We identified and determined individuals as *B. numenius* by easily visible external characteristics described in works of European authors [2, 8] using various stereomicroscopic magnifications (Zeiss, Stemi 305). Documentation photos of specimens of adult and nymph stages were taken with Zeiss Axiocam 105 color camera.

Specimens were stored dry and in alcohol in the entomological collection of prof. Nacheski at the Faculty of Forestry in Skopje.

## RESULTS

The first specimen of *B. numenius* in North Macedonia was collected on *Platanus x acerifolia* in Skopje (N 41°58’27”’ E 21°28’15”, leg. Srebrova, 10.07.2019). In total, nymph (Figure 2) and adult (Figure 3) specimens of *B. numenius* were registered and collected from 33 sites of the visited 44 locations in North Macedonia (Figure 1). In Skopje alone, *B. numenius* was registered and collected on 11 sites from various locations throughout the city from seed balls of all three plane species present in the country – *P. orientalis*, *P.* x *acerifolia* and *P. occidentalis*. All records in Skopje are listed as one in this publication (Figure 1).

In many cases, numerous individuals were recorded per single seed ball, including both adults and larvae (up to 13 individuals per single seed ball). On the other hand, there were cases where hundreds of seed balls had to be inspected per location (or tree) before registering the presence of a single specimen of *B. numenius*.

The highest altitude from which viable specimens were collected was 964 m a.s.l. in the town of Kratovo. On the contrary, the single plane tree in Krushevo was thoroughly inspected and did not bare any *B. numenius*, and similarly no presence was registered in Berovo (where only several seed balls from 1 of the 2 present trees were in reach). The southernmost finds in the country were near Dojran lake, close to the border with Greece.

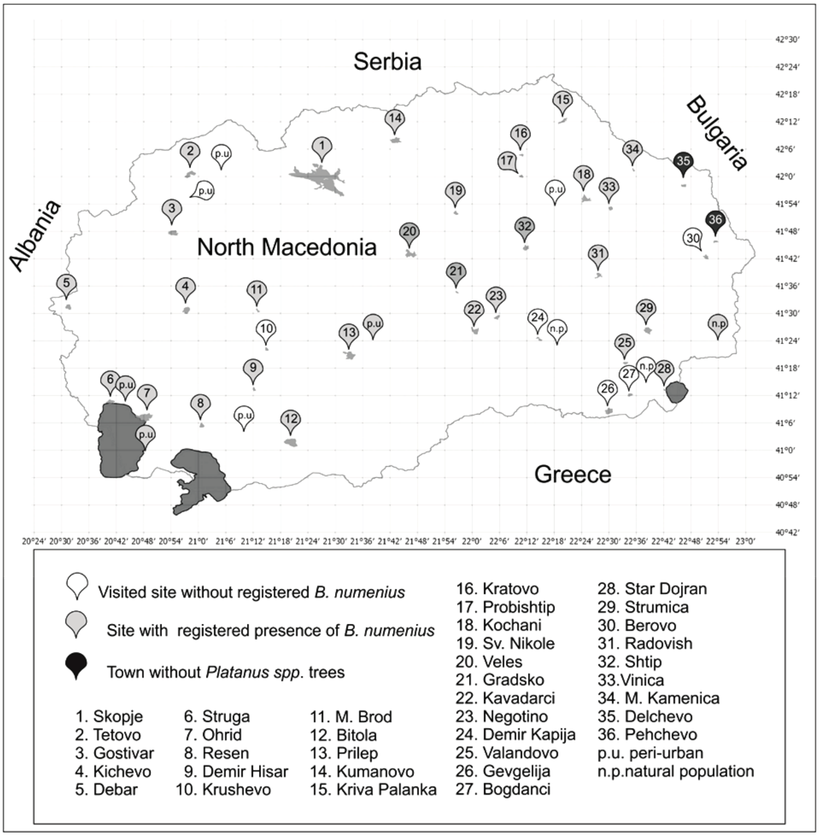


**FIGURE 1.** Inspected sites and records of *Belonochilus numenius* in North Macedonia in 2019.

**FIGURE 2.** Nymph of *B. numenius* collected in Skopje (photo: Velian Jagev)

**FIGURE 3.** Adult specimen of *B. numenius* (photo: Velian Jagev)

## DISCUSSION AND CONCLUSIONS

Having in mind that we registered the presence of this insect on most of the visited sites, it can be stated that it has been overlooked for many years, likely entering the territory of North Macedonia not long after being registered in Serbia and Bulgaria in 2011 and 2012, respectively. The main modes of dispersal and spread of the sycamore seed bug are flight, winds and passive transport, mainly by plant trade, as it is the case with other insects [24-26], and any of these modes could have been responsible for its entry into North Macedonia, either from neighboring countries, or from farther countries by imports of plant material. All of these modes have also likely played a role in fast dissemination and establishment of this Nearctic species in North Macedonia. Furthermore, the possibility of multiple introductions is very high by means of trade and transport of plant material, which is also applicable for other regions and countries in Europe, especially since this species is now widespread and established throughout the continent.

Although we did not find the presence of *B. numenius* in Demir Kapija (town and nearby natural population), Gevgelija and Bogdanci, we are inclined to believe that a more resolute inspection would likely reveal the presence of this insect species in some, if not all, subpopulations where we did not register it in 2019. Similarly, finding *B. numenius* near Dojran, very close to the border with Greece, is an indicator that further finds in Greece are only a matter of a more thorough search in this region.

Although this insect species is not considered to be a threat to its host species, it needs to be followed and eventually analyzed in the context of its relationship with insect species considered to be in their natural range in the Balkans, *Arocatus roeselii* (Schilling, 1829) and *A. longiceps* (Stål, 1872) [27, 28], which occupy and are dependent on the same ecological niche, i.e. seed balls of *Platanus*. It should be noted that during our inspections we recorded widespread presence of *Arocatus* spp., often occupying the same trees, and in rare cases both *B. numenius* and *Arocatus* sp. were present on the same seed balls. Weather the establishment of *B. numenius* will have any effects on populations of *Arocatus* spp. and whether potential mass populations of *B. numenius* can have any negative impact on the reproduction of natural populations of plane trees through seed propagation, as well as other wider environmental implications, remains to be investigated in the future.

### Acknowledgements

We express our gratitude to Velian Jagev for the photographs, and Boshko Cvetkovski, Mihajlo Risteski and Karolina Jangelova for help during the collection of specimens.

## REFERENCES

1. WHEELER JR A 1984 Seasonal history, habits, and immature stages of *Belonochilus numenius* (Hemiptera: Lygaeidae) [Pennsylvania]. *Proceedings Entomological Society of Washington* 86 (4): 790-796
2. GESSÉ F, RIBES J, GOULA M 2009 Belonochilus numenius, the sycamore seed bug, new record for the Iberian fauna. *B Insectol* 62 (1): 121-123
3. MAW HEL, FOOTTIT RG, HAMILTON KA, SCUDDER GG 2000 Checklist of the Hemiptera of Canada and Alaska. NRC Research Press, Ottawa, Canada, 220 p
4. SCUDDER GG 2012 Additional provincial and state records for Heteroptera (Hemiptera) in Canada and the United States. *Journal of the Entomological Society of British Columbia* 109: 55-69

5. BAENA M, TORRES JL 2012 Nuevos datos sobre heterópteros exóticos en España y Francia: Tempyra biguttula STÅL, 1874, *Belonochilus numenius* (Say, 1832) y *Zelus renardii* (Kolenati, 1856)(Heteroptera: Rhyparochromidae, Orsillidae, Reduviidae). *Boletín de la Asociación española de Entomología* 36 (3-4): 351-360
6. GOGALA A, KAMIN J, ZDEŠAR M 2016 Three new records of Heteroptera in Slovenia. *Acta Entomologica Slovenica* 24 (1): 55-58
7. RIBA JM, MARTÍ I, GOULA M 2015 Updating data on the sycamore seed bug, *Belonochilus numenius* (Say, 1832) (Hemiptera: Lygaeidae) in Spain. *Butlletí de la Institució Catalana d'Història Natural* 79: 157-163
8. KÜCHLER S, STRAUß G 2010 *Belonochilus numenius* (Say, 1832)(Heteroptera: Lygaeidae)—bald auch in Mitteleuropa? *Beiträge zur Entomofaunistik* 11: 27-33
9. WERNER D 2014 Die amerikanische Platanen-Samen-Wanze *Belonochilus numenius* (Say, 1831)(Heteroptera: Lygaeidae, Orsillinae) als Neozoon in Europa und in Deutschland: Verbreitung und Biologie. *Andrias* 20: 245-250
10. RABITSCH W, BRÄU M, FRIESS T 2011 *Belonochilus numenius* (Say, 1832)(Heteroptera: Lygaeidae) has reached Austria. *Beiträge zur Entomofaunistik* 12: 148-149
11. KMENT P, HRADIL K, BAŇAŘ P, BALVÍN O, CUNEV J, DITRICH T, JINDRA Z, ROHÁČOVÁ M, STRAKA M, SYCHRA J 2013 New and interesting records of true bugs (Hemiptera: Heteroptera) from the Czech Republic and Slovakia V. *Acta Musei Moraviae, Scientiae Biologicae* 98 (2): 495-541
12. KMENT P, CUNEV J 2013 First record of the alien seed bug *Belonochilus numenius* (Hemiptera: Heteroptera: Lygaeidae) in Slovakia. *Entomofauna Carpathica* 25 (2): 15-20
13. PROTIĆ L, ŠEAT J 2016 First records of the alien sycamore seed bug *Belonochilus numenius* in Serbia (Heteroptera: Lygaeidae). *Acta Entomologica Serbica* 21: 13-19
14. TORMA A 2012 First record of the alien sycamore seed bug *Belonochilus numenius* (Heteroptera: Lygaeidae) in Hungary. *Növényvédelem* 48 (10): 467-468
15. WERNER DJ, BRANDNER J, MULLER A, ZAPF M 2013 Ein Fund von *Belonochilus numenius* (Say, 1831) in Deutschland (Heteroptera: Lygaeidae) mit Diskussion zum Jahr der Erstbeschreibung der Art. *Heteropteron* 39: 37-39
16. RABITSCH W, HEISS E 2015 *Belonochilus numenius* (Say, 1832), the sycamore seed-bug (Hemiptera: Heteroptera: Lygaeidae), new to Madeira. *Heteropterus Revista de Entomología* 15 (1): 83-86
17. KULIJER D, MILJEVIC I 2016 First report of *Belonochilus numenius* (Say, 1832) in Bosnia and Herzegovina (Heteroptera, Lygaeidae). *Folia Historico-Naturalia Musei Matraensis* 40: 61-63
18. RABITSCH W 2018 Snapshot of the terrestrial true bug fauna of the Pocem floodplains (Insecta: Hemiptera: Heteroptera). *Acta ZooBot Austria* 155: 251-256
19. DAVRANOGLOU L-R, KOUTSOUKOS V 2018 First record of the Nearctic sycamore seed bug *Belonochilus numenius* (Hemiptera: Heteroptera: Lygaeidae) from Greece. *Ecologica Montenegrina* 16: 32-33
20. WERNER DJ 2017 New records of *Belonochilus numenius* (SAY, 1831) in Germany and fundamental statements about the species. *Heteropteron* 49: 21-22
21. HILPOLD A 2018 Die Platanen-Samenwanze *Belonochilus numenius* (SAY, 1832)(Heteroptera: Lygaeidae) - neu für Südtirol. *Gredleriana* 18: 129-130
22. SWEET MH 1960 The seed bugs: a contribution to the feeding habits of the Lygaeidae (Hemiptera: Heteroptera). *Ann Entomol Soc Am* 53 (3): 317-321. DOI: https://doi.org/10.1093/aesa/53.3.317
23. DZEKOV S 1988 Dendrology. Ss. Cyril and Methodius University, 538 p
24. 24. MUTUN S, CEYHAN Z, SÖZEN C 2009 Invasion by the oak lace bug, *Corythucha arcuata* (Say)(Heteroptera: Tingidae), in Turkey. *Turk J Zool* 33 (3): 263-268. DOI: https://doi.org/10.3906/zoo-0806-13
25. 25. IZHEVSKY S, MASLYAKOV VY 2010 New invasions of alien insects into the European part of Russia. *Russian Journal of Biological Invasions* 1 (2): 68-73. DOI: https://doi.org/10.1134/S2075111710020037
26. MACELJSKI M 1986 Current status of *Corythuca ciliata* in Europe 1. *EPPO Bulletin* 16 (4): 621-624. DOI: https://doi.org/10.1111/j.1365-2338.1986.tb00332.x
27. BIANCHI Z, ŠTEPANOVIČOVÁ O 2003 Some notes on the occurrence of *Arocatus* genus (Heteroptera, Lygaeidae) in Slovakia. *Folia Faunistica Slovaca* 8: 75-77
28. GAO C, KONDOROSY E, BU W 2013 A review of the genus *Arocatus* from Palearctic and Oriental regions (Hemiptera, Heteroptera: Lygaidae). *Raffles B Zool* 61 (2): 687-704

SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

PRELIMINARY COMMUNICATION

DOI: https://doi.org/10.15177/seefor.19-11

# Heavy Metals Content in Foliar Litter and Branches of *Quercus petraea* (Matt.) Liebl. and *Quercus robur* L. Observed at Two ICP Forests Monitoring Plots

**Srđan Stojnić[1]*, Marko Kebert[1], Milan Drekić[1], Zoran Galić[1], Lazar Kesić[1], Aleksandar Tepavac[2], Saša Orlović[1]**

**(1)** University of Novi Sad, Institute of Lowland Forestry and Environment, Antona Čehova 13d, RS-21000 Novi Sad, Serbia; **(2)** Public Enterprise "Vojvodinašume", Preradovićeva 2, RS-21000 Petrovaradin, Serbia

* **Correspondence:** e-mail: srdjan.stojnic@uns.ac.rs

**Citation:** STOJNIĆ S, KEBERT M, DREKIĆ M, GALIĆ Z, KESIĆ L, TEPAVAC A, ORLOVIĆ S 2019 Heavy Metals Content in Foliar Litter and Branches of *Quercus petraea* (Matt.) Liebl. and *Quercus robur* L. Observed at Two ICP Forests Monitoring Plots. *South-east Eur for* 10 (2): 151-157. DOI: https://doi.org/10.15177/seefor.19-11

**Received:** 17 May 2019; **Revised:** 24 Jun 2019; **Accepted:** 5 Jul 2019; **Published online:** 20 Aug 2019

## ABSTRACT

**Background and Purpose:** Due to the ability to uptake and accumulate heavy metals (HM) in their aboveground tissues, trees may be used for phytoremediation purposes, but also as bioindicators of environmental pollution. The aims of the present study were: a) to investigate the content and temporal variation of the studied HMs in different plant organs during the period of intensive leaf falling (September-October), in two species from genus *Quercus*; b) to evaluate the observed HMs content relative to plausible ranges of element concentration in foliar litter, as recommended by ICP Forests Foliar Co-ordinating Centre (IFFCC).

**Material and Methods:** The contents of zinc (Zn), manganese (Mn), copper (Cu) and iron (Fe) were assessed in the litterfall (i.e. leaves and branches) of *Quercus petraea* (Matt.) Liebl. and *Quercus robur* L. grown at two ICP Forests Level II monitoring plots (Fruška Gora and Odžaci, Serbia). Plant material was sampled during September-October 2018 and analyzed by atomic absorption spectrophotometry.

**Results:** Comparing the content of investigated HMs in foliar litter and branches of *Q. robur* and *Q. petraea*, notably higher concentrations of Mn and Fe have been observed in the foliage of both species, whereas Zn and Cu concentrations were higher in collected branch material of both of the above-mentioned tree species. The results further showed that, when compared to plausible ranges of element concentrations in foliar litter, given by IFFCC, average concentrations of Fe and Zn in the leaves were within suggested limits, whereas certain concentrations of Mn and Cu exceeded the proposed ranges. Furthermore, the content of the studied HMs in plant material of both *Quercus* species significantly varied during sampling period.

**Conclusions:** Although it was observed that concentrations of certain HMs were beyond plausible limits recommended by IFFCC, our results were in accordance with the findings of other authors who studied HMs content in *Quercus* species grown in natural forests. For that reason, these limits should be considered optionally, i.e. in the cases when the results significantly deviate from the suggested values. Moreover, we believe that the observed variation in the HMs content during sampling period is related to the sampling procedure commonly applied at ICP Forests monitoring plots, which is indirectly associated with the capacity of trees to accumulate HMs and their phenological properties.

**Keywords:** *Quercus robur* L., *Quercus petraea* (Matt.) Liebl., heavy metals content, litterfall

## INTRODUCTION

Recent studies have evidenced that trees can be efficiently used as bioindicators of heavy metals (HMs) contamination in diverse environments, such as urban areas, mining sites, natural forests, etc. [1-4]. Trees are able to uptake HMs throughout their root and leaves and accumulate it in various organs over time [5]. However, due to different uptake and accumulation paths of different HMs in trees, identification of the principal source of accumulated elements is rather difficult [6]. For that reason, certain authors believe that for the purpose of air pollution monitoring, lower plants (e.g. mosses and lichens) are more suitable [7, 8]. Nevertheless, using trees for such purpose has a number of advantages. For example, unlike moss and lichens, a clear separation/ distinction among different parts (e.g. leaves, branches, fruit, etc.) is possible in plant species [9]. Leaves usually have large surface area, thus contributing to the removal of airborne inorganic and organic pollutants, which might be either sedimented on the leaf blade or translocated into the leaf [10]. Likewise, as long-lived organisms, trees can reflect the cumulative effect of HMs polluting elements from both soil and ambient air [11]. Finally, the same tree species are widely distributed throughout many countries, thus providing the opportunity for establishing international monitoring networks, such as International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests), which enables continent-wide comparison and modeling of data across Europe [12].

Functioning of forest ecosystems largely depends on soil nutrient status, which is, in turn, highly correlated with litterfall amount and its chemical composition, as well as the vicinity of different pollution sources (e.g. highways, mines, etc.). Litterfall has a key role in the global biogeochemical cycles, being an important source of elements (including HMs) and organic matter for soils [13]. Besides macro elements in litterfall, forest production is greatly influenced also by the quantity of micro-components, among which HMs contribute to a large extent [14]. For example, Fe, Mn, Cu and Zn have been described as essential elements for physiological processes in trees [15]. However, although being reported as important micronutrients for plant growth and development regulations, these elements might be also very toxic in high concentrations [16]. Likewise, excessive amounts of HMs in litterfall can reduce the rate of litter decomposition, thus disturbing biological processes in the soil [17]. For these reasons, one of the principal activities within ICP Forests programme is sampling and analysis of litterfall, due to the importance of litter biomass and its chemical content in cycling processes of elements and organic matter along the forest canopy to the soil and vice versa [13].

In the present paper we studied the content and temporal variation of four HMs (Mn, Fe, Cu and Zn) in litterfall fractions (i.e. leaves and branches) of *Quercus petraea* (Matt.) Liebl. and *Quercus robur* L., grown at two ICP Forests monitoring plots, in Serbia. The mentioned oak species are among the most important tree species in Serbia, both from economic and ecological point of view. According to National Forest Inventory of the Republic of Serbia [18], *Q. petraea* accounts for 5.9% of volume and 6.1% of volume increment, being the third most abundant tree species in Serbia (after *Fagus sylvatica* and *Quercus cerris*). On the other hand, although it covers only 2.5% of volume and 1.7% of increment, *Q. robur* is economically the most valuable tree species in Serbia [19]. The aims of the study were: 1) to investigate the pattern of HMs accumulation in different plant organs, in two species from genus *Quercus*, 2) to determine the content of HMs in relation to plausible ranges of element concentration in foliar litter, given by ICP Forests Foliar Co-ordinating Centre [13], and 3) to study temporal variation in the concentrations of studied HMs during the period of leaf falling (September-October).

## MATERIAL AND METHODS

Plant material was collected from *Q. petraea* and *Q. robur* grown at two ICP Forests Level II monitoring plots situated in Serbia, respectively. The first plot was established in 2009 at Fruška Gora Mountain, in a mixed forest of *Quercus petraea, Fagus sylvatica* and *Tilia platyphyllos*, whereas the second plot was founded in 2011, in a pure forest of *Q. robur* on meadow-black soil. Both plots have been founded and maintained by the University of Novi Sad, Institute of Lowland Forestry and Environment (Novi Sad, Serbia). More information about monitoring plots are given in Table 1.

According to ICP Forests manuals [13], 20 fixed litterfall traps have been evenly distributed across the plot to represent the whole area and allow the collection of all tree species plant material. A top height of litterfall traps is approx. 1 m, while the catching area (i.e. the area of trap upper frame) amounts to 0.25 $m^2$. Canopy leaves and other litterfall inputs were collected in nylon nets, 0.5 m deep, which were attached to trap frames.

Sampling of plant material was performed five times at Fruška Gora and seven times at Odžaci plot during September and October 2018. At both sites, litterfall was collected from each trap (20 per single plot) and pooled in each sampling period, respectively. After collection, plant material was transported to the laboratory and temporarily stored at 4°C [13]. Prior to chemical analyses any litter collected was sorted out into foliar and non-foliar fractions (i.e. branches and fruit) and dried at 70°C for 24 hours [13].

Determination of selected microelements (Zn, Mn, Cu and Fe) was done in digested solutions that were made from powdered litterfall samples using standard method of microwave assisted digestion (D series; Milestone, Bergamo, Italy), while the quantification of metals was performed by Atomic Absorption Spectrophotometer in a flame regimen (model FS AAS240/GTA120, Varian – AAS, California, US). Approximately 0.3 g of oven-dried material were ground and homogenized in a laboratory mill and then digested in 10 ml of nitric acid and 2 ml 30% (w/v) hydrogen peroxide using a microwave-assisted digestion system (D series; Milestone,

**TABLE 1.** Description of ICP Forests monitoring plots Fruška Gora and Odžaci.

| Locality | Latitude (Deg.Min) | Longitude (Deg.Min) | Altitude (m a.s.l.) | Soil type | Mean air temperature (°C) | Annual sum of precipitations (mm) |
|---|---|---|---|---|---|---|
| Fruška Gora | 45°09' | 19°48' | 490 | Cambisol | 11.2 | 795 |
| Odžaci | 45°27' | 10°10' | 86 | Meadow-black | 10.9 | 577 |

Bergamo, Italy) for 45 min at 180°C (900 W) [20]. Filtrates were then diluted to 25 ml with deionizer water. Pre-treated samples were processed by AAS using the acetylene/air burner flame technique (with an atomization temperature of about 2300°C). Concentrations of Zn, Mn, Cu and Fe were determined by using single element hollow-cathode lamps at 213.9 nm (Zn), 324.8 nm (Cu), 248.3 nm (Fe) and 279.5 nm (Mn) respectively, and expressed in $\mu g\ g^{-1}$ dry weight (d.w.) of plant material.

The data were processed in Statistica 13 software [21], using Analyses of Variance (ANOVA) and methods of descriptive statistics (mean value and standard deviation). Significant differences in concentration of HMs in the leaves and branches of two oak species were determined at $p<0.05$.

## RESULTS

Descriptive statistics of HMs concentrations in *Q. petraea* and *Q. robur* litterfall from ICP Forests monitoring plots at Fruška Gora and Odžaci are reported in Table 2. Notably higher concentrations of Mn and Fe have been detected in leaves than in branches of *Q. petraea* and *Q. robur*, respectively. On the other hand, the content of Zn and Cu was higher in collected branch material of the above-mentoned tree species.

The ratio between the content of four HMs in leaves and branches, based on the average concentration during the sampling period, is presented in Figure 1. The highest ratio in the leaves of both species was reached by Fe (*Q. petraea* = 74.2%; *Q. robur* = 74.3%), which was followed by Mn (*Q. petraea* = 71.8%; *Q. robur* = 66.7%). In contrast, slightly higher ratios of Cu (*Q. petraea* = 52.1%; *Q. robur* = 54.3%) and Zn (*Q. petraea* = 64.1%; *Q. robur* = 56.8%) were calculated for branches of the studied tree species.

The results showed that the average detected amount of Mn in the leaves and branches of *Q. petraea* was 788.6 $\mu g\cdot g^{-1}$ (ranging between 630.7 and 976.8 $\mu g\cdot g^{-1}$) and 309.9 $\mu g\cdot g^{-1}$ (229.4–408.0 $\mu g\cdot g^{-1}$), respectively (Figure 2). In *Q. robur*, average concentrations of Mn were found to be 602.9 $\mu g\cdot g^{-1}$ (455.1–753.3 $\mu g\cdot g^{-1}$) and 301.4 $\mu g\cdot g^{-1}$ (137.2–460.3 $\mu g\cdot g^{-1}$) in the leaves and branches, respectively (Figure 3).

**TABLE 2.** Average concentration of heavy metals (mean value ± standard deviation) in litterfall of *Quercus petraea* (Matt.) Liebl. and *Quercus robur* L. observed on two ICP Forests monitoring plots.

| Heavy metal concentration ($\mu g\cdot g^{-1}$) | *Quercus petraea* (Matt.) Liebl. | | | *Quercus robur* L. | | |
|---|---|---|---|---|---|---|
| | Leaves | Branches | F-test | Leaves | Branches | F-test |
| Mn | 788.6±141.5 | 309.9±72.9 | 45.2*** | 602.9±110.4 | 301.4±116.2 | 24.8*** |
| Fe | 165.2±24.5 | 57.4±21.0 | 55.7*** | 145.3±17.5 | 50.2±17.5 | 103.6*** |
| Cu | 8.6±0.7 | 9.4±2.1 | 0.61 ns | 10.1±1.4 | 12.0±2.1 | 4.1 ns |
| Zn | 14.0±1.7 | 24.4±8.8 | 7.2* | 18.9±2.9 | 24.8±3.1 | 13.9** |

* - p<0.05; ** - p<0.01; *** - p<0.001; ns – non-significant

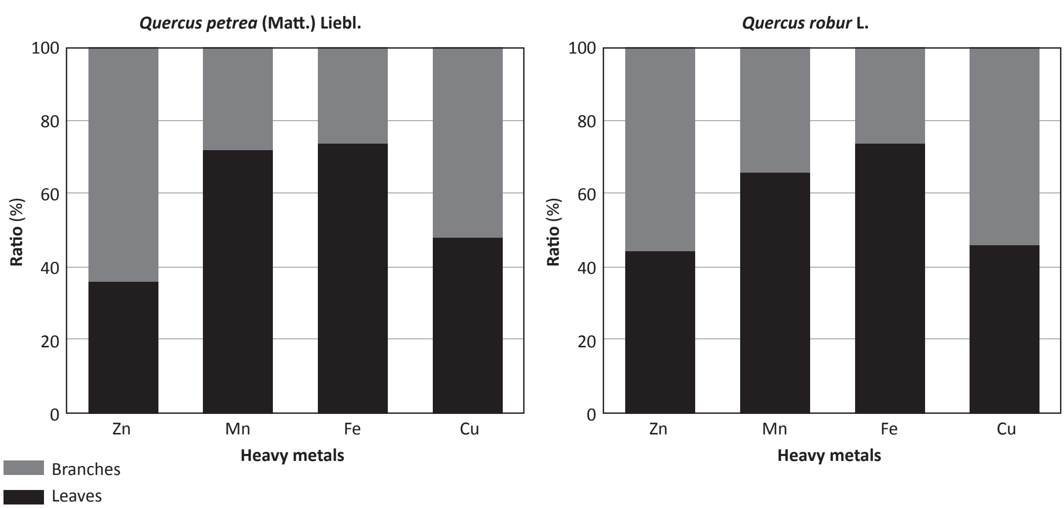


**FIGURE 1.** The ratio between the content of four heavy metals (Zn, Mn, Fe and Cu) in the leaves and branches, based on the average concentration ($\mu g\cdot g^{-1}$) during the sampling period.

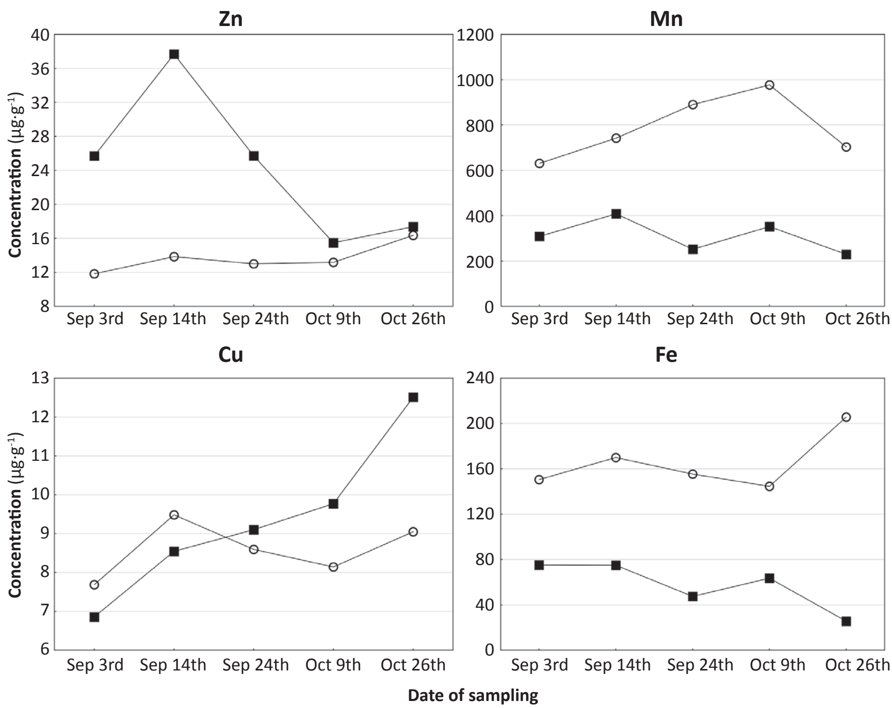


**FIGURE 2.** Temporal variation of heavy metals (Zn, Mn, Fe and Cu) content in the leaves (□) and branches (■) of *Quercus petraea* (Matt.) Liebl.

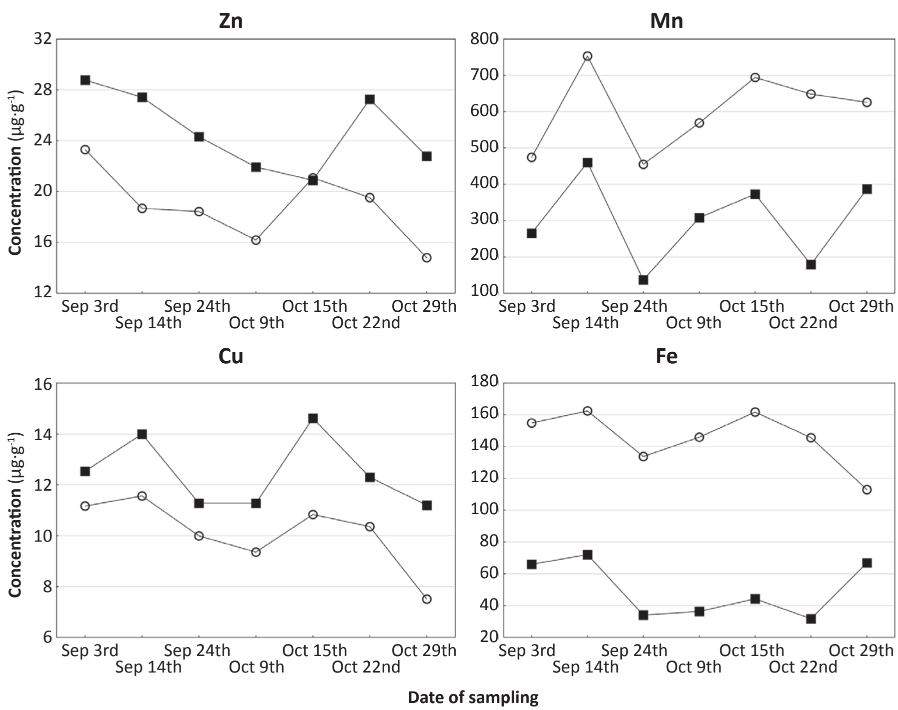


**FIGURE 3.** Temporal variation of heavy metals (Zn, Mn, Fe and Cu) content in the leaves (□) and branches (■) of *Quercus robur* L.

Average detected concentration of Fe in *Q. petraea* leaves was 165.2 $\mu g \cdot g^{-1}$, ranging between 144.5 and 205.6 $\mu g \cdot g^{-1}$, while its concentration in branch material was 57.4 $\mu g \cdot g^{-1}$ and varied between 25.7 and 75.2 $\mu g \cdot g^{-1}$. Concerning *Q. robur*, the observed concentration of Fe in the leaves and branches was a bit lower than it was recorded in sessile oak and amounted to 145.3 $\mu g \cdot g^{-1}$ (ranging between 112.9 and 162.5 $\mu g \cdot g^{-1}$) and 50.2 $\mu g \cdot g^{-1}$ (31.8 and 72.0 $\mu g \cdot g^{-1}$), respectively.

In contrast to Mn and Fe, slightly higher content of Cu was observed in the branch material of both species. In *Q. petraea* average content of Cu amounted to 9.4 $\mu g \cdot g^{-1}$ (ranging between 6.9 and 12.5 $\mu g \cdot g^{-1}$) and 8.6 $\mu g\ g^{-1}$ (7.7–9.0 $\mu g \cdot g^{-1}$), in the branches and leaves, respectively. Similar values for Cu content have been also recorded in *Q. robur* branches (12.0 $\mu g \cdot g^{-1}$; ranging between 8.3–14.6 $\mu g \cdot g^{-1}$) and leaves (10.1 $\mu g \cdot g^{-1}$; ranging between 7.5–11.6 $\mu g \cdot g^{-1}$).

Average content of Zn was almost the same in the branches of both tree species; i.e. 24.4 $\mu g \cdot g^{-1}$ (17.4–37.7 $\mu g \cdot g^{-1}$) in *Q. petraea*, and 24.8 $\mu g \cdot g^{-1}$ (21.9–28.8 $\mu g \cdot g^{-1}$) in *Q. robur*. Finally, Zn content in the leaf material of *Q. petraea* and *Q. robur* amounted to 13.6 $\mu g \cdot g^{-1}$ (11.8–16.4 $\mu g \cdot g^{-1}$) and 18.9 $\mu g \cdot g^{-1}$ (14.8–23.3 $\mu g \cdot g^{-1}$), respectively.

## DISCUSSION

Previous studies demonstrated that HMs content within *Quercus* genus is species- and organ-dependent [22, 23], although environmental conditions [5] and tree lifetime have certain effects on HMs accumulation as well [24]. Since HMs content in two oak species occurring at separated sites and, therefore, growing under different environmental conditions was examined, direct comparison of absolute values of HMs content in their organs was not possible. For that reason, the ratio was used to evaluate accumulation pattern of different HMs in leaves and branches. Similar approach was applied by Węgiel *et al.* [25] for studying of HMs accumulation in Scots pine stands of different densities. It was found that HMs content ratio in the leaves and branches of *Q. petraea* and *Q. robur* was similar in both species. Concerning Mn and Fe notably higher concentrations, and therefore higher ratios of these elements, were recorded in the foliage. Considering the time frame of sample collection (i.e. end of the growing season), the results obtained in this study are in accordance with the findings of Santa Regina *et al.* [24]. Namely, the authors continually reported seasonal accumulation of these two elements in the leaves of *Quercus pyrenaica*, whereas only slight increase in accumulation, but not statistically significant, was observed to have occurred in the branches. In contrast, the ratios of Zn and Cu were higher in branch material of the studied oak species. Similar results have been reported by Serbula *et al.* [4], who found slightly higher concentrations of Zn and Cu in branches than in leaves of *Robinia pseudoacacia* trees growing on unpolluted area.

Considering plausible range of element concentrations in foliar litter, given by ICP Forests Foliar Co-ordinating Centre [13], our results evidenced that concentrations of Fe and Zn in the studied tree species leaf material were within suggested limits. According to Pitman *et al.* [13] foliar concentration of Fe should range between 50 and 200 $\mu g \cdot g^{-1}$ in *Q. petraea*, and 90–150 $\mu g \cdot g^{-1}$ in *Q. robur*, which is also confirmed by the results of other authors (e.g. [26-28]). Unlike these findings, Aboal *et al.* [29] and Santamaría and Martin [30] recorded Fe concentration outside the given ranges. In case of Zn, recommended foliage content should vary between 14 and 25 $\mu g \cdot g^{-1}$ in *Q. petraea*, and 15–25 $\mu g \cdot g^{-1}$ in *Q. robur*. Similar values have been reported by other authors [30, 31], although certain authors reported the content of Zn in the leaves of studied oak species that was beyond these limits [26, 27, 29].

In contrast to Fe and Zn, certain concentrations of Mn and Cu were outside of plausible limits recommended by Pitman *et al.* [13]. Namely, while the previously mentioned authors stated that concentration of Mn in the leaf material should vary between 700 and 1700 $\mu g \cdot g^{-1}$ for *Q. petraea,* and 1000–1200 $\mu g \cdot g^{-1}$ for *Q. robur*, our results showed that average concentration of Mn in the leaves of the latter species was much lower (602.9 $\mu g \cdot g^{-1}$). Lower values were also reported by other authors: i.e. Kovács *et al.* [26] and Santamaría and Martin [30] reported that average foliar concentration of Mn in *Q. robur* amounted to 817 and 821 $\mu g \cdot g^{-1}$, respectively. Likewise, studying HMs content in the leaves of *Q. robur* trees grown across rural areas of Galicia, Aboal *et al.* [29] evidenced that average concentration of Mn was approximately 305 $\mu g \cdot g^{-1}$. Therefore, it is likely that upper and lower limits should be considered only conditionally. For example, Stanković *et al.* [32] showed that concentration of Mn in the leaves of *Q. petraea* varied over a broad range (434.5–722.0 $\mu g \cdot g^{-1}$), depending on properties of the growing site. Intriguingly, De Visser [22] observed various foliage concentration of Mn in three *Q. robur* populations (i.e. 180, 420 and 1180 $\mu g \cdot g^{-1}$, respectively).

Regarding Cu content in the leaves, slightly higher concentration of this element in case of *Q. petraea* was observed, whereas its concentration in *Q. robur* foliage significantly exceeded the upper limit (7 $\mu g \cdot g^{-1}$) given by Pitman *et al.* [13]. Similar results to Pitman *et al.* [13] have been reported by Kovács *et al.* [26] and Aboal *et al.* [29]. On the other hand, Santamaría and Martin [29] have found that average concentration of Cu in *Q. robur* leaves observed across 14 mixed stands in Spain amounted to 9.8 $\mu g \cdot g^{-1}$.

Our results showed that the content of all HMs in litterfall of studied oak species varied between sampling dates, although sampling was performed in a quite short period of time (Figures 2 and 3). Possible explanation for this phenomenon might be the sampling procedure applied at ICP Forests plots. Namely, according to ICP Forests procedures [13], HMs content in plant fractions is estimated from the bulk samples consisting of litterfall collected from all traps on the plot. As sampled litterfall originates from different oak genotypes spanned randomly across the sampling plot area, the results probably depended on both the ability of different genotypes to accumulate HMs in their tissues and the amount of certain genotypes of litterfall collected in the traps. Indeed, previous studies evidenced that HMs content in the plant material may vary over a broad range even among trees within a single population. For example, studying the concentration of Zn, Mn and Fe in the leaves of *Ulmus laevis* Pall. trees, Devetaković *et al.* [33] reported that their contents greatly varied between different trees grown on a small and isolated island. Similarly, studying the content of Pb, Mn, Zn, Ni and Fe in different lime genotypes grown across several sites at Fruška Gora Mountain, Šijačić-Nikolić *et al.* [34] concluded that genotype (i.e. genetic architecture of each sampled tree) was the main driver influencing the concentration of the studied HMs in the leaves (i.e. since metal transporters are genetically coded proteins).

In addition to different capacity of genotypes to accumulate HMs in their tissues, the observed differences in HMs content in litterfall during the sampling period may be also the consequence of phenological characteristics of oak trees on the plots. It is well known that plant phenology depends on a number of factors, such as air temperature, soil moisture, day length, activities of herbivores and pollinators, etc. [35]. Giving an overview of spring and autumn phenology in *Q. petraea* and *Q. robur* at current ICP Forests monitoring plots in the six-year period (2011-2016), Pekeč *et al.* [36] reported that leaf fall phases may take between 8 and 29 days, depending on tree species and year of observation. However, phenological stages may also be influenced by genotype properties within single tree species [37]. In the case of *Q. robur* the existence of four varieties occurring along Danube and Sava River (*precox*, *typica*, *tardiflora* and *tardissima*) was even documented, which are distinguished based on spring phenology [38]. In this sense, it might be assumed that phenological phases, and, therefore the intensity of leaf falling in autumn, differ among various trees on the plots, thus contributing to unequal amount of each genotype litterfall in the bulk sample.

## CONCLUSIONS

The results of this study showed that concentrations of Mn and Fe were significantly higher in the foliage of both oak species, whereas slightly higher content of Zn and Cu was observed in the collected branch material. Considering plausible range of element concentrations in foliar litter, suggested by ICP Forests Foliar Co-ordinating Centre [13], it was observed that average concentrations of Fe and Zn in the leaves were within suggested limits, whereas certain concentrations of Mn and Cu were beyond these limits. Nevertheless, our results correspond to the findings of other authors who studied HMs content in natural and unpolluted areas, and therefore we believe that these limits should be considered mainly in the cases when the results significantly deviate from the suggested values. Moreover, it was also observed that the content of HMs in the leaves and branches of the studied tree species varied during the sampling period (September – October 2018), probably as the consequence of sampling procedure commonly applied at ICP Forests monitoring plots, as well as biological characteristics of sampled trees (i.e. the capacity to accumulate HMs and phenological features).

### Acknowledgements

This paper was realized as part of the project "Program praćenja uticaja prekograničnog aerozagađenja u šumskim ekosistemima na teritoriji AP Vojvodine u 2019. godini", financed by the Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia.

## REFERENCES

1. BATOS B, VESELINOVIĆ M, RAKONJAC LJ, MILJKOVIĆ D 2019 Morphological properties of pollen as bioindicators of deciduous woody species in Belgrade parks (Serbia). *Topola* 203: 19-30
2. ALAHABADI A, EHRAMPOUSH MH, MIRI M, AVAL HE, YOUSEFZADEH S, GHAFFARI HR, AHMADI E, TALEBI P, *et al.* 2017 A comparative study on capability of different tree species in accumulating heavy metals from soil and ambient air. *Chemosphere* 172: 459-467. DOI: https://doi.org/10.1016/j.chemosphere.2017.01.045
3. PATEL KS, SHARMA R, DAHARIYA NS, YADAV A, BLAZHEV B, MATINI L, HOINKIS J 2015 Heavy metal contamination of tree leaves. *Am J Analyt Chem* 6: 687-693. DOI: https://doi.org/10.4236/ajac.2015.68066
4. SERBULA SM, MILJKOVIC DDJ, KOVACEVIC RM, ILIC AA 2012 Assessment of airborne heavy metal pollution using plant parts and top soil. *Ecotoxicol Environ Saf* 76: 209-214. DOI: https://doi.org/10.1016/j.ecoenv.2011.10.009
5. BARGAGLI R, MONACI F, AGNORELLI C 2003 Oak leaves as accumulators of airborne elements in an area with geochemical and geothermal anomalies. *Environ Pollut* 124 (2): 321-329. DOI: https://doi.org/10.1016/S0269-7491(02)00465-7
6. SAWIDIS T, CHETTRI MK, PAPAIOANNOU A, ZACHARIADIS G, STRATIS J 2001 A study of metal distribution from lignite fuels using trees as biological monitors. *Ecotoxicol Environ Saf* 48: 27-35. DOI: https://doi.org/10.1006/eesa.2000.2001
7. LIPPO H, POIKOLAINEN J, KUBIN E 1995 The use of moss, lichen and pine bark in the nationwide monitoring of atmospheric heavy metal deposition in Finland. *Water Air Soil Pollut* 85 (4): 2241-2246. DOI: https://doi.org/10.1007/BF01186167
8. JIANG Y, FAN M, HU R, ZHAO J, WU Y 2018 Mosses are better than leaves of vascular plants in monitoring atmospheric heavy metal pollution in urban areas. *Int J Environ Res Public Health* 15 (6): 1105. DOI: https://doi.org/10.3390/ijerph15061105
9. JAMNICKÁ G, VÁĽKA J, BUBLINEC E 2013 Heavy metal accumulation and distribution in forest understory herb species of Carpathian beech ecosystems. *Chem Spec Bioavailab* 25 (3): 209-215. DOI: https://doi.org/10.3184/095422913X13785568683285
10. NOWAK JD HIRABAYASHI S BODINE A GREENFIELD E 2014 Tree and forest effects on air quality and human health in the United States. *Environ Pollut* 193: 119-129. DOI: http://dx.doi.org/10.1016/j.envpol.2014.05.028
11. SAWIDIS T, BREUSTE J, MITROVIC M, PAVLOVIC P, TSIGARIDAS K 2011 Trees as bioindicator of heavy metal pollution in three European cities. *Environ Pollut* 159: 3560-3570. DOI: https://doi.org/10.1016/j.envpol.2011.08.008
12. BERKI I, RASZTOVITS E, MÓRICZ N, KOLOZS L 2016 The

role of tree mortality in vitality assessment of sessile oak forests. *South-east Eur for* 7 (2): 91-97. DOI: https://doi.org/10.15177/seefor.16-14

13. PITMAN R, BASTRUP-BIRK A, BREDA N, RAUTIO P 2010 Sampling and analysis of litterfall. Part XIII. *In:* Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. UNECE ICP Forests Programme Co-ordinating Centre, Hamburg, Germany, pp 16
14. PARZYCH A, MOCHNACKÝ S, SOBISZ Z, KURHALUK N, POLLÁKOVÁ N 2017 Accumulation of heavy metals in needles and bark of *Pinus* species. *Folia For Pol Ser A 59* (1): 34-44. DOI: https://doi.org/10.1515/ffp-2017-0004
15. BRECKLE SW, KAHLE H 1992 Effects of toxic heavy metals (Cd, Pb) on growth and mineral nutrition of beech (*Fagus sylvatica* L.). *Vegetatio* 101 (1): 43-53
16. DOGANLAR BZ, DOGANLAR O, ERDOGAN S, ONAL Y 2012 Heavy metal pollution and physiological changes in the leaves of some shrub, palm and tree species in urban areas of Adana, Turkey. *Chem Spec Bioavailab* 24 (2): 65-78. DOI: https://doi.org/10.3184/095422912X13338055043100
17. JONCZAK J, PARZYCH A 2014 The content of heavy metals in the soil and litterfall in a beech-pine-spruce stand in Northern Poland. *Arch Environ Prot* 40 (4): 67-77. DOI: https://doi.org/10.2478/aep-2014-0039
18. BANKOVIĆ S, MEDAREVIĆ M, PANTIĆ D, PETROVIĆ N 2009 National forest inventory of the Republic of Serbia. Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia, Forest Directorate, Belgrade, Serbia, 244 p
19. STOJNIĆ S, TRUDIĆ B, GALOVIĆ V, ŠIMUNOVAČKI Đ, ĐORĐEVIĆ B, RAĐEVIĆ V, ORLOVIĆ S 2014 Conservation of Pedunculate oak (*Quercus robur* L.) genetic resources in the Public Enterprise "Vojvodinašume" (*in Serbian with English summary*). *Topola* 193-194: 47-71
20. NOVAKOVIĆ AR, KARAMAN MA, MILOVANOVIĆ ILJ, TORBICA AM, TOMIĆ JM, PEJIN BM, SAKAČ MB 2018 Nutritional and phenolic profile of small edible fungal species *Coprinellus disseminatus* (Pers.) J.E. Lange 1938. *Food and Feed Research* 45 (2): 119-128. DOI: https://doi.org/10.5937/FFR1802119N
21. TIBCO SOFTWARE INC 2017 Statistica (data analysis software system), version 13. URL: http://statistica.io.
22. DE VISSER PHB 1992 The relations between chemical composition of oak rings, leaf, bark, and soil solution in a partly mixed stand. *Can J Forest Res* 22 (12): 1824-1831. DOI: https://doi.org/10.1139/x92-238
23. OPYDO J UFNALSKI K OPYDO W 2005 Heavy metals in Polish forest stands of *Quercus robur* and *Q. petraea. Water Air Soil Pollut* 161 (1-4): 175-192. DOI: https://doi.org/10.1007/s11270-005-3522-5
24. SANTA REGINA I, RICO M, RAPP M, GALLEGO HA 1997 Seasonal variation in nutrient concentration in leaves and branches of *Quercus pyrenaica*. *J Veg Sci* 8 (5): 651-654. DOI: https://doi.org/10.2307/3237369
25. WĘGIEL A, BIELINIS E, POLOWY K 2018 Heavy metals accumulation in Scots pine stands of different densities growing on not contaminated forest area (northwestern Poland). *Austrian J For Sci* 35 (3): 259-281
26. KOVÁCS M, PENKSZA K, TURCSÁNYI G, KASZAB L, TÓTH S, SZÔKE P 1994 Comparative investigation of the distribution of chemical elements in an *Aceri tatarico-quercetum* plant community and in stands of cultivated plants. *In:* Markert B (eds) Environmental Sampling for Trace Analysis. VCH, Weinheim, pp 435-442
27. STANKOVIĆ D, MEDAREVIĆ M, KRSTIĆ B, BJELANOVIĆ I, ŠLJUKIĆ B, KARIĆ D, JANJIĆ M 2013 Concentration of heavy metals and stand state of sesille oak (*Quercus petraea* (Matt.) Liebl.) on Avala mountain (Serbia). *Carpath J Earth Environ Sci* 8 (3): 59-66
28. STANKOVIĆ D, ŠIJAČIĆ-NIKOLIĆ M, VILOTIĆ D, IVETIĆ V, KARIĆ D, VESELINOVIĆ M 2015 Iron (Fe) content in vegetation cover of the natural protected area Kosmaj, Serbia. *Fresen Environ Bull* 24 (2a): 626-631
29. ABOAL JR, FERNÁNDEZ JA, CARBALLEIRA A 2004 Oak leaves and pine needles as biomonitors of airborne trace elements pollution. *Environ Exp Bot* 51 (3): 215-225. DOI: https://doi.org/10.1016/j.envexpbot.2003.11.003
30. SANTAMARÍA JM, MARTÍN A 1998 Influence of air pollution on the nutritional status of Navarra's forests, Spain. *Chemosphere* 36 (4-5): 943-948. DOI: https://doi.org/10.1016/S0045-6535(97)10152-7
31. STANKOVIĆ D, JOKANOVIĆ D, VESELINOVIĆ M, LETIĆ LJ, JOVIĆ Đ, KARIĆ D 2015 Zinc concentration in woody and herbaceous plants at Kosmaj area, Serbia. *Fresen Environ Bullet* 24 (11): 3672-3675
32. STANKOVIĆ D, IVETIĆ V, OCOKOLJIĆ M, JOKANOVIĆ D, OLJAČA R, MITROVIĆ S 2015 Manganese concentration in plants of the protected natural resource, Kosmaj, in Serbia. *Arch Biol Sci* 67 (1): 251-255. DOI: https://doi.org/10.2298/ABS141112031S
33. DEVETAKOVIĆ J, STANKOVIĆ D, IVETIĆ I, MITROVIĆ B, TODOROVIĆ N 2017 The concentration of Zn, Mn and Fe in leaves of *Ulmus laevis* Pall. at Veliko Ratno Ostrvo island (Belgrade, Serbia). *Carpath J Earth Env* 12 (1): 69-75
34. ŠIJAČIĆ-NIKOLIĆ M, STANKOVIĆ D, KRSTIĆ B, VILOTIĆ D, IVETIĆ V 2012 The potential of different lime tree (*Tilia* spp) genotypes for phytoextraction of heavy metals. *Genetika+* 44 (3): 537-548. DOI: https://doi.org/10.2298/GENSR1203537S
35. MIN MB 2000 Comparison of phenological characteristics for several woody plants in urban climates. *J Plant Biol* 43 (1): 10-17. DOI: https://doi.org/10.1007/BF03031030
36. PEKEČ P, ORLOVIĆ S, KATANIĆ M, STOJNIĆ S, DREKIĆ M 2017 Fenološka osmatranja hrasta kitnjaka (*Quercus petraea* Matt/Liebl.) i hrasta lužnjaka (*Quercus robur* L.) na području Vojvodine *(in Serbian with English summary)*. *Topola* 199-200: 11-20
37. MILOŠEVIĆ T, MILOŠEVIĆ N, GLIŠIĆ I, KRŠKA B 2010 Characteristics of promising apricot (*Prunus armeniaca* L.) genetic resources in Central Serbia based on blossoming period and fruit quality. *Hort Sci* 37 (2): 46-55. DOI: https://doi.org/10.17221/67/2009-HORTSCI
38. ORLOVIĆ S, ERDEŠI J, RADIVOJEVIĆ S, OBUĆINA Z, JANJATOVIĆ G 2001 Semenske plantaže hrasta lužnjaka *(Quercus robur* L.) – osnov za dalje oplemenjivanje u ravnom Sremu *(in Serbian with English summary)*. *Šumarstvo* 1: 1-9

SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

PRELIMINARY COMMUNICATION

DOI: https://doi.org/10.15177/seefor.19-13

# Structural Features of Old Growth Forest from South Eastern Carpathians, Romania

**Valentin Cristea[1], Ștefan Leca[2]*, Albert Ciceu[2], Șerban Chivulescu[2], Ovidiu Badea[1,2]**

**(1)** Transilvania University of Brasov, Faculty of Silviculture and Forest Engineering, 1 Șirul Beethoven 1, RO-500123 Brasov, Romania; **(2)** National Institute for Research and Development in Forestry "Marin Drăcea", 28 Eroilor Blvd., RO-077190 Voluntari, Romania

*** Correspondence:** e-mail: stefan.leca@icas.ro

**Citation:** CRISTEA V, LECA Ș, CICEU A, CHIVULESCU Ș, BADEA O 2019 Structural Features of Old Growth Forest from South Eastern Carpathians, Romania. *South-east Eur for* 10 (2): 159-164. DOI: https://doi.org/10.15177/seefor.19-13

**Received:** 24 May 2019; **Revised:** 10 Jul 2019; **Accepted:** 11 Jul 2019; **Published online:** 15 Aug 2019

## ABSTRACT

**Background and Purpose:** Romania's forests are of globally significant value due to their natural characteristics, as similar forests in some other parts of the world have been lost forever. These types of forests, so-called "virgin" and "quasi-virgin (old growth)" forests, are also identified in the Buzau Mountains, which are part of the Eastern Carpathians in Romania (Curvature Region).

**Materials and Methods:** To study and understand the structure and dynamics of primeval forest, four permanent one-hectare research plots were installed in the Penteleu Mountains, part of the Buzau Mountains. All trees with a diameter at breast height (DBH) greater than 80 mm were measured and their main dendrometric characteristics (DBH, height and social position) registered. The forest structure was analysed by fitting different theoretical distribution functions (beta, gamma, gamma 3P, gamma 3P mixt, loglogistic 3p, lognormal 3P and Weibull 3p). The structural homogeneity of the permanent research plots was tested using the Camino index (H) and Gini index (G).

**Results:** For the smaller DBH categories, Norway spruce was relatively shorter in height, but with increasing DBH, the heights of Norway spruce exceeded those of European beech. Stand volume varied between 615 and 1133 $m^3$ per hectare. The area of maximum stability where we encountered the lowest tree height variability was recorded between the 60 cm and 100 cm diameter categories. The Lorenz curve and the Gini index indicated that the studied stands have high structural biodiversity.

**Conclusions:** The results showed that the studied forests have an optimal structural diversity, assuring them a higher stability and multifunctionality. Thus, these forests are models for managed forests.

**Keywords:** forest structure, quasi-virgin forests, old growth forests, DBH, optimal diversity, multifunctionality

## INTRODUCTION

Romania's primary forests are of globally significant value due to their natural characteristics, as similar forests in some other parts of the world have been lost forever [1, 2]. Quasi-virgin forests are those that have been managed in the past but that over time have been left to develop naturally, gaining specific features such as mixed tree ages, the presence of development phases, and strong relationships between dendrometric elements (i.e., diameter at breast height - DBH, height, and volume) [3, 4]. The study of these forests is of high value, as they are considered an important source of scientific information that can be used in the management of uneven-aged forests [5]. Quasi-virgin forests have numerous ecological, scientific, economic, social, and cultural characteristics, and they provide shelter for numerous species of flora and fauna [6] that have disappeared from managed forests.

Despite their importance, many quasi-virgin forests are partially or completely unprotected, and their surface area is decreasing. Given their importance, there is an urgent concern to protect all of these types of forests, in Romania as well as on a global scale [2, 7]. Recently, interest in sustainable forest management concerning biodiversity and the protection of nature has increased enormously [8].

Numerous scientists have highlighted the importance of these types of ecosystems in different locations around the world [2]. In Europe, interest in natural forest stands began to appear with the publication of G. Gayer's Silviculture Treaty

(1878), in which he proposed respecting natural laws in forest development. After World War II, Leibundgut carried out multiple studies in natural forest stands [9-11], promoting the importance of these special ecosystems at the International Union of Forest Research Organizations (IUFRO). In 1971, IUFRO established a research group focused on studying natural forest stands and, taking into account the remarkable results and work done by Leibundgut, appointed him chairman of this scientific group [12]. In the period from 1995-1999, research was carried out within the secular forest stands situated in the boreal area of the Scandinavian Peninsula and in the northern European region of Russia, which exhibited the dangers of forest loss due to excessive logging [13]. Other studies of this kind were carried out in the Perućica Forest Reserve in the territory of Bosnia and Herzegovina; that work concluded that these natural forests are clearly superior in terms of biodiversity and structure compared to managed forests [14]. In 2000, a research area of 10 hectares was installed in the Uholka-Shyrokyi Luh Reserve (total area of the reserve is 15,974 ha, of which approx. 9,000 ha are considered virgin beech forests) located in the Transcarpathian region of Ukraine [15]. The naturalness, uniqueness, and the high level of biodiversity of these forests have attracted the attention of politicians and led to changes in the legislative framework in order to better protect them [12]. In Croatia, laws adopted for the protection and maintenance of natural forests date back to the 18th century [16]. In Romania, quasi-virgin forests have been protected by modifying the legal framework [17]. The aim of this paper is to emphasize the structural characteristics and very high structural diversity of quasi-virgin forests located in the Curvature Carpathians region (Romania) and to highlight the knowledge of their special structural features. The results of research on primary forests are extremely valuable for developing sustainable forest management practices.

## MATERIALS AND METHODS

Four permanent research plots (Plots A, B, C and D) were established in the Penteleu Mountains in the Curvature Carpathians Region, Romania (Figure 1).

The forest stands where the permanent research plots were located have not been influenced by human activity for a very long time, according to the criteria for identifying quasi-virgin forests [17, 18]. The permanent research plots were established during the period 2015-2018 and have dimensions of 100×100 m (1 ha). The perimeter of each plot was delineated using a Global Positioning System (GPS). All trees in each permanent research plot with a DBH>8 cm were inventoried by measuring the DBH and height (H) and establishing the tree's social position in the canopy. Tree height was measured using an ultrasonic hypsometer (Vertex IV) and DBH using a measuring tape. Based on the field inventory of the forest stands, their structural characteristics were processed and analysed. First the DBH distribution was analysed, then the structural biodiversity of the studied forest stands. It has been established that in the absence of human intervention, natural dynamics lead to very diverse forest stand structures [19, 20]. One of the important aspects of diversity in forests is tree size variability. Gini [21] and Camino [22] are two relevant indices of forest structure based on dispersion estimates of tree size [20]. The structural homogeneity of the studied forest plots was tested using the Camino and Gini indexes, and a graphic representation was made using the Lorenz curve [23]. The Gini coefficient has proven to perform better as an indicator of forest structure than Shannon's diversity index, Simpson or other indices [24]. Therefore, the Gini coefficient is recognised as the best estimator of stand structure based on DBH [25, 26].

The volume of each tree was determined using the following formula:

$$\log v = b_0 + b_1 \log d + b_2 \log^2 d + b_3 \log h + b_4 \log^2 h \qquad [27]$$

where $b_0$, $b_1$, $b_2$, $b_3$ and $b_4$ are nationally (Romanian) specific coefficients for each species. The experimental DBH distribution was fitted using different theoretical distribution functions (beta, gamma, gamma 3P, gamma 3P mixt, loglogistic 3p, lognormal 3P and Weibull 3p). To estimate the goodness of fit of the theoretical distributions to the measured DBH values, the $\chi 2$ criterion, Kolmogorov Smirnov (KS) [28] and Anderson Darling (AD) [29] statistical tests were used. Analyses were performed using Microsoft Excel Software, Mathwave - EasyFit Distributions, IBM SPSS Statistics, and packages fitdistrplus [30] and mixdist [31] of the software R.

## RESULTS AND DISCUSSION

All the permanent research plots exhibited uneven-aged structure, a large number of trees and a high volume per hectare (Table 1).

### Fitting of Experimental DBH Distribution Related to Number of Trees

To identify the best theoretical function to fit the distribution of the collected field data, beta, gamma, gamma

**TABLE 1.** General characteristics of permanent research plots.

| Research Plot | Altitude (m) | Area (ha) | Shape | Stand structure | No. of trees per ha | Volume ($m^{3}\cdot ha^{-1}$) |
|---|---|---|---|---|---|---|
| Plot A | 1130 | 1 | square | uneven - aged | 612 | 1133.34 |
| Plot B | 1100 | 1 | square | uneven - aged | 749 | 785.44 |
| Plot C | 1250 | 1 | square | uneven - aged | 522 | 910.25 |
| Plot D | 1250 | 1 | square | uneven - aged | 486 | 615.13 |

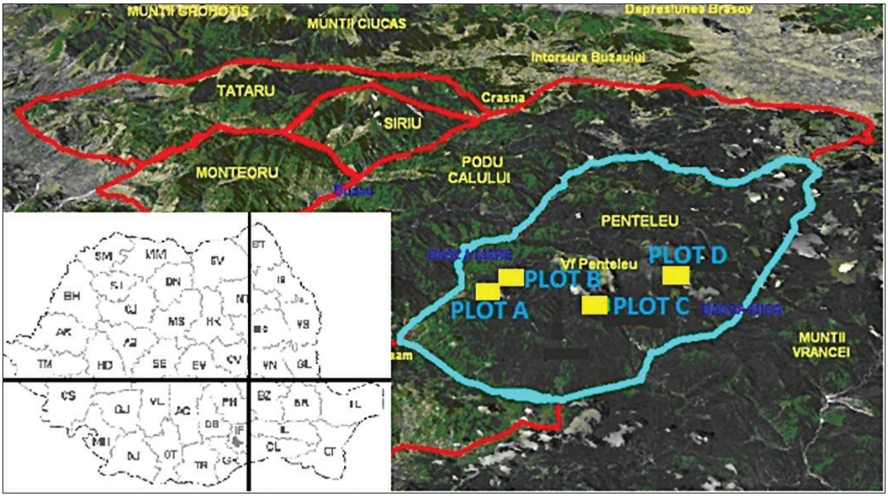


**FIGURE 1.** Research plots location (www. fetch.ro).

3P, gamma 3P mixt, loglogistic 3p, lognormal 3P and Weibull 3p functions were tested (Figure 2). In the case of research plot C, a bimodal experimental distribution was observed. For this particular situation where the forest stand could not be fitted with the studied theoretical functions, a combination of two gamma functions was used. The bimodal distribution is more accentuated in research plot C than in the other plots and is related to the plot's history [32, 33] and events like fire [34], wind disturbance or other biotic and abiotic factors.

The KS test and $\chi^2$ criterion for goodness of fit for plot A showed no differences between the experimental and theoretical distributions for the lognormal 3P function. The AD test showed no differences between the experimental and theoretical distributions for the Weibull 3P, gamma 3P and lognormal 3P functions. In the case of plot B, all of the goodness of fit tests indicated that the experimental DBH distribution followed the theoretical distributions except for the gamma distribution, where the statistical tests showed significant differences between the experimental and theoretical distributions. In the case of plot D, the relationship between DBH distribution and number of trees was analysed using the lognormal 3P, gamma 3P and beta functions. None of these theoretical functions adjusted the experimental DBH distribution (Table 2). Using the $\chi^2$ criterion, in the case of plot C, the theoretical frequencies resulting from the mixed gamma 3P function were significantly different from the experimental distribution (p>0.05) (Table 3). The experimental DBH distribution has a descending form, with the highest numbers of trees in small DBH categories and a shape similar to a reverse "J" [35], which is specific to the structure of quasi-virgin forests. All research plots exhibited high variation in DBH, over 90 cm, an aspect specific to uneven-aged stands [36, 37].

## Structural Biodiversity Analysis of Studied Forest Stands

To test the biodiversity of the studied stands, the Gini (G) and Camino (H) indexes were calculated, and for graphical analysis, a Lorenz curve was generated (Figure 3). The Lorenz

**TABLE 2.** Main indicators of theoretical distributions.

| Research plot | Distribution | Kolmogorov Smirnov Test | | Anderson Darling Test | | $\chi^2$ Criterion | |
|---|---|---|---|---|---|---|---|
| | | Experimental values | Theoretical values | Experimental values | Theoretical values | Experimental values | Theoretical values |
| Plot A | Weibull 3p | 0.06 | 0.054 | 2.47* | 2.50 | 25.76 | 16.92 |
| | Lognormal 3p | 0.05* | 0.054 | 2.05* | 2.50 | 13.21* | 16.92 |
| | Gamma 3p | 0.06 | 0.054 | 2.33* | 2.50 | 25.17 | 16.92 |
| Plot B | LogLogistic 3p | 0.04* | 0.049 | 1.99* | 2.50 | 8.02* | 16.92 |
| | Lognormal 3p | 0.03* | 0.049 | 1.38* | 2.50 | 10.71* | 16.92 |
| | Gamma | 0.15 | 0.049 | 22.46 | 2.50 | 130.91 | 16.92 |
| Plot D | Lognormal 3p | 0.07 | 0.057 | 5.22 | 2.50 | 38.47 | 16.92 |
| | Beta | 0.09 | 0.057 | 5.74 | 2.50 | 48.39 | 16.92 |
| | Gamma 3p | 0.09 | 0.057 | 5.57 | 2.50 | 49.42 | 16.92 |

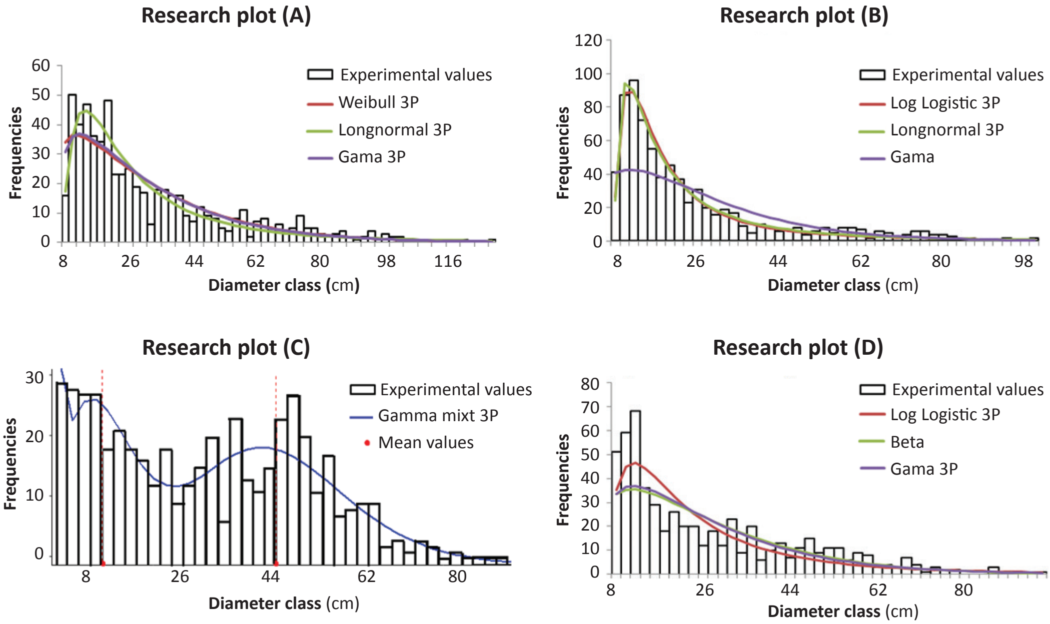


**FIGURE 2.** Fitting experimental (observed) DBH distributions with theoretical functions.

curve and the Gini indexes indicate that the studied stands have high structural biodiversity, which is specific to this type of forest ecosystem. The Gini index of the plots ranged from 0.69-0.71 which is very close to the index's maximum value of 1 [24]. The Camino index of the plots ranged between 1.62 and 1.71. The Gini and Camino coefficients calculated for the

**TABLE 3.** The results of the statistical test χ2 used to fit experimental distribution with Gamma mixt function in research plot C.

| Research plot | Function | f | χ2 | p |
|---|---|---|---|---|
| Plot C | Gamma | 42 | 48.567 | 0.2254 |

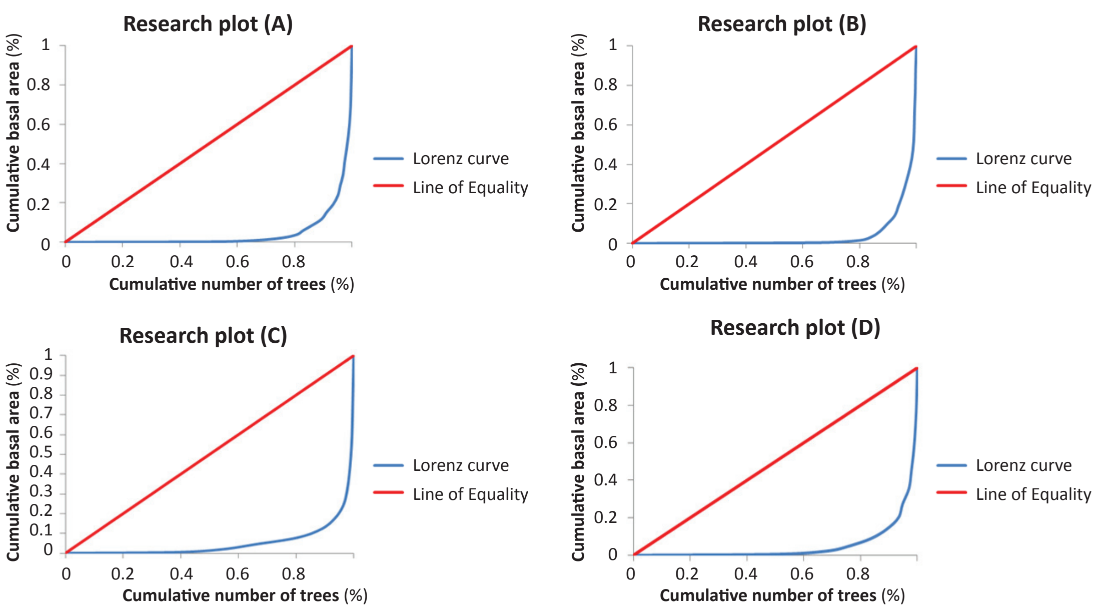


**FIGURE 3.** Lorenz Curve for each permanent research plot.

forest stands in the present research are close to the values obtained for other uneven-aged forests, which emphasizes that the studied stands are characterized as uneven-aged stands [38-40].

## CONCLUSIONS

Based on the results presented in this research, it can be concluded that due to their structural complexity, quasi-virgin forests represent a very good scientific base for studying the natural structure and dynamics of a forest, and can be considered as "real laboratories in situ". The presence of large-DBH trees and fast development phase alternations are signs of strong dynamics as well as a great capacity to regenerate after natural competition processes.

The protection of quasi-virgin forests should be a precondition for successful scientific research in natural science. To develop improved forest management practices, it is very important to understand the structural principles and development of natural forests. The legislative system in Romania for protection of natural areas where we still encounter natural ecosystems that are not influenced by humans must generally be improved, and very valuable quasi-virgin forest areas must be included among other natural conservation areas.

## REFERENCES


1. REININGER H 1997 Romanian old growth forest, archetype for an ecological silviculture (in romanian). *In:* Forest magazine. Romsilva, Bucharest, Romania, pp 92-94
2. GIURGIU V 2013 Virgin and quasi – virgin forests of Romania (in romanian). Romanian Academy Publishing Home, Bucharest, Romania, 390 p
3. ROMANIAN FOREST RESEARCH AND MANAGEMENT INSTITUTE 2005 Virgin forests in Romania: inventory and strategy for sustainable management and protection of virgin forests in Romania. URL: http://www.greenpeace.org/romania/Global/romania/paduri/2015-12-22_Virgin_forest_Romania_Summary.PDF (25 March 2019)
4. WIRTH C, MESSIER C, BERGERON Y, FRANK D, FANKHÄNEL A 2009 Old- Growth Forest Definitions: a Pragmatic View. *In:* Old - Growth Forests Function, Fate and Value, Springer-Verlag, Berlin, Germany, pp 11-33
5. CHIVULESCU S, BADEA O, TOMESCU R, SILAGHI D, LECA S, TURCU D 2014 Structural features of virgin beech forests in Semenic mountains. The dynamic structure of virgin beech forest P20 Semenic between 2005–2013. *Proceedings of Romanian Academy-Series B: Chemistry, Life Science and Geoscience* 16 (2): 115-124
6. TOMESCU R, TÂRZIU D, TURCU D 2013 Contributions to knowledge of virgin beech structure dynamics from Izvoarele Nerei – Semenic Natural Reservation (in romanian). *In*: Giurgiu V (*ed*): Virgin and quasi – virgin forests of Romania. Romanian Academy Publishing Home, Bucharest, Romania, pp 209-257
7. GILG O 2004 Old-Growth forest: characteristics, conservation and monitoring. Habitat and species management. Techn. Report 74, Montpellier, France, 96 p
8. CHIVULESCU S, LECA S, SILAGHI D, BADEA O 2016 Growth of virgin forests in the southern Carpathians. *Agriculture and Forestry* 62 (3): 39-48. DOI: https://doi.org/10.17707/AgricultForest.62.3.03
9. LEIBUNDGUT H 1959 Purpose and methodology of structural analysis and growth of virgin forests (*in German*). *Schweiz Zeitschr f Forstwesen* 110 (3): 111-124
10. LEIBUNDGUT H 1978 About the dynamics of European virgin forest (*in German*). *Allg Forstzeitschr* 24: 686-690
11. LEIBUNDGUT H 1982 European primary forests of Bergstufe: presented for foresters, scientists and forest friends (*in German*). Haupt, Bern-Stuttgart, Zwitzerland – Germany, 308 p
12. SCHUCK A, PARVIAINEN J, BÜCKING W 1994 A Review of Approaches to Forestry Research on Structure, Succession and Biodiversity of Undisturbed and Semi – Natural Forests and Woodlands in Europe. European Forest Institute, Joensuu, Finland, 71 p
13. AKSENOV D, KARPACHEVSKIY M, LLOYD S, YAROSHENKO A 1999 The Last of the Last: The Old-growth Forests of Boreal Europe. Taiga Rescue Network, Moskow, Russia, 63 p
14. PINTARIĆ K 1999 Forestry and Forest Reserves in Bosnia and Herzegovina. *In:* Diaci J (*ed*) Virgin forests and forest reserves in central and east European countries. Department of Forestry and Renewable Forest Resources - Biotechnical Faculty, Ljubljana, Slovenia, pp 1-15
15. COMMARMOT B, BUNDZIAK Y, BACHOFEN H, BÜRGI A 2005 Structure of virgin and managed beech forests in Uholka (Ukraine) and Sihlwald (Switzerland). *Forest Snow and Landscape Research* 79 (1): 45-56
16. MATIĆ S 1999 The forests of Croatia – country report. *In:* Diaci J (*ed*) Virgin forests and forest reserves in central and east European countries. Department of Forestry and Renewable Forest Resources - Biotechnical Faculty, Ljubljana, Slovenia, pp 17-24
17. THE MINISTRY OF ENVIRONMENT AND FORESTRY 2012 Establishing criteria and indicators for identifying virgin and quasi-virgin forests (*in Romanian*). Official Monitor 668, Bucharest, Romania. URL: http://legislatie.just.ro/Public/DetaliiDocument/141475.html (28 March 2019)
18. FRELICH LE, REICH PB 2003 Perspectives on development of definitions and values related to old-growth forests. *Environ Rev* 11 (S1): 9-22. DOI: https://doi.org/10.1139/a03-011
19. HETT JM, LOUCKS OL 1976 Age structure models of Balsam Fir and Eastern Hemlock. *J Ecol* 64: 1029-1044. DOI: https://doi.org/10.2307/2258822
20. VALBUENA R, PACKALÉN P, MARTI S, MALTAMO M 2012 Diversity and equitability ordering profiles applied to study forest structure. *Forest Ecol Manag* 276: 185-195. DOI: https://doi.org/10.1016/j.foreco.2012.03.036
21. CERIANI L, VERME P 2012 The origins of the Gini index: extracts from Variabilità e Mutabilità (1912) by Corrado Gini. *J Econ Inequal* 10 (3): 421-443. DOI: https://doi.org/10.1007/s10888-011-9188-x
22. DE-CAMINO R 1976 Determination of the homogeneity of stands (in Spanish). *Bosque* 1 (2): 110-115

23. LORENZ MO 1905 Methods of measuring the concentration of wealth. *Publ Am Stat Assoc* 9 (70): 209-219. DOI: https://doi.org/10.2307/2276207
24. DUDUMAN G 2011 A forest management planning tool to create highly diverse uneven-aged stands. *Forestry* 84 (3): 301-314. DOI: https://doi.org/10.1093/forestry/cpr014
25. ICHIM R 1968 Research on the precision of cubing methods applied in the spruce stands in relation to the variability of trees shape (*in Romanian*). PhD thesis, Polytechnic Institute, Brasov, Romania, 192 p
26. KLOPČIČ M, BONČINA A 2011 Stand dynamics of silver fir (*Abies alba* Mill.)–European beech (*Fagus sylvatica* L.) forests during the past century: a decline of silver fir? *Forestry* 84 (3): 259-271. DOI: https://doi.org/10.1093/forestry/cpr011
27. GIURGIU V 1979 Dendrometry and forest auxology (*in Romanian*). Ceres, Bucharest, Romania, 691 p
28. STEPHENS MA 1979 Tests of Fit for the Logistic Distribution Based on the Empirical Distribution Function. *Biometrika* 66 (3): 591-595. DOI: https://doi.org/10.1093/biomet/66.3.591
29. ANDERSON TW, DARLING DA 1954 A Test of Goodness of Fit. *J Am Stat Assoc* 49 (268): 765-769
30. DELIGNETTE ML, DUTANG C, POUILLOT R., DENIS JB 2019 Help to Fit of a Parametric Distribution to Non-Censored or Censored Data R package. URL: https://rdrr.io/cran/fitdistrplus/ (2 April 2019)
31. MACDONALD P, DU J 2018 Finite Mixture Distribution Models R package version 0.5-5. URL: https://cran.r-project.org/web/packages/mixdist/mixdist.pdf (3 April 2019)
32. KARJALAINEN L, KUULUVAINEN T 2002 Amount and diversity of coarse woody debris within a boreal forest landscape dominated by *Pinus sylvestris* in Vienansalo wilderness, eastern Fennoscandia. *Silva Fenn* 36 (1): 147-167. DOI: https://doi.org/10.14214/sf.555
33. ROUVINEN S, KUULUVAINEN T 2005 Tree diameter distributions in natural and managed old *Pinus sylvestris*-dominated forests. *Forest Ecol Manag* 208 (1-3): 45-61. DOI: https://doi.org/10.1016/j.foreco.2004.11.021
34. ENGELMARK O, HOFGAARD A, ARNBORG T 1998 Successional trends 219 years after fire in an old *Pinus sylvestris* stand in northern Sweden. *J Veg Sci* 9 (4): 583-592. DOI: https://doi.org/10.2307/3237274
35. WESTPHAL C, TREMER N, VON OHEIMB G, HANSEN J, VON GADOW K, HÄRDTLE W 2006 Is the reverse J-shape diameter distribution universally aplicable in European virgin beech forests? *Forest Ecol Manag* 223 (1-3): 75-83. DOI: https://doi.org/10.1016/j.foreco.2005.10.057
36. SCHÜTZ JP 2001 The selection forest and other forms of structured and mixed forests (in german). Parey, Berlin, Germany, 240 p
37. BONCINA A 2011 History, current status and future prospects of uneven-aged forest management in the Dinaric region: an overview. *Forestry* 84 (5): 467-478. DOI: https://doi.org/10.1093/forestry/cpr023
38. ROIBU CC, TOMESCU C, SAVIN A, MIRON-ONCIUL M 2008 Analysis of biodiversity regarding structural and phytocoenological aspect in “old growth beech forest of Humosu” Reservation. *Romanian Academy Journal* 2: 25-31
39. CENUȘĂ R, POPA C, TEODOSIU M 2002 Researches on the structure-function relationship and the evolution of natural forest ecosystems in the north of the country (*in Romanian*). *Ann For Res* 45 (1): 9-20
40. DUDUMAN G 2009 The ecological foundation of the calculation of the possibility in forests treated in the garden gardening (*in Romanian*). University of Suceava Publishing House, Suceava, Romania, 300 p

SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

PRELIMINARY COMMUNICATION

DOI: https://doi.org/10.15177/seefor.19-20

# Coppice Forest Management Planning and the Regeneration Potential of Pure and Mixed Oak Coppice Forests in North Macedonia

**Pande Trajkov[1]*, Tomislav Dubravac[2], Vladimir Tanovski[1], Ljupco Nestorovski[1], Kiril Sotirovski[1], Zdravko Trajanov[1]**

**(1)** "Ss. Cyril and Methodius" University, Faculty of Forestry, Aleksandar Makedonski bb, MK-1000 Skopje, Republic of North Macedonia; **(2)** Croatian Forest Research Institute, Division for Silviculture, Cvjetno naselje 41, HR-10450 Jastrebarsko, Croatia

* **Correspondence:** e-mail: pbabunski@gmail.com

**Citation:** TRAJKOV P, DUBRAVAC T, TANOVSKI V, NESTOROVSKI LJ, SOTIROVSKI K, TRAJANOV Z 2019 Coppice Forest Manage-ment Planning and the Regeneration Potential of Pure and Mixed Oak Coppice Forests in North Macedonia. *South-east Eur for* 10 (2): 165-172. DOI: https://doi.org/10.15177/seefor.19-20

**Received:** 21 Jun 2019; **Revised:** 28 Sep 2019; **Accepted:** 4 Oct 2019; **Published online:** 3 Nov 2019

## ABSTRACT

**Background and Purpose**: Coppicing is the most widely used silvicultural system in North Macedonia and coppice forests together with shrubs cover cca. 69% of the forest cover area. Pure and mixed stands of oak coppice forests alone cover about 50% of the total forest area subject to current Forest Management Plans. In general, coppices are routinely managed, especially when coppicing as a system is planned to be continued. However, sustainability can be threatened if attention is not paid regarding the age of trees/stands and the presence of undesired tree species. The purpose of this study was to determine: (1) quantitative and qualitative aspects of planned management activities in oak coppices throughout the country, (2) the resprouting potential of over-mature oak coppices, and (3) their potential for generative regeneration.

**Materials and Methods**: We analyzed all official forest management plans in the country, in order to assess planned activities and the methods of management. Additionally, 21 experimental plots were set in order to determine the resprouting potential of over-mature (85 to 95 years) coppices of *Quercus petraea* and *Q. frainneto* which previously have been subject of clear-cutting. We took a total count of sprouts on all experimental plots, while generative regeneration seedlings were counted on 4 schematically positioned subplots in each experimental plot. Sprouts and generative seedlings were categorized by height.

**Results and Conclusions**: According to the data from forest management plans, coppicing is planned to remain as a management system on 401,636 ha, of the total of 450,975 ha of oak coppice forests. Indirect conversion to high forests is planned on 39,137 ha, while direct conversion with substitution is planned for 10,202 ha. In field trials, resprouting was registered on only 38% of the stools. Generative regeneration was recorded in both oak species in numbers which indicate good potential for conversion of oak coppice stands into high forests by seed felling. However, numerous sprouts of other species (*Corylus avellana, Fraxinus ornus, Acer heldreichii*), which reach up to 3 meters in height within two seasons, are potentially dangerous for dominating oak seedlings.

**Keywords**: management activities, resprouting, vegetative regeneration, generative regeneration

## INTRODUCTION

Coppicing has been, and in many cases still is, an important traditional forest land use system across Europe [1]. Apart from providing many wood products, such as firewood, biomass chips, fencing, assorted and industrial wood, coppice forests are a source for a variety of non-wood forest products, such as truffles, mushrooms and honey [2].

While in Central and Northern Europe coppice forests comprise just a small share of the total forest area (e.g. in Austria 2%; Germany 0.7%), they take up a large part of the forest area in South-Eastern Europe (e.g. Croatia 21%, Albania 43%, Bulgaria and France 47%, North Macedonia 59% (without shrubs), Serbia and Greece 65% each) [3-6]. Both high diversity of site conditions and vegetation patterns in South-Eastern Europe, accompanied by diverse socio-cultural backgrounds of countries, have induced an abundance of diverse coppice stands and a variety of management practices [5].

In historical regards, the most important common characteristics in the establishment of coppicing as a practice were the absence of any silvicultural activities in the early ages and very weak and inadequate silvicultural treatments in the later stages [5, 7, 8].

Coppicing as a practice has been and still is usually performed by the method of annual coupes by area, and regeneration is achieved by stool shoots or suckers. In most tree species, stools of large sizes do not coppice strongly, hence for the production of stool shoots it is usually necessary to fell trees at an age of not above than 40 years [9]. The rotation usually varies from 10 to 30, or even up to 40 years, depending on the region, tree species and market demands [3, 10].

In North Macedonia (at the time People's Republic of Macedonia) after World War II, coppice forests occupied 648,000 ha, which was cca. 75% of the total forest covered area. Of these, 286,000 ha were regular coppice forests, 131,000 ha were overused forests and 231,000 ha were shrubs [11]. In the second half of the 20$^{th}$ century, as a result of the fast development of the wood industry and of the fear of deficiency of technical wood, the attention of both researchers and practitioners was focused on the transformation of coppice forests into high forests [11-19]. One of the results of their efforts is the "Long-term Program for development of forestry in SR Macedonia for the period 1971-1990". Within this Program coppice forests are classified into regular coppice forests, occupying 250,700 ha, and degraded coppice forests, occupying 379,000 ha, of which shrubs occupy 155,500 ha and pollarded and shredded forests 27,200 ha.

Within this Program, regular coppice forests are classified into three categories: i) coppice forests which will continue to be managed as such, ii) coppice forests on rich sites, planned for conversion into high forests by the method of indirect conversion, and iii) coppice forests planned for direct conversion by the method of substitution of tree species.

Degraded coppice forests are further classified as degraded and highly degraded, and for them resurrective cutting and direct conversion are planned, respectively.

For the period of validity of the Program, indirect conversion was planned for all categories and tree species of coppice forests on an area of 150,000 ha, in two time points, set apart by 10 (8-12) years, while direct conversion was planned for an area of 92,000 ha.

During the 20$^{th}$ century, a strategic concept related to coppice forests in Europe was their transformation into high forests, and in some countries this concept continues at present [6, 21]. Their transformation is managed by means of direct and indirect conversion. It should be noted here that there is ambiguity regarding the definition of the terms direct and indirect conversion, especially in European academic literature. In some Balkan countries (especially ex-Yugoslavia), the term indirect conversion refers to the transformation of coppice forest stands with a sufficient number of good quality trees, evenly distributed throughout the stand, which will provide seeding and conversion of coppices into high forests by natural means [8, 22]. This same procedure of transformation of coppice forests into high forest stands is defined by some authors as direct conversion: "The method of direct conversion includes (i) conversion by ageing….where the simple coppice is no longer cut so that stands reach a maturity in which they are able to regenerate naturally by seed" [23]. In this paper, the meaning of terms (direct and indirect conversion) is according to the definitions used in Balkan countries (in particular ex-Yugoslavia).

The total forest covered area in North Macedonia in 2017 was 1,001,489 ha (Statistical Yearbook 2018). Forest management planning in the country is realized through FMPs, FMPr and by instructions for management of small-scale private forests (Forest Law 2009).

However, even 30 years after the expiration of the Program, no analyses were derived from the extent, quality and success of the undertaken activities. This fact was our main motive to collect and analyze data from the current FMPs for the planned means, methods and activities in coppice oak forests, as well as to analyze results in situ within areas managed as coppices. Our main task was to generate data which would clarify the regenerative potential of over-aged coppice oak forests, and eventually shed light on the capacity for vegetative or generative regeneration.

## MATERIAL AND METHODS

### Planned Management Activities

Planning and management of forests in North Macedonia is based on Forest Management Plans (FMPs) which are made for areas larger of 30 ha, and Forest Management Programs (FMPr) for forests between 10 and 30 ha. Forests up to 10 ha are managed by instructions issued by the Ministry of Agriculture, Forestry and Water Economy of RNM for managing small scale private forests (Forest Law, 2009).

In the process of forest management planning, the level at which sustainability is provided (guaranteed), i.e. wood production or yield sustainability, is the management class (MC), which is defined as a sum of areas of stands which will be managed in the same manner in the future. The MCs are defined with the Rulebook for the content of FMP. Depending on site and stand quality, some MCs are further divided into subclasses.

Accordingly, coppice oak forests are grouped into 2 MCs - coppice *Q. petraea* forests designated as MC 'M' and coppice forests of other oak species (*Q. conferta*, *Q. cerris*, *Q. macedonica*, *Q. pubescens*) designated as MC executive class 'L'. Depending on the site and stand quality, coppice *Q. petraea* forests (class 'M') are further divided into 4 subclasses (M1-M4).

In order to assess the planned activities and the methods of management, we analyzed all 197 official forest management plans in the country. Planned activities were grouped by MCs (subclasses) and the type of activity.

### Regeneration Potential

We set 21 circular experimental plots (EPs) in order to determine the regeneration potential of over-mature oak coppice stands, in which clear-cut has been previously performed. We located the EPs in 2 locations in North Macedonia. One was in the western part of the country near the city of Kichevo, on over-mature *Q. petraea* coppice forest stands (QPCF) in the management unit (MU) "Ljuben – Srbjani", while the other was in the eastern part of the country near the city of Berovo, on over-mature *Quercus frainetto* coppice forest (QFCF) stands in MU "Goten – Shiroki Dol".

EPs each had a radius of 5.64 meters, i.e. an area of 100 $m^2$, and were grouped into clusters of three, whereof they were positioned on the vertices of an equilateral triangle with side length of 50 meters (Figure 1). Clusters were randomly located in each stand.

During 2015 and 2017, a count was made of all sprouting and dead stools in each EP. On each sprouting stool all sprouts were counted and categorized in 6 classes based on height (up to 30 cm; 31-60 cm; 61-130 cm; 131-200 cm; 201-250 cm, and 251-300 cm).

Four subplots with a radius of 1 m were set in each EP; the first subplot was positioned in the center of the EP, while the remaining 3 subplots were positioned at a distance of 3 m in relation to the center of the first one, at azimuths of 120°, 240° and 360°. In each subplot, all individuals of generative origin were counted, and their heights were registered. Individuals were categorized in the same 6 classes based on height, as described previously for the sprouts.

At MU "Ljuben-Srbjani" in QPCF stands, a total of 12 EPs were set in four clusters, i.e. two clusters in each of the departments 4a and 61a. According to the FMP, in department 4a a clear-cut was performed two vegetation periods prior to our assessments. At the time of cutting, the stand was aged 85 years, mean diameter of breast height ($d_g$) was 18 cm, mean height ($h_g$) 16 m, and there were 532 trees per hectare. In department 61a, a clear-cut was performed one vegetation period prior to our assessments when the stand was aged 87, mean diameter of breast height ($d_g$) was 22 cm, mean height ($h_g$) 17 m, and there were 706 trees per hectare.

At MU "Goten-Shiroki Dol" in QFCF stands, a total of 9 experimental plots were set in three clusters, of which two clusters in department 5a and one cluster in department 54a. At department 5a a clear-cut was performed five vegetation years prior to our assessments when the stand was aged 95 years ($d_{1,3}$=23 cm, $h_{sr}$=17 m, N=532). At department 54a, a clear-cut was performed one vegetation year prior to our assessments when the stand was aged 92 years ($d_{1,3}$=22 cm, $h_{sr}$=15 m, N=747).

## RESULTS

### Planned Activities

According to our analyses, the total forest cover area which is subject to current FMPs for the entire country is 888,649 ha (state 2017). Of these, *Q. petraea* coppice forests (QPCF) are classified as management class 'M' and cover an area of 163,036 ha. For QPCF, at the class level, simple coppicing (coppice system & resurrection) is planned to continue on an area of 114,447 ha. On the other hand, the transformation of coppice stands to high forests is planned for 16,409 ha through indirect conversion, while for 3,749 ha through direct conversion with substitution. For 28,432 ha QPCF objectives are not defined, and the often-used term in these cases is "stands at rest" (Table 1). This term is usually applied for low productive oak coppice stands or small areas at the management class level which have been recently coppiced. For those types of stands even the aim of management is not defined, and they are just categorized as management class/subclass in a specific Forest Management Unit (FMU).

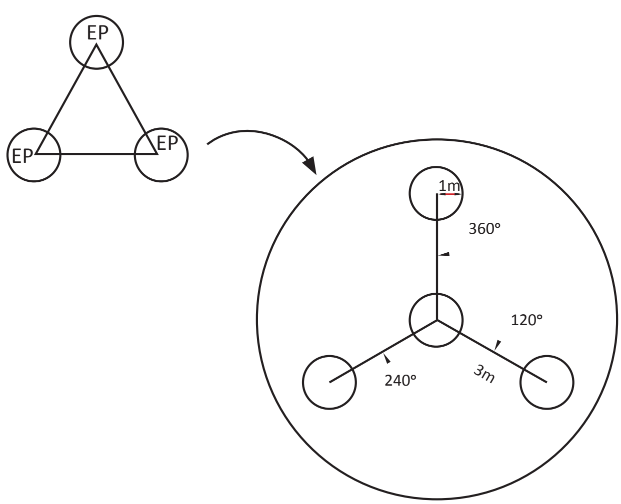


**FIGURE 1.** Cluster of the experimental plots.

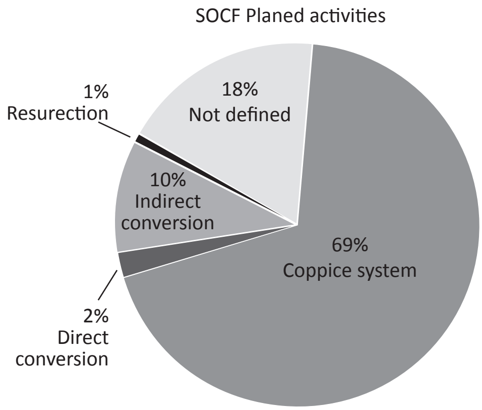


**FIGURE 2.** Planned activities in sessile oak coppice forest (%).

According to site and stand quality, QPCF are divided into four stand types: i) quality QPCS on quality sites - management subclass 'M1'; ii) low-quality QPCS on good quality (rich) sites - management subclass 'M2'; iii) low-quality QPCS on poor sites - management subclass 'M3'; and iv) QPCS in which other species are introduced, deciduous or coniferous - management subclass 'M4'.

Stands of the management subclass 'M1' cover an area of 39,306 ha. Of these, 15,470 ha are planned to be managed as coppice forests in the future; for 15,051 ha transformation into high forests is planned through indirect conversion, while no activities are planned for 8,785 ha.

Stands of the management subclass 'M2' cover an area of 112,179 ha. The majority of these stands, 92,960 ha, are set to continue to be managed as coppice forests. For 1,358 ha transformation into high forests is planned through indirect conversion; 3,609 ha are planned to be transformed into high forests through direct conversion, while for 12,908 ha no activities are planned.

Stands considered as management subclass 'M3' cover an area of 9,442 ha. For about half of those (4,832 ha) no activities have been decided; for 4,470 ha it is planned to be managed as coppice forests in the future, while for only 40 ha transformation into high forests is planned through direct conversion.

Stands within management subclass 'M4' cover an area of 2,109 ha. In these stands, various coniferous or broadleaved species have been introduced, by means of planting of seedlings or by sowing seeds, but the main part is still coppice. For stands in this subclass, clear-cutting is planned on a total area of 203 ha.

Other oak species present in the country (*Q. frainetto* Ten., *Q. cerris* L., *Q. macedonica* A.DC., *Q. pubescens* Willd.) are in a separate management class 'L' and cover an area of 287,938 ha. In some FMPs stands are grouped into subclasses, while in others not, because according to the Rulebook for the content of FMPs (1998) the division into subclasses of these stands is not compulsory. Because of this reason, the analyses for stands within 'L' management classes are performed on the class level only (Table 2).

In this management class, it is planned for nearly 80% (79.61%) of the stands to continue to be managed as coppice forests. Indirect conversion is planned for an area of 22,728 ha (7.89%), direct conversion for 6,453 ha, resurrection for 7,466 ha, while for 29,511 ha (10.25%) the type of management is not defined (Figure 3).

**TABLE 1.** Planned activities for coppice forests of management class 'M' according to FMPs (state 2017).

| Type of stands (subclass) | Total area of subclass | Planned activities in ha | | | | |
|---|---|---|---|---|---|---|
| | | Coppice system | Indirect conversion | Direct conversion | Resurrection | Not defined |
| M1 | 39306 | 15470 | 15051 | | | 8785 |
| M2 | 112179 | 92960 | 1358 | 3609 | 1344 | 12908 |
| M3 | 9442 | 4470 | | 140 | | 4832 |
| M4 | 2109 | 203 | | | | 1906 |
| Total M | 163036 | 113103 | 16409 | 3749 | 1344 | 28431 |
| % | 100 | 69.4 | 10.1 | 2.3 | 0.8 | 17.4 |

**TABLE 2.** Planned activities for coppice forests of management class 'L' according to FMPs (state 2017).

| Management class 'L' | Total area of subclass | Planned activities in ha | | | | |
|---|---|---|---|---|---|---|
| | | Coppice system | Indirect conversion | Direct conversion | Resurrection | Not defined |
| ha | 287.938 | 221.781 | 22.728 | 6.453 | 7.466 | 29.511 |
| % | 100 | 77.02 | 7.89 | 2.24 | 2.59 | 10.25 |

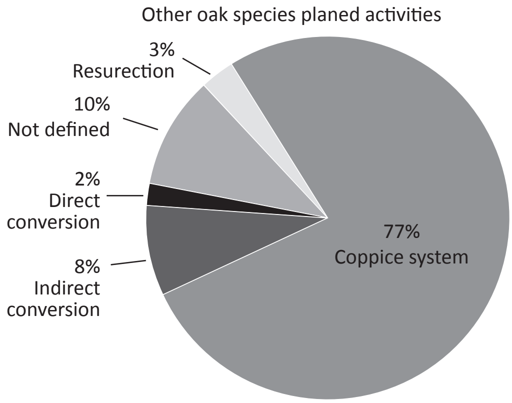


**FIGURE 3.** Planned activities in coppice forests on other (*Q. frainetto, Q. macedonica, Q. pubescens*) oak species (%).

## Regeneration Potential

In department 61a we registered 751 stools per hectare, of which 317 were regenerating and 431 were dead. On the regenerated stools we counted 5,139 sprouts per hectare, of which 1,318 were 30 cm or less, 2,236 were 31-60 cm, and 1,585 were 61-130 cm. In this stand, 1,035 stools of hazel (*C. avellana*) were registered per hectare, with a count of 14,083 sprouts, of which the majority (7,776) are within the height class 61-130 cm. We also counted 24,632 individuals per hectare of *Q. petraea* of generative origin, all within the height class of 30 cm or bellow (Table 3, Figure 4)..

In department 4a we registered 701 stools per hectare, of which 234 were regenerated and 467 were dead. On regenerated stools we counted 3,471 sprouts per hectare, of which 384 are 31-60 cm; 1,552 are 61-130 cm; 1,135 are 131-200 cm; 267 are 201-250 cm, and 133 251-300 cm in height. In this department, 617 stools of hazel were registered per hectare on which there were 12,098 sprouts; more than half of those are over 1.3 m in height, and 1,185 are over 2.5 m. Also, 27,866 individuals per hectare of *Q. petraea* of generative origin were registered, of which 19,904 are 30 cm or lower and 7,962 are 31-60 cm (Table 3, Figure 5, 6).

In department 54a we registered 590 stools per hectare, of which 134 were regenerating and 456 were dead. On regenerating stools, we registered a total of 1,648 sprouts. Of these, 423 are 30 cm or bellow; 717 are 31-60 cm, and 508 are 61-130 cm. In this department, we registered 250 stools of *Fraxinus ornus* per hectare, on which we registered 1,595 sprouts. Of these, 472 are 30 cm or less; 874 are 31-60 cm, and 249 are 61-130 cm in height. In the stand, we registered 45,117 seedlings of *Q. frainetto* of generative origin per hectare. Of these, 35,297 are 30 cm or bellow, and 9,820 seedlings are 31-60 cm (Table 4).

In department 5a we registered 366 stools of *Q. frainetto* per hectare, of which 33 were regenerating and 333 were dead. On regenerating stools, we registered 367 sprouts per hectare; 31 of these were 61-130 cm; 178 are 131-200 cm; 114 are 201-250 cm; and 44 are 251-300 cm. In the stand, we registered 28,264 seedlings of *Q. frainetto* of generative origin per hectare. Of these, 7,962 are 30 cm or bellow, 13,004 seedlings are 31-60 cm, and 7,298 are 61-130 cm height. In this department, we registered 67 stools of *Fraxinus ornus* per hectare, on which we registered 386 sprouts. Of these, 46 are 61-130 cm; 92 are 131-200 cm, 137 are 201-250 cm, 102 are 251-300 cm, and 10 are more than 300 cm in height (Table 4).

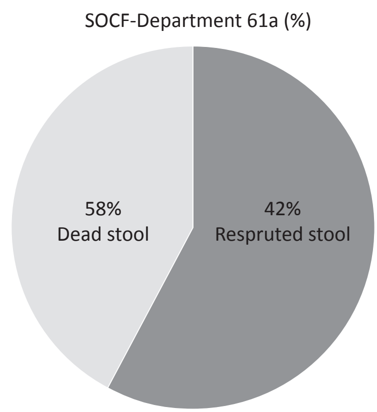


**FIGURE 4.** Resprouted and dead stools in *Q. petraea* coppice stands in department 61a.

**TABLE 3.** The number of stools (resprouted and dead), sprouts and seedlings in QPCF (per hectare).

| Stand | Species | Number of stools / nests | Number of sprouts - seedlings by height in cm | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | up to 30 | 31 - 60 | 61 - 130 | 131 - 200 | 201-250 | 251-300 | 301-350 | Total |
| One year after clear cut (dprt.61) | Oak resprouted | 317 | 1318 | 2236 | 1585 | 0 | 0 | 0 | 0 | 5139 |
| | Oak - dead stool | 434 | | | | | | | | |
| | Hazelnut trees | 1035 | 200 | 6107 | 7776 | 0 | 0 | 0 | 0 | 14083 |
| | Oak | Seedlings | 24632 | 0 | 0 | 0 | 0 | 0 | 0 | 24632 |
| Two years after clear cut (dprt.4) | Oak resprouted | 234 | 0 | 384 | 1552 | 1135 | 267 | 133 | 0 | 3471 |
| | Oak - dead stool | 467 | | | | | | | | |
| | Hazelnut trees | 617 | 0 | 684 | 3704 | 4272 | 2253 | 1185 | 0 | 12098 |
| | Oak | Seedlings | 19904 | 7962 | 0 | 0 | 0 | 0 | 0 | 27866 |

**TABLE 4.** The number of stools (resprouted and dead), sprouts and seedlings in QFCF (per hectare).

| Stand | Species | Number of stools / nests | Number of sprouts - seedlings by height in cm | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | up to 30 | 31 - 60 | 61 - 130 | 131 - 200 | 201-250 | 251-300 | 301-350 | Total |
| One year after clear cut (dprt. 54a) | Oak resprouted | 134 | 423 | 717 | 508 | | | | | 1648 |
| | Oak - dead stool | 456 | | | | | | | | |
| | *Fraxinus ornus* | 250 | 472 | 874 | 249 | | | | | 1595 |
| | Oak | Seedlings | 35297 | 9820 | | | | | | 45117 |
| Five years after clear cut (dprt. 5a) | Oak resprouted | 33 | | | 31 | 178 | 114 | 44 | | 367 |
| | Oak - dead stool | 333 | | | | | | | | |
| | *Fraxinus ornus* | 67 | | | 46 | 92 | 137 | 102 | 10 | 386 |
| | Oak | Seedlings | 7962 | 13004 | 7298 | | | | | 28264 |

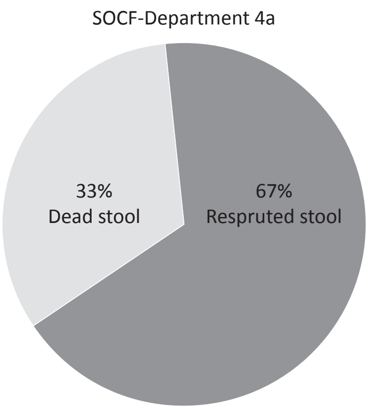


**FIGURE 5.** Resprouted and dead stools in *Q. petraea* coppice stands in department 4a.

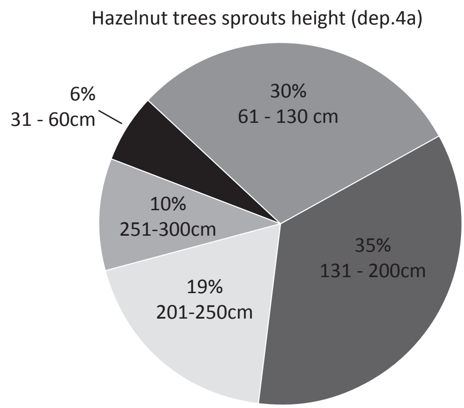


**FIGURE 6.** Height of hazel tree sprouts in department 4a

## DISCUSSION

Our research showed that the total area of forests managed by planned and approved FMPs, i.e. managed forests, was 888,649 ha in 2017, of which 612,479 ha (69%) are coppice forests and shrubs. The total managed forest coverage has declined from 902,000 ha in 2012 [20]. This registered decrease of the forest areas covered by forest management between 2012 and 2017 is mainly because of a decision in 2014 of the Ministry of Agriculture, Forestry and Water Economy, by which companies managing state-owned forests should exclude private forests from FMPs.

The total area of coppice forests in North Macedonia is 549,267 ha (bushes and shrubs not included; state 2017), of which 450,985 ha are oak coppice forests and these are classified in 2 management classes ('M' and 'L'). The remaining 98,282 ha are beech coppice forests. During the second half of the 20th century, some coppice forests in North Macedonia were planned to be converted by direct and indirect means, while the others were planned to be managed as coppice forests with a rotation period up to 50 years (Long-term State Program), similarly to other European countries [5, 21, 24].

Indirect conversion was planned for a large proportion of coppice forest stands of oak and beech, i.e. a total of 150,000 ha. In the period of validity of the Program, in many stands, activities were accordingly implemented, i.e. one to two thinning operations have been performed. Presently, these stands should be at age of 70-90 years and activities to finally transform them into high forests should be planned and performed, i.e. the provision of natural regeneration and the removal of the older stand. In planning the activities for final transformation, an important aspect is the capability of the stand for generative regeneration, i.e. seed production, as well as resprouting capacity of the stools. Low capacity for seed production of trees could pose a problem for successful regeneration, while high capability of resprouting impedes successful development of seedlings. On the other hand, low capacity for resprouting disables regeneration by vegetative means.

In QPCF stands in which clear-cutting has been performed we registered 24-28 thousand seedling individuals per hectare, while in QFCF 28-45 thousand seedling individuals per hectare. These data in particular suggest that for QPCF stands at ages of over 80 years activities could, and should, be planned for their final transformation into high forests by natural means. Our results suggest that, should the uniform shelterwood system be used for these stands, the regeneration of oak of generative origin would be of appropriate quality and quantity [7, 25].

Some trees of *Q. petraea* and *Q. frainetto* can produce shoots for up to 100 years or even indefinitely [23]. However, in QPCF and QFCF stands managed as simple coppice, from the aspect of resprouting potential the maximum rotation age should be 40 years [10]. On the other hand, investigations of the resprouting ability of *Q. petraea* stumps 80-100 years after the last coppicing show low stool mortality and vigorous sprout growth after two vegetation years and demonstrate that old stumps can still regenerate well [24].

However, our research has shown that the production of sprouts at ages over 80 years is substantially decreased and that the number of resprouted stools is far from desired levels for restocking a site, which have been calculated in previous research [24]. Accordingly, it cannot be considered that at ages over 80 years coppice forests can be regenerated vegetatively.

Additionally, our results have revealed a large presence of other woody species (*Corylus avelana, Fraxinus ornus*), which present a realistic threat for both generative and vegetative regeneration of the stands. If, in these types of stands, measures for nursing and protection of the young plants are not applied, they will transform into hazel bushes, as was registered in the case of QPCF stands which were the subject of our research (Figure 7).

## CONCLUSIONS

Finally, data derived from our research have shown that for the biggest part of oak coppice forests the coppice system is planned, i.e. the continuation of management as coppice forests. Further on, for both oak species the production of sprouts at ages over 80 years is substantially decreased. We have registered some resprouting, but in numbers far from desired levels for restocking a site. Thus, it cannot be considered that at ages over 80 years coppice forests can be regenerated vegetatively.

In the stands of both oak species, we recorded a sufficient number of generative individuals per hectare, which exposes the prospect for their transformation into high forests by natural means.

Large presence of other woody species (*Corylus avelana, Fraxinus ornus*) presents a realistic threat for both generative and vegetative regeneration of the stands. If, in these types of stands, measures for nursing and protection of the young plants are not applied, they will transform into bushes.

**FIGURE 7.** Department 4a (QPCF) four years after coppicing.

## REFERENCES


1. UNRAU A, BECKER G, SPINELLI R, LAZDINA D, MAGAGNOTTI N, NICOLESCU V-N, BUCKLEY P, BARTLETT D, KOFMAN P 2018 Coppice Forests in Europe. University of Freiburg, Germany, 389 p
2. CARVALHO J, MAGAGNOTTI N, NICOLESCU V-N, RUCH P, SPINELLI R, TOLOSANA E 2018 Active Management of Traditional Coppice Forests: An Interface Between Silviculture and Operations. *In*: Unrau A, Becker R, Spinelli R, Lazdina D, Magagnotti N, Nicolescu VN, Buckley P, Bartlett D, Kofman P (*eds*) Coppice Forests in Europe. Albert Ludwig University of Freiburg, Freiburg, Germany, pp 72-77

3. CHATZIPHILIPPIDIS G, SPYROGLOU G 2004 Sustainable management of coppice forests in Greece. Towards the Sustainable Use of Europe's Forests-Forest Ecosystem and Landscape Research: Scientific Challenges and Opportunities, EFI Proceedings 49, pp 51-60
4. LEXER MJ, BOBINAC M, DEKANIĆ S, DUBRAVAC T, GEORGIEV G, GEORGIEVA M, HOCHBICHLER E, IVANOV G, JOVIC D, KASTNER E 2009 CForSEE: Multifunctional Management of Coppice Forests. Scientific results of the SEE-ERA.NET Pilot Joint Call. Centre for Social Innovation (ZSI), pp 49-56
5. STAJIC B, ZLATANOV T, VELICHKOV I, DUBRAVAC T, TRAJKOV P, LEXER M 2009 Past and recent coppice forest management in some regions of South Eastern Europe. *Silva Balcanica* 10 (1): 9-19
6. BARTLETT D, LAINA R, ZUPANIC M, GOMEZ MARTIN E 2018 The potential barriers to persistence and development of small scale coppice forest management in Europe. *In*: Unrau A, Becker R, Spinelli R, Lazdina D, Magagnotti N, Nicolescu VN, Buckley P, Bartlett D, Kofman P (*eds*) Coppice Forests in Europe. Albert Ludwig University of Freiburg, Freiburg, Germany, pp 166-175
7. KREJČI V, DUBRAVAC T 2004 From coppice wood to high forest of evergreen oak (*Quercus ilex* L.) by shelterwood cutting. *Šumar List* 128 (7-8): 405-412
8. KRSTIC M 2006 Silviculture. Transformation, reclamation and artificial regeneration. Faculty of Forestry, Belgrade, Serbia, 375 p
9. MATTHEWS JD 1991 Silvicultural systems. Oxford University Press, 284 p
10. NICOLESCU V-N 2018 The Practice of Silviculture. Aldus, Brashov, Romania, 254 p
11. NIKOLOVSKI T 1957 The problem of conversion of forests in PR Macedonia. *Journal of Forestry* (5-6): 15-30
12. NIKOLOVSKI T 1955 Situation of bushes and guidance for their management. *Forest Review* 1: 3-44
13. NIKOLOVSKI T 1958 The forest vegetation types in Dub Mountain near Dojran Lake. *Forest Review* 5-6: 28-48
14. NIKOLOVSKI T 1960 The conversions problem of degraded hardwood forest in PR Macedonia. *Forest review* 5-6: 48-61
15. MIRCEVSKI S 1998 State and role on degraded forest vegetation in Macedonia, results from experimental plots, possibilities and direction for melioration. Melioration of degraded forest and shrubs Negorski Banji, Gevgelija, pp 12-24
16. GRUJOSKI B 1959 General development of the forestry in PR Macedonia (1944-1959). *Forest Review* Jubilee edition 7-27
17. MIRCEVSKI S 1977 Biostructural relations in lowtrunk wood of beech in Macedonia. *Journal of Forestry* 3-4: 12-26
18. NIKOLOVSKI T 1964 Low income forest in SFR Yugoslavia and possibilities for transformation into high income ones. *Forest review* 3-4: 3-15
19. POPOVSKI P 1979 Associable and economical value of the degrading forests and brushwood of S.R. Macedonia. *Journal of Forestry* 3-4: 13-19
20. TRAJKOV P, NESTOROVSKI L, TRAJANOV Z 2016 The Republic of Macedonia. *In*: Vidal C, Alberdi I, Hernández L, Redmond JJ (*eds*) National Forest Inventories. Springer International Publishing, Switzerland, pp 667-682. DOI: https://doi.org/10.1007/978-3-319-44015-6
21. BARTLETT D, LAINA R, PETROVIĆ N, SPERANDIO G, UNRAU A, ŽUPANIĆ M 2018 Socio-Economic Factors Influencing Coppice Management in Europe. *In*: Unrau A, Becker R, Spinelli R, Lazdina D, Magagnotti N, Nicolescu VN, Buckley P, Bartlett D, Kofman P (*eds*) Coppice Forests in Europe. Albert Ludwig University of Freiburg, Freiburg, Germany, pp 158-165
22. MIRCEVSKI S, VASILEVSKI K, VELKOVSKI N 2012 Amelioration of degraded forests and shrubs. "Ss. Cyril and Methodius" University, Faculty of Forestry, Skopje, North Macedonia, 211 p
23. NICOLESCU V-N, CARVALHO J, HOCHBICHLER E, BRUCKMAN V, PIQUÉ-NICOLAU M, HERNEA C, VIANA H, ŠTOCHLOVÁ P, ERTEKIN M, TIJARDOVIC M 2018 Silvicultural guidelines for European coppice forests. *In*: Unrau A, Becker R, Spinelli R, Lazdina D, Magagnotti N, Nicolescu VN, Buckley P, Bartlett D, Kofman P (*eds*) Coppice Forests in Europe. Albert Ludwig University Freiburg, Freiburg, Germany, pp 46-63
24. PYTTEL PL, FISCHER UF, SUCHOMEL C, GÄRTNER SM, BAUHUS J 2013 The effect of harvesting on stump mortality and re-sprouting in aged oak coppice forests. *Forest Ecol Manag* 289: 18-27 https://doi.org/10.1016/j.foreco.2012.09.046 :
25. DUBRAVAC T, TURK M, BARCIC D 2018 Konverzija panjača hrasta crnike (*Quercus ilex* L.) oplodnim sječama - rezultati višegodišnjih znanstvenih istraživanja. *In*: Šarić T, Beus V (*eds*) Poljoprivreda i šumarstvo na kršu mediteransko-submediteranskog istočnojadranskog područja-stanje i perspektive, 5 June 2018, pp 103-121

SEEFOR SOUTH-EAST EUROPEAN FORESTRY
OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

PRELIMINARY COMMUNICATION
DOI: https://doi.org/10.15177/seefor.19-18

# Research into Dendro-Acoustic Properties of Introduced Clones' Wood as Material for Manufacturing Musical Instruments

**Vladimir Ilyich Fedyukov[1*], Ekaterina Yurevna Saldaeva[1], Maria Sergeyevna Chernova[1], Vasilii Yuryevich Chernov[1]**

**(1)** Volga State University of Technology, Department of Standardization, Certification and Merchandizing, Lenin Sq., 3, RU-424 000 Yoshkar-Ola, Russia

* **Correspondence:** e-mail: fiv48@mail.ru

**Citation:** FEDYUKOV VI, SALDAEVA EY, CHERNOVA MS, CHERNOV VY 2019 Research into Dendro-Acoustic Properties of Introduced Clones' Wood as Material for Manufacturing Musical Instruments. *South-east Eur for* 10 (2): 173-179. DOI: https://doi.org/10.15177/seefor.19-18
**Received:** 17 Jun 2019; **Revised:** 2 Aug 2019; **Accepted:** 11 Sep 2019; **Published online:** 3 Nov 2019

## ABSTRACT

**Background and Purpose:** Studies of the physical-mechanical and acoustic properties of maple wood as a potential material for musical instruments manufacturing are extremely scarce. Related to this, dendro-acoustic studies of maples introduced by geographic origin are of great practical importance in order to create target plantations with predicted technical quality of wood.
**Materials and Methods:** Maples from abroad introduced by geographic origin into the Botanical Garden of the Volga State University of Technology of the Republic of Mari El of Russia were used for the research. For comparison, the Norway maple of local origin (*Acer platanoides* L.) was selected. The studies were carried out by the frequency-amplitude method for determining Young's dynamic modulus and the acoustic constant of sound emission according to the criterion of academician N. Andreyev.
**Results:** It was revealed that there are differences in the density and dendroacoustic indices of maple wood of local origin and maple trees introduced by geographic origin. Norway maple (*Acer platanoides* L.) turned out to possess the largest acoustic constant characterizing the resonant properties of wood. Introduced maple trees, plane-tree maple (*Acer pseudoplatanus* L.) and sugar maple (*Acer saccharinum* L.) are only slightly inferior in terms of this indicator.
**Conclusions:** The dendroacoustic properties of maple wood are generally much lower than that of resonant spruce. Consequently, the acoustic role of maple wood in the back plates of the violin and other string instruments is completely different than that of the top plate made from the resonant material of coniferous species. To reveal this difference in more detail, comparative studies and dendroacoustic identification of maple wood in blanks and musical instruments with different levels of acoustic characteristics are necessary.

**Keywords:** introduced maples, maple wood, density, modulus of elasticity, speed of sound, acoustic constant

## INTRODUCTION

It is known that maple wood plays no less important role in achieving special sound of a musical instrument designed of two levels of plates - top and back - than that of spruce resonant wood. A good confirmation of this is the fact that the mannerism of Amati, Guarneri, Stradivarius and other old Italian masters in different years can be determined by the macro-structure of wood used for making violins, not only for the top plate, from spruce, but also for the back plate, mainly from maple [1].

In addition to the production of musical instruments, wood of this species is widely used in other industries where material with beautiful texture, high density, wear resistance, hardness and strength is required in manufacturing machine parts, special types of veneer, parquet, furniture and so on. Therefore, today high-quality maple wood, along with spruce resonant wood, is in deficit and is very expensive timber worldwide.

Russia is not an exception, where after the harsh winter of 1978 there was a massive drying of maples, even in mixed stands, and the operational stands of this breed were sharply reduced. Their natural recovery is far from the best. For example, in the forests of the Republic of Mari El, where these studies were carried out, maple trees are preserved only in mixed stands on an area of only about 2000 hectares, and the share of maples does not exceed 10% in these plantations.

Meanwhile, when in 1910 a large expedition of forestry scientists from Germany and Russia took place along Volga, it found large areas of resonant spruce and maple stands in this area. First, these riches were exported to Germany in large quantities, where it was decided to build workshops for the production of violins, guslias and other musical instruments from local wood in Kozmodemyansk [2].

One of the main ways of preserving and increasing the timber reserves of this valuable species in the forests of Russia today is to create target plantations with predictable technical quality of maple wood, including those introduced by geographic origin. In solving this problem, the search for the best genetic taxa plays a special role. It should be done by performing complex studies of the physical-mechanical and acoustic properties of standing wood by non-destructive methods, i.e. without cutting trees.

## MATERIALS AND METHODS

The object of this study were maples introduced by geographic origin on the territory of the Botanical Garden of the Volga State University of Technology (VSUT), which are characterized by the following dendrometric indicators (Table 1).

For comparison, local maple (*Acer platanoides* L.) was selected.

The type of habitat conditions is $C_2$; the soil is soddy-low podzolic, clay loam, fresh. Planting was carried out without prior preparation of the soil. The seedlings were brought from the State Botanical Garden of the USSR Academy of Sciences (Moscow), where special plantations of these maples introduced by geographic origin had been previously established. The seedlings were placed in groups for each introduced species at a distance sufficient for growth and development.

The material for research in the form of side branches was taken strictly from the south side of the trees with the help of a special tool - pruner (Figure 1).

Experimental cuttings from 3.0 to 7.0 mm in diameter and from 70.0 to 100.0 mm long without bark were made on these branches under laboratory conditions and kept until they reached moisture content of wood of W=8±2%. The cuttings were taken from the third and subsequent (of at least 2) segments from the end of the branches, i.e. the relatively soft wood of the last two years of growth was excluded (Figure 2). Immediately before the study, test cuttings were straightened with a special clamp.

### Theoretical Background and Research Method

Today, in many countries, the main criterion of 'musicality' of the material under study is the acoustic constant of sound radiation, K, proposed by Andreyev [3]:

$$K = \sqrt{\frac{E_{dyn}}{\rho^3}}, \int \qquad E_{dyn} = C^2 \cdot \rho \qquad (1)$$

where $E_{dyn}$ is dynamic modulus of elasticity, MPa; C is the speed of sound, m·s$^{-1}$; and ρ is density, kg·m$^{-3}$.

It is important to keep in mind that research requires manufacturing of standard samples in the form of bars 20×20 mm in width and thickness across and 300 mm in

**TABLE 1.** Dendrometric characteristics (age, height, diameter at breast height - DBH) of maple trees.

| **Taxon name** | **Age** (years) | **Height** (m) | **DBH** (cm) |
|---|---|---|---|
| Field maple (*Acer campestre* L.) | 35 | 8.7 | 7. 8 |
| Plane-tree maple-sycamore (*Acer pseudoplatanus* L.) | 35 | 3.6 | 3.8 |
| Manchus maple (*Acer tegmentosum* Maxim) | 60 | 18.1 | 14.7 |
| Subspecies Ginnala Tatarian maple (*Acer tataricum* subsp. *Ginnala* Maxim*)* | 70 | 8.7 | 6.0 |
| Sugar maple (*Acer saccharinum* L*.)* | 44 | 15.3 | 12.6 |
| Red maple (*Acer rubrum* L.) | 30 | 13.1 | 10.8 |
| Ash-leaved maple (*Acer negundo* L.) | 57 | 12.3 | 11.0 |
| Norway maple (*Acer platanoides* L.) | 63 | 15.6 | 13.4 |

**FIGURE 1.** Taking research material from growing maple trees.

length along the wood fibers. It is clear that it is impossible to manufacture such samples without cutting a tree. Therefore, this destructive method is more suitable for the selection of resonant wood from harvested timber in woodworking shops than in the forest.

Diagnostics of resonance properties of standing timber should be carried out by a non-destructive vibration method by determining eigenfrequency (resonant frequency) on samples in the form of radial-transverse cores taken by a hollow drill from the stem part of the tree [4]. Such tool is widely used by foresters in determining the age of a growing tree.

In recent years, scientific works have appeared abroad, confirming the existence of a relationship between the modulus of elasticity of the wood of the branches and the stem [5-8]. In other words, the modulus of elasticity of the wood of the branches is an objective indicator to be used as a criterion in a non-destructive method for assessing the technical properties of wood of a tree stem.

Since $E_{dyn}$ according to Equation 1 is one of the main characteristics of the resonance material, in dendroacoustic studies of tree species with hard wood or young stock with small stem diameter, where it is difficult or impossible to take radially transverse cores, cuttings can be used as experimental samples made from side branches of growing trees even at an early age.

Acoustic constant K, according to the results of vibration measurements of cylindrical shape samples (cuttings), is determined by Equation 2 [9]:


**FIGURE 2.** Test cuttings for experimenting.

$$K = \sqrt{0.328 \frac{m \cdot l^3 \cdot f^2}{\rho^3 \cdot \left( m_k \cdot l'^2 + \frac{m \cdot l^2}{3} \right)} \cdot 10^{-6}} \qquad (2)$$

where K is acoustic constant, $m^4 \cdot kg^{-1} \cdot s^{-1}$; f is resonant (eigen-) frequency, Hz; ℓ is sample working length, m; ρ is sample density, $kg \cdot m^{-3}$; $m_k$ is mass of a ferromagnetic 'cap' on the sample (Figure 3, 4), kg; m is mass of sample working part, kg; and d is sample mean diameter, m.

The threshold value for resonant wood in the longitudinal direction along the fibers is $K \geq 12.0\ m^4 \cdot kg^{-1} \cdot s^{-1}$, and for transverse radial measurements it is $K \geq 3.5\ m^4 \cdot kg^{-1} \cdot s^{-1}$. However, it should be borne in mind that this indicator is set for conifers (spruce, caucasian fir and cedar); the speed of sound along the fibers in their wood reaches an average of 5500.0-6000.0 $m \cdot s^{-1}$ [10].

Hardwood with a more complex anatomical structure has different parametres, which is confirmed by other studies [10, 11]. It is more convenient to determine the density of wood in samples of arbitrary shape, cuttings, by the method of buoyancy [12].

Vibration studies were carried out using a hardware-software complex. Figure 3 shows a general view of a fragment of the device with a cantilever mount of a prototype, and the complete schematic diagram is shown in Figure 4.

Previously, this method was used in non-destructive diagnostics of the resonant properties of standing spruce. It is protected by a patent of the Russian Federation for invention [13] and was widely tested in other works [4, 9, 14]. Therefore, without going into a detailed presentation, we only noted the essence of dendroacoustic measurements.

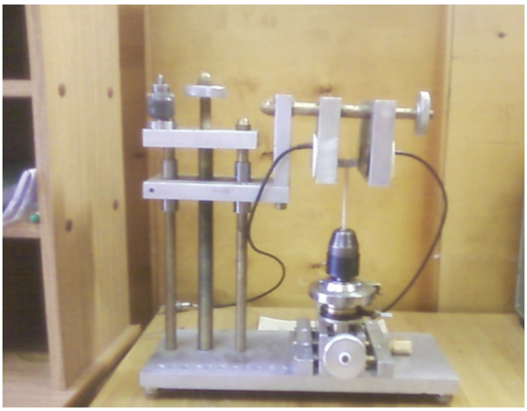

**FIGURE 3.** General view of the device with a cantilever mount prototype.

The harmonic signal comes from full-duplex sound card (2) of the computer system unit to electromagnetic sensor (vibrator) (3) exciting transverse oscillations of vertically installed sample (5) by means of soft iron 'cap' (6) with an internal diameter adjusted to the diameter of the sample (cutting). After fixing, the signal taken by the electromagnetic sensor is fed to the input of the full-duplex sound card. The corresponding histogram is displayed on monitor screen (1), and the sample eigenfrequency (resonant frequency) is determined by the maximum peak.

For non-standard samples, in this case the cuttings, it is advisable to determine the *basic* density of wood through the identification of buoyancy.

Basic wood density is known to be expressed as

$$\rho_b = m_o / V_{max} \quad (3)$$

where $\rho_b$ is basic wood density, g·cm$^{-3}$; $m_o$ is mass of absolutely dry sample, g; $V_{max}$ is volume at humidity equal to or higher than the saturation limit of the wood cell walls, cm$^3$.

With the basic wood density of maple wood given it is possible to calculate its standard density at 12% humidity according to the following equation (4) [10]:

$$\rho_{12} = \rho_b / 0.823 \quad (4)$$

where $\rho_{12}$ is standard density at 12% humidity, g·cm$^{-3}$.

The method of determining wood density by measuring the buoyancy force is given in the monograph by Poluboyarinov [12] and is as follows (Figure 5).

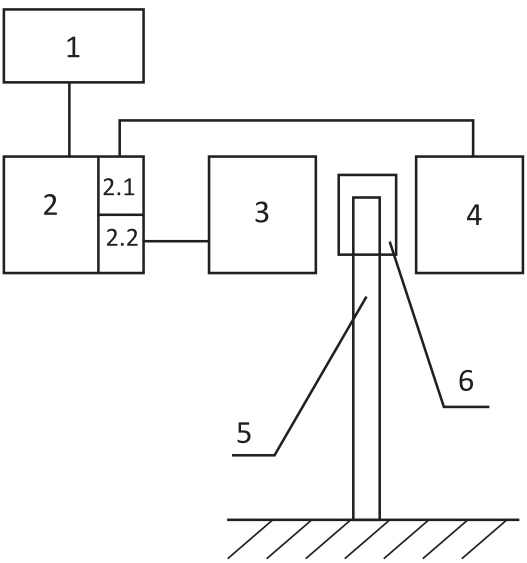


**FIGURE 4.** Principle diagram of hardware-software complex for defining frequency -amplitude properties of wood: 1 - monitor; 2 - computer, containing: 2.1 - sound board input, 2.2 - sound board output; 3 - TK-67-H-type vibrator; 4 - TK67-H-type transducer; 5 - sample; 6 - ferromagnetic 'cap'.

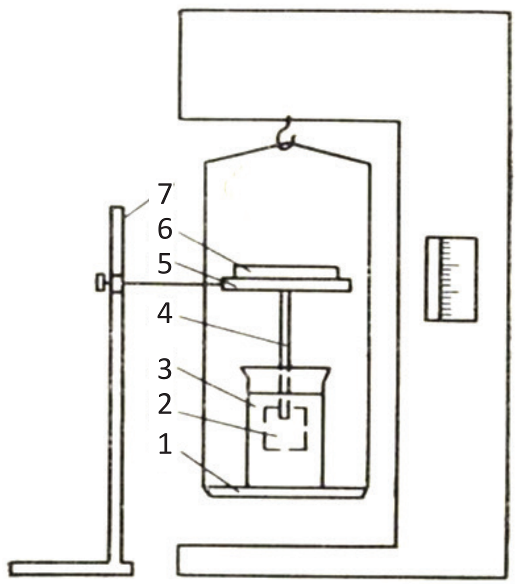


**FIGURE 5.** Diagram of the device for determining wood density by measuring buoyancy: 1 – weighing pan; 2 - sample; 3 - vessel with water; 4 - needle; 5 - ring; 6 - holder; 7 – tripod.

A vessel with water (3) is placed on the weighing pan (1). Ring (5) fixed to tripod (7) is placed above the vessel. The ring serves as a support for the holder (6), having needle (4) with its end doused into water. In this position, the vessel with water is weighed. After that, the holder is removed and the sample (2), previously held in water, is placed onto the needle to determine its volume. After immersing the sample, a second report is taken. An additional load on the weighing pan is created by overcoming the buoyant force acting on the sample (Archimedes' Law) and is numerically equal (if we take the density of water equal to 1) to the sample volume. Consequently, the difference in readings on the scale gives the desired volume in cubic centimeters.

The sample mass in absolutely dry condition will be determined by weighing on an electronic scale after drying at 103°C for about 10 hours.

## RESULTS AND DISCUSSION

Table 2 shows a comparative analysis of the results obtained by the vibration method on samples of Norway maple and taxa.

For better clarity, the results of the research are given in the form of graphic images (Figure 6-8).

In recent years, the activity of foreign scientists in the field of studying acoustic and elastic properties of wood has increased [5-7, 15-21]. In some countries, exploratory physical-acoustic studies have begun to identify the possibility of using not only spruce wood, but also other species for manufacturing musical instruments, especially string instruments (violin, classical guitar, etc.). For this purpose, fruit wood was studied, namely, sweet cherry, cherry, pear, crab apple, walnut and prune. The results

**TABLE 2.** Dendroacoustic characteristics of maple wood.

| Taxon name | Valid N | ρ (kg·m$^3$) | $f_o$ (Hz) | $E_{dyn}$ (MPa) | K (m$^4$·kg$^{-1}$·s$^{-1}$) |
|---|---|---|---|---|---|
| Field maple (*Acer campestre* L.) | 48 | 535.05 | 188.75 | 2027.15 | 1.5 |
| Plane-tree maple-sycamore (*Acer pseudoplatanus* L.) | -«- | 553.5 | 562 | 21635.6 | 2.5 |
| Manchus maple (*Acer tegmentosum* Maxim) | -«- | 599.8 | 169 | 22067.2 | 0.6 |
| Subspecies Ginnala Tatarian maple (*Acer tataricum* subsp. *Ginnala* Maxim) | -«- | 513.4 | 149 | 16572.2 | 1.1 |
| Sugar maple (*Acer saccharinum* L.) | -«- | 492.2 | 328 | 28556.6 | 2.3 |
| Red maple (*Acer rubrum* L.) | -«- | 615.2 | 228 | 35131.3 | 1.2 |
| Ash-leaved maple (*Acer negundo* L.) | -«- | 493.2 | 228.0 | 37341.1 | 3.1 |
| Norway maple (*Acer platanoides* L.) | -«- | 522.5 | 365.7 | 28362.2 | 2.6 |

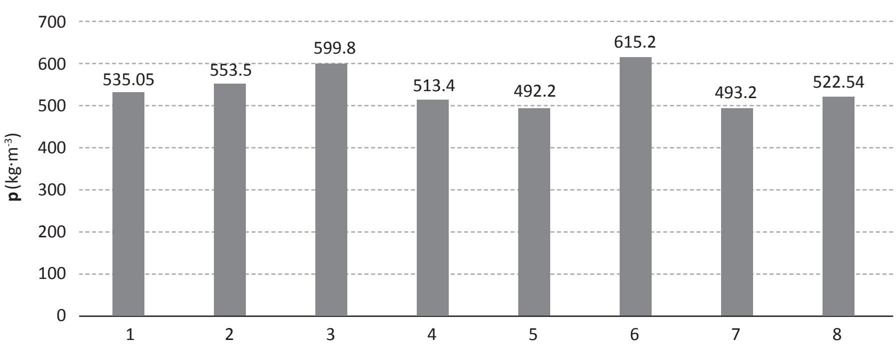


**FIGURE 6.** Distribution of the average density of maple wood by taxa: 1 - field maple (*Acer campestre* L.); 2 - plane-tree maple-sycamore (*Acer pseudoplatanus* L.); 3 - Manchus maple (*Acer tegmentosum Maxim*); 4 - subspecies Ginnala Tatarian maple (*Acer tataricum* subsp. *Ginnala* Maxim); 5 - sugar maple (*Acer saccharinum* L.); 6 - red maple (*Acer rubrum* L.); 7 - ash-leaved maple (*Acer negundo* L.); 8 - Norway maple (*Acer platanoides* L.).

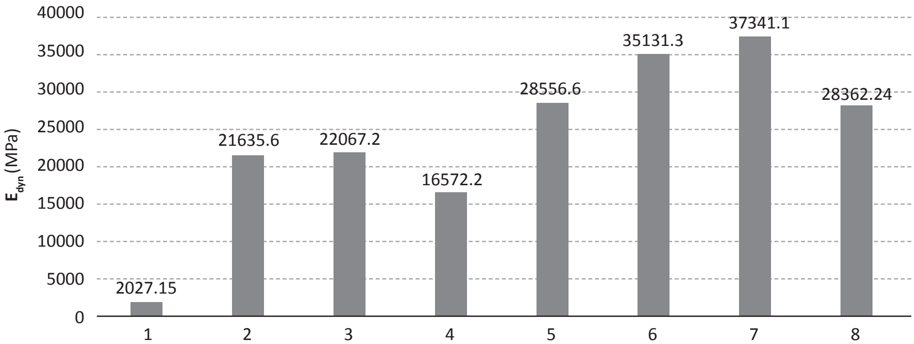


**FIGURE 7.** Taxon distribution of the average dynamic modulus of elasticity ($E_{dyn}$) of maple wood by frequency-amplitude method (taxon numbering corresponds to the keys in Figure 6).

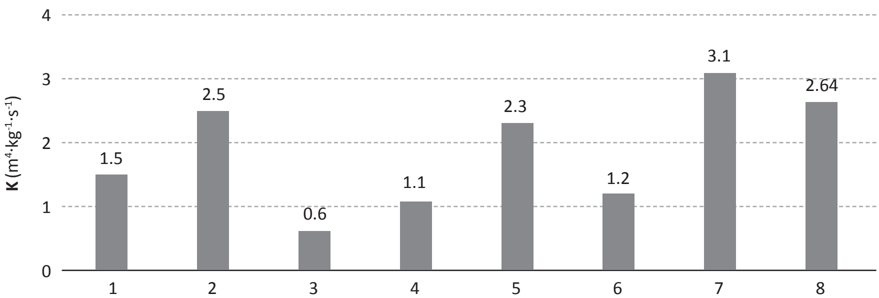


**FIGURE 8.** Taxon distribution of the average value of acoustic constant (K) of maple wood by the frequency-amplitude method (taxon numbering corresponds to the keys in Figure 6).

obtained showed that the wood of these species does not meet the requirements for the top plate acoustic and other physical-mechanical properties, but can be used in manufacturing separate parts of musical instruments. Moreover, sweet cherry wood is of greatest practical interest because it is close to maple by the value of acoustic constant, i.e. it is suitable for making the back plate. Thanks to this combination, the original sound of a musical instrument is achieved [22].

It is important to note that maple wood, especially with 'birdseye' fiddle mottle, along with spruce resonant wood, plays a major role in forming acoustic properties of musical instruments' sounds [1]. Such wood texture is more often formed in sugar maple (*Acer saccharinum* L.), but it can also occur in other species of maple: field maple (*Acer campestre* L. and *Acer campestre*), red maple (*Acer rubrum* L.), Manchurian maple (*Acer mandschuricum* L.), Norway maple (*Acer platanoides* L.) and plane-tree maple-sycamore (*Acer pseudoplatanus* L.).

Consequently, to study the dendroacoustic properties of maple wood in general, and especially depending on the genetic and geographic origin is of practical importance.

In this aspect, the scientific work on identifying the quality of maple wood for manufacturing the back plate of a violin is of great interest [11]. The paper shows that the highest quality wood for this purpose should have high density (about 600 rg·m$^{-3}$), low acoustic constant of sound propagation (about 6.7 m$^4$·kg$^{-1}$·s$^{-1}$) and sound speed from 3800 up to 4600 m·s$^{-1}$. Although these indicators have not yet been accepted in wide practice as a criterion for selecting material in the production of musical instruments, we will analyze our research results in comparison with these data.

In terms of density, red maple (*Acer rubrum* L.) and Manchus maple (*Acer tegmentosum Maxim*) mostly correspond with the data mentioned above; wood density of these species is about 615.0 and 600.0 and rg·m$^{-3}$, correspondingly.

Sugar maple (*Acer saccharinum* L.) and ash-leaved maple (*Acer negundo* L.) have lower density of wood of 492.2 and 493.2 rg·m$^{-3}$, correspondingly.

Judging by the acoustic constant of sound propagation, the wood of Manchus maple is even more different from not only red maple (only 0.6 vs. 1.2 m$^4$·kg$^{-1}$·s$^{-1}$), but also from all other species of maple for which the acoustic constant of sound propagation is in the range of 1.1-3.1 m$^4$·kg$^{-1}$·s$^{-1}$, this indicator being the highest for ash-leaved maple (*Acer negundo* L.) and Norway maple (*Acer platanoides* L.), 3.1 and 2.6 m$^4$·kg$^{-1}$·s$^{-1}$, correspondingly.

According to the maple of local origin, Norway maple (*Acer platanoides* L.), compared to the introduced species, has average density (522.5 rg·m$^{-3}$), but relatively high acoustic constant of sound propagation (2.6 m$^4$·kg$^{-1}$·s$^{-1}$).

In general, all studied trees have a relatively low acoustic constant of sound propagation. This is explained by the fact that the object for non-destructive research were lateral branches having the indicator of acoustic constant of sound propagation lower than the trunk of the tree [9].

## CONCLUSIONS

Thus, the maples introduced by geographical origin under the conditions of the Volga region of Russia differ in density and dendroacoustic characteristics of wood. According to scientific criteria [11], in the forest conditions of the Republic of Mari El, the wood of red maple (*Acer rubrum* L.) and Manchus maple (*Acer tegmentosum Maxim*) introduced by geographic origin is more appropriate as the material for making the back plate of the violin. Local maple is somewhat inferior in wood quality for this purpose. However, the results of the work presented are only scientific and educational in nature and cannot pretend to the development of practical recommendations for the target selection and cultivation of one or another kind of maple in these conditions. To solve this problem, it is necessary to monitor the growth of these trees and supplement comprehensive studies by combining the efforts of forestry scientists, wood scientists, physicists, acousticians, and musical instruments production specialists.

## REFERENCES


1. VITACHEK EF 1964 Essays on the history of the manufacturing string instruments Moscow, Music, 341 p
2. SANUKOV NK 1994 The only one in Russia. Mari El: Yesterday, Today, Tomorrow. 5-6: 82-84
3. ANDREYEV NN 1938 On the tree for musical instruments. Collection of works, CMSRL ML, 1:11-18.
4. FEDYUKOV VI 2016 Resonant spruce: selection from standing trees, cultivation, target use: Scientific publication. Yoshkar-Ola, VSUT, 256 p
5. HSU LC-Y, CHAUHAN S, KING N, LINDSTRÖM H 2003 Modulus of elasticity of stemwood vs branchwood in 7-year-old *Pinus radiata* families. *N Z J Forest Sci* 33 (1): 35-46
6. LINDSTRÖM H, HARRIS P, NAKADA R 2002 Methods for measuring stiffness of young trees. *Holz als Roh-und Werkstoff* 60: 165-167
7. MAMDY C, ROZENBERG P, BASTION JC 1995 Non-Distructive assessment modulus of elastivity in genetic field tests in France: 20 IUERO World :mgr., Tampere, 7-11 Aug. 1995. *IAWA J* 1: 16
8. LINDSTRÖM H, NAKADA R, RALSTON J 2003 Cell wall structure and wood properties determined by acoustics - a selective review. *Holz als Roh-und Werkstoff* 61 (5): 321-335
9. SALDAYEVA YY 2015 Development of a method for early non-destructive diagnostics of the resonant properties of standing spruce. PhD Thesis Tech. Voronezh, Russia
10. UGOLEV BN 2001 Wood science with basic concepts of timber merchandizing. Moscow State Forestry University, Moscow, Russia, 340 p
11. WEGST UGK 2006 Wood for sound. *Am J Bot* 93 (10): 1439-1448. DOI: https://doi.org/10.3732/ajb.93.10.1439
12. POLUBOYARINOV OI 1976 Wood density. Forest industry, Moscow, Russia, 159 p
13. Pat. 2439561 RF. IPC G 01 N 33/46. Method for early diagnosis of resonant properties of wood. Fedyukov VI, Saldayeva EY, Vasenev AL, No 2439561 C2; appl. 26.032009; publ. 10.01.2012; Bul. of invent. 2012. No 1.
14. FEDYUKOV V, SALDAYEVA E, CHERNOVA M 2017 Different ways of elastic modulus comparative study to predict resonant properties of standing spruce wood. *Wood Res* 62 (4): 607-614
15. BUCUR V 2006 Acoustics of Wood. Springer Verlag Berlin Heidelberg, Germany, 393 p. DOI: https://doi.org/10.1007/3-540-30594-7
16. BLSKOVA G, BRDAROV N 2003 Sounding wood acoustic characteristics studies. *In*: Collection of scientific reports at 50th anniversary of the Forest Engineering Institute: Woodworking and furniture production section. Sofia, Bulgaria, pp 49-53
17. CULIK M 2013 Drevo a jeho vyuzitie vo vyrobe hudobnych nastrojov. Technicka univerzita vo Zvolene, Zvolen, Slovakia, 93 p
18. DANIHELOVA A 2004 Relevant Physical Acoustics of Spruce Wood as a Material for Musical Instruments. *In*: Proceedings of the 8th World Conference on Timber Engineering WCTE 2004, Lahti, Finland, pp 491-494
19. DANIHELOVA A, CULIK M 2013 Netradicne vyuzitie jarabiny vtacej na vyrobu konstrukcnych sucasti violy. *In*: Noise and vibration in practice, Proceedings of the 18th International Acoustic Conference. Slovenska technicka univerzita v Bratislave, Bratislava, Slovakia, pp 27-30
20. NAKAMURA N 1997 Development of measuring Yong's modulus of planting stock. *Journal of the Japanese Forestry Society* 79(1): 43-48. DOI: https://doi.org/10.11519/jjfs1953.79.1_43
21. YOSHIHARA H 2012 Off-axis Young's modulus and off-axis shear modulus of wood measured by flexural tests. *Holzforchung* 66 (2): 207-213
22. HALACHAN P, SPISIAK D 2014 Phisical-acoustical characteristics of chosen fruitwoods. *In*: Proceedings of the 5th International Symposium of Regional Coordination Council on Wood Sci."The Structure, Quality, Properties of Wood-2014, pp 22-25

SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

PRELIMINARY COMMUNICATION

DOI: https://doi.org/10.15177/seefor.19-10

# Modernization of Harvesting and Processing Head

**Konstantin Pavlovich Rukomojnikov[1]*, Sergei Vladimirovich Vedernikov[1], Victoriia Olegovna Kuptcova[1]**

**(1)** Volga State University of Technology, Department of technology and equipment for timber and chemical industries, Lenin Sq., b. 3., RU-424 000 Yoshkar-Ola, Russia

* **Correspondence:** e-mail: rukomojnikovKP@volgatech.net

**Citation:** RUKOMOJNIKOV KP, VEDERNIKOV SV, KUPTCOVA VO 2019 Modernization of Harvesting and Processing Head. *South-east Eur for* 10 (2): 181-185. DOI: https://doi.org/10.15177/seefor.19-10

**Received:** 22 Oct 2018; **Revised:** 18 Jan 2019; 4 May 2019; **Accepted:** 11 Jun 2019; **Published online:** 14 Aug 2019

## ABSTRACT

**Background and Purpose:** The article is devoted to the reduction of energy consumption necessary for delimbing.

**Materials and Methods:** Branch delimbing method includes feeding the tree trunk through the ring formed by the delimbing knives and simultaneous reciprocator movement of the delimbing knives along the axis of the processed trunk. The distinctive feature of the construction is the presence of the beater unit comprising a pusher and a piston mounted inside a sealed housing.

**Results:** As a result of the suggested construction the force of the beater impact of the delimbing knife is increased. Using this method, the branches are removed not only due to the force generated when the knives come in contact with branches pushed by feed rolls moving the trunk, but also due to extra beater stress affecting the delimbing knife. The use of the aforesaid method and the construction of the mechanism allows to reduce energy consumption necessary for the delimbing process.

**Conclusions:** The design of harvesting and processing head proposed in this article can be used in the design and manufacture of logging machines and mechanisms. The technical solution may be an interesting advance of the delimbing process when processing trees, especially when cutting big branches or when cutting forces are temporarily higher than average force values.

**Keywords:** forestry machinery, harvester head, delimbing mechanism, tree, harvester, processor

## INTRODUCTION

A shift of harvesting enterprises to progressive logging technologies ensures enhancing the productivity, improving the quality of the logging site processing and minimizing negative environmental impact. Over the past decade forestry machinery pool has significantly expanded and become diverse all over the world. Ever increasing requirements for such equipment force manufacturers to constantly improve forestry machinery. One of the most promising and intensively developing technological processes of timber harvesting are technological processes which use state-of-the-art harvesting machinery capable to remove branches from tree trunks on the logging site (harvesters and processors) [1].

Summing up the aforesaid, it is worthwhile to note that modernization of harvester and processor technological equipment is vitally important and has a valuable scientific and practical value.

## LITERATURE REVIEW

Many researchers are involved in searching for solutions to improve the structure of the working elements of harvesting machines [2-6] and modern machines working in close connection with them [7-11]. Based on the functional and technological analysis of harvester head, Budnik [12] and Demchuk [13] devise a development matrix, which contains all possible ways for its improvement. Among other ways of efficiency enhancement of the harvester head operation we consider it to be necessary to reduce the impact of dissipative forces emerging during trunk feeding process.

At present, delimbing methods and the construction of mechanisms patented in [14-17] using the feeding wheels mounted on the movable gripping device and the delimbing device ensure the removal of branches on the side adjacent to the mechanism case. The feed rollers embrace the tree trunk from both sides and force the tree trunk with the effort necessary to remove branches by the delimbing knives. The dependence on the feed roller drive with sufficient delimbing capacity is a significant drawback of aforesaid method and the construction of the mechanism.

Another delimbing method presented in the patent publications [18-20] comprises the use of three feeding rolls, one of which is mounted on the frame structure, while the other two are mounted on the movable gripping elements. The device ensures increased feeding force. The branches are removed through the impact force emerging when the feeding rolls move in the absence of additional mechanical impact on the branches. It means that the feed roller drive should have the increased capacity, which again represents a significant drawback of the aforesaid method and the construction of the mechanism.

Attempts to create vibrations of the cutting tool to influence the processes of mechanical processing of wood have been known since the 1940s. They are among the options for reducing the energy consumption necessary for delimbing.

Auto-resonant ultrasound technologies alongside with vibration technologies in general are characterized by high performance, efficiency and productivity, as they allow the obtaining of the maximum possible amplitudes of the working body (or other defining characteristics) with minimum power expenditures [21]. Ultrasonic-assisted cutting experiments have been performed on different wood species in dry and wet state. Compared to conventional cutting, the reduction of cutting forces by 50% is achieved at relatively small vibration amplitudes of 8 µm. [22].

However, ultrasonic cutting of wood has not yet found wide practical application for several reasons: the complexity of the development of ultrasonic oscillatory systems for the implementation of the processes of machine cutting; high cost and low reliability of ultrasonic equipment (ultrasonic generators and emitters) [23].

At the same time, high-performance perforators, original designs of vibration-damping devices and new designs of percussion mechanisms were developed and introduced into mass production. In the system of pneumatic impact mechanism, an increase in the working pressure is achieved through the use of compressed air. The increase in shock power by 2.8 times theoretically corresponds to an increase in air pressure from 0.5 to 1 MPa, and with a further increase to 2 MPa - by 8 times, etc. [24].

A positive decision on obtaining a patent for the invention of the Russian Federation on the design of this harvesting and processing head was received by the authors of the publication [25].

## MATERIALS AND METHODS

Our invention aims to reduce the energy consumption necessary for delimbing. When designing the mechanism, the task was to develop a design that would increase the power of the harvester head during the operation of cleaning the branches from trees. The methods used in solving the problem are most common in the design of percussion mechanisms of jackhammers and perforators.

The proposed principle of impact is provided by the reciprocating movement of the pusher in the cylinder. This creates a compression of air between the pusher and the piston. The energy of compressed air drives the piston, which strikes the rod. The return of the piston occurs due to the dilution of air during the return stroke of the pusher.

The suggested method is illustrated as follows.

Figure 1a represents a general view of the delimbing mechanism. Branch delimbing method includes feeding the tree trunk through the ring formed by the delimbing knives and simultaneous reciprocator movement of the delimbing knives along the axis of the processed trunk. The delimbing mechanism is attached to the manipulator of the harvesting vehicle and contains the following parts: (1) the structural frame with the mounted feeding wheels (4, 5) driven by hydraulic motors (2, 3). Some feeding wheels are mounted on the griping elements (6), and some on the frame structure to ensure the trunk grip from three sides and feeding the processed tree trunks in the longitudinal direction. The mechanism requires several delimbing knives (7) with tilting axes (8) to grasp the tree trunk parallel the aforesaid longitudinal direction. The device comprises one fixed delimbing knife (9), ensuring branch removal on the side of the tree trunk adjacent to the delimbing head, and a chainsaw (10).

Figure 1b presents a general sectional view of the delimbing mechanism against the plane of the beating mechanism. The fixed delimbing knife is mounted on the rear part of the rod (11). For the purpose of cross cutting of full-length logs, the device comprises a chainsaw and a measuring wheel (12) to measure the assortment lengths. The distinctive feature of the construction is the presence of the beater unit comprising a pusher (13) and a piston (14) mounted inside a sealed housing (15). Only one delimbing knife is equipped with the vibrating/bitting mechanism.

Figure 1c presents the type of interaction among the gear wheels of the beating mechanism drive. The feed roller (5) mounted on the mechanism frame features a fixed tooth gear (16), which meshes with a set of consequently interacting gears (17). These gears are mounted so that they carry out torque transmission (16) and proportionally accelerate the rotation speed of the final drive gear (18) which is a balance wheel for the slider-crank mechanism. The crank-and-rod mechanism (19) is used for the beater unit drive.

All the above described mechanisms driving the crank-and-rod mechanism and comprising a feed roller (5), tooth gear (16), a gear kit (17), and a balancing wheel (18) are mounted in one housing (20) attached to the axis (21) in axial alignment of the balancing wheel with a pressing element (22) in order to provide its pivoting, and pressing the feed roller against the tree trunk.

The exposed gears are very much subjected to mechanical damage and blocking by branch residuals and other contaminations, so gear wheels should be closed by a casing (this is not shown in the figures).

The developed delimbing and cutting device operates as follows.

The tree trunk is grasped by the feed rolls and is embraced by the delimbing knives. The feed roll mounted on the frame of the device is pressed against the frame due to stress from the trunk embraced by the grapples. Thus, the frame on which the feed roll is mounted rotates on its rotary axis causing the pressing unit to come into the pressed position.

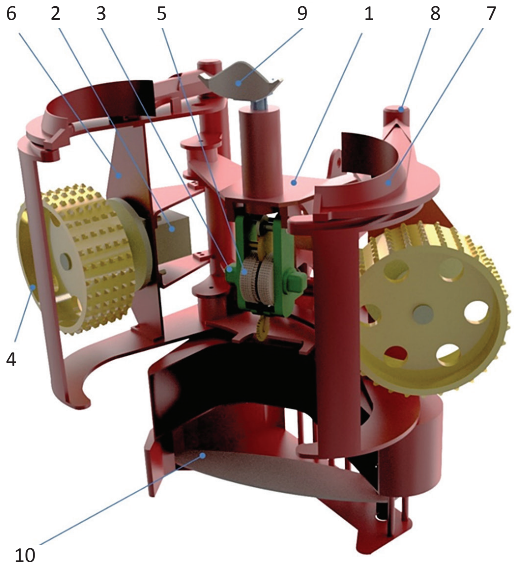


**FIGURE 1a.** General view of the delimbing mechanism: 1 - structural frame; 2, 3 - hydraulic motors; 4, 5 - feeding wheels; 6 - griping elements; 7 - delimbing knives; 8 - tilting axes; 9 - fixed delimbing knife; 10 - chainsaw.

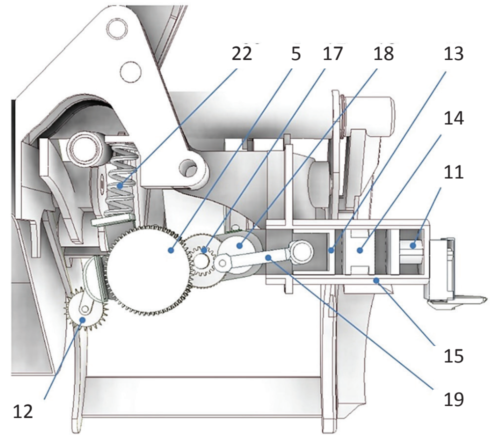


**FIGURE 1b**. General sectional view of the delimbing mechanism against the plane of the beating mechanism: 11 - rod; 12 - measuring wheel; 13 - pusher; 14 - piston; 15 - sealed housing; 17 - gear kit; 18 - balancing wheel; 19 - crank-and-rod mechanism; 22 - pressing element.

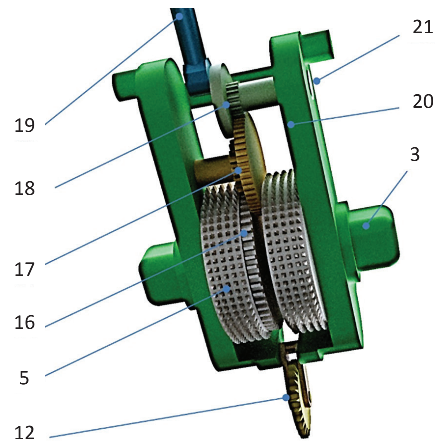


**FIGURE 1c.** Type of interaction among the gear wheels of the beating mechanism drive: 3 - hydraulic motors; 5 - feeding wheels; 12 - measuring wheel; 16 - tooth gear; 17 - gear kit; 18 - balancing wheel; 19 - crank-and-rod mechanism; 20 - housing; 21 - axis.

The knives form a ring. The wheels are driven in rotation to force the cut tree stem through the delimbing knives in the longitudinal direction.

Figure 2 presents the position of the striking elements after the forward moving of the pusher and beating on the piston rod. Figure 3 presents the position of the elements of the beating mechanism when the pusher returns to the initial position. The rotation of the feed rolls is accompanied by the rotation of the tooth gear, which, in its turn, transmits rotation via the gear kit onto the balance wheel of the slider-crank mechanism. The latter converts the rotary motion of the balance wheel into a reciprocal motion of the pusher inside the sealed housing. Sliding of the pusher inside a sealed housing under higher air pressure between a pusher and a piston when it moves forward and under lower air pressure when a pusher moves in the reversed direction causes a reciprocal motion of the piston. Sharp movement of the piston along the axis of the sealed housing towards the rod triggers a beater impact on the rod.

As soon as the desired length of a tree trunk is measured, it is crosscut by a chainsaw.

After the crosscutting, the feeding of the tree trunk proceeds, until the entire tree trunk has been processed.

## RESULTS AND DISCUSSIONS

When designing a device, it is possible to set a design optimization problem. The impact force required to cut the branches of a tree can be obtained at various values of the parameters of the mass of the piston (m) and its speed $\vartheta$. Changing the speed of movement of the piston is possible when changing the gear ratio between the feed rollers and the pusher.

Cutting force $F\rho$ (N) without chip formation depends on a number of factors [26] and can be determined by the formula:

$$F\rho=\alpha_n\cdot\alpha_\varepsilon\cdot\alpha_\delta\cdot\alpha_\omega\cdot\alpha_\upsilon\cdot\alpha_\rho\cdot n\cdot d_c^2\cdot k$$

$k$ - the specific resistance to the cutting of branches, H/m$^2$ ($k = 3.15\cdot10^6$); $\alpha_n$- correction factor for tree species (for pine, one can take $\alpha_n=1.0$); $\alpha_\varepsilon$- correction factor for the angle of inclination of the branches (for pine, one can take $\alpha_\varepsilon= 1.0$); $\alpha_\delta$- correction factor for cutting angle (at a cutting

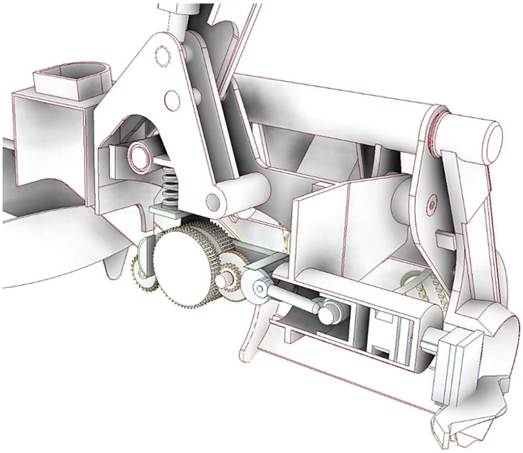

**FIGURE 2.** Position of the striking elements after the forward moving of the pusher and beating on the piston rod.

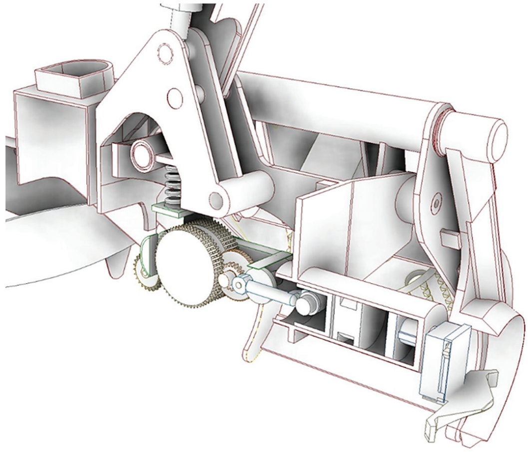

**FIGURE 3.** Position of the elements of the beating mechanism when the pusher returns to the initial position.

angle of 45° one can take $\alpha_\delta$= 1.0); $\alpha_\omega$- correction factor for wood moisture content (for freshly felled pine one can take $\alpha_\omega$= 0.95); $\alpha_\upsilon$- correction factor for the feed rate (at cutting speeds not exceeding 50 m/s one can take $\alpha_\upsilon$= 1.0); $\alpha_\rho$- correction factor for the blunting of the knife (depends on the time work of the knife after sharpening, one can take the average $\alpha_\rho$= 0.83); *n* - the number of simultaneously cutting branches (*n*=1, because only the work of one knife of the harvester head is considered); $d_c$ - average diameter of the cutting branches (m).

Consider an example of processing pine branches with 0.06 m. Substituting data into a formula, we get the result:

$$F_\rho = 8.9\ kN.$$

The power spent on cutting the branches at a speed of pulling a tree of $\vartheta_\rho$=1 m·s$^{-1}$ can be calculated by the formula:

$$E_\rho = F_\rho \cdot \vartheta_\rho = 8.9\ kW$$

We will model one blow of a knife with a tree pulling speed equal to $\vartheta$ = 1 m·s$^{-1}$.

Suppose that the gear ratio from the pulling roller to the pusher is 1/20. The pusher delivers 20 blows when moving a tree at a distance equal to one meter. The piston speed is 20 times faster than the tree pulling speed and is $\vartheta$ = 20 m·s$^{-1}$. One hit is *t* = 0.05 seconds.

We calculate the additional energy of the mechanism developed by a piston strike with a mass of three kilograms (m=3 kg).

$$A = \frac{1}{2} \cdot m \cdot \vartheta^2 = \frac{1}{2} \cdot 3 \cdot 20^2 = 600\ J$$

The additional power of the mechanism developed on impact will be:

$$E = \frac{A}{t} = 12\ kw$$

Thus, the obtained power value is sufficient for cutting branches of 0.06 meters in diameter and allows the reduction of the total power of the harvester head consumed during branch pruning. Cutting off the branches of a large diameter is carried out at the expense of several blows accompanying the cutting process.

The speed and mass of the piston can be adjusted, selecting a rational design of the device. Any efficiency of the harvester head achieved in its design can always be increased by increasing the mass of the piston, or by optimizing the gear ratio between the rollers and the pusher, without changing the mass of the piston.

## CONSLUSION

Thus, as a result of the suggested construction the force of the beater impact of the delimbing knife is increased. Using this method, the branches are removed not only due to the force generated when the knives come in contact with branches pushed by the feed rolls moving the trunk, but also due to extra beater stress affecting the delimbing knife.

The use of the aforesaid method and the construction of the mechanism allows to reduce energy consumption necessary for the delimbing process. To ensure the reliability of the presented developments and field tests, further theoretical and practical research is needed.

### Acknowledgment

The research was conducted with financial support by the OOO Martreyd, (a limited liability company under the laws of the Russian Federation) in the frame of the scientific and research project № 06.522/18.

## REFERENCES


1. POHARNIKOV FV, YUDINA NY, BULANOV AS, LADENTSOV PG 2012 Analysis of the state of the technical equipment of the forest process industry (*in Russian with English summary*). *Lesotechnic journal* 2:100-105
2. №1401258 B1 EP 2007 Felling head. PITKÄNEN, HANNU ALPO ANTERO PATENT AGENCY PITKÄNEN OY - 02727625.2; appl. 30.05.2001; publ. 15.08.2007
3. №3391737 A1 EP 2018 Log processing head. ALFTHAN ARTO (DE), PALMROTH LAURI (DE) – 17167284.3; appl. 20.04.2017; publ. 24.10.2018
4. SYUNYOV VS, SELIVERSTOV AA 2005 Working bodies of harvesters: designing and calculation (*in Russian*). Petrozav. state un-t, Petrozavodsk, 204 p
5. №2702865 A1 EP 2014 Harvester head and method in processing tree trunks. LASTUNEN, TURKKA (FI)– 12181988.2; appl. 28.08.2012; publ. 05.03.2014
6. №9545062 B2 US 2017 Integrated hydraulic system for harvester. CALIN RASZGA, DUBUQUE, IA (US), MARK BREUTZMAN, POTOSI, WI (US) – 13/613169; appl. 13.09.2012; publ. 17.01.2017
7. №3202253 A1 EP 2017 Feed means and log processing head. ALFTHAN ARTO (FI) – 17151122.3; appl. 12.01.2017; publ. 09.08.2017
8. PANDUR Z, ŠUŠNJAR M, BAČIĆ M, LEPOGLAVEC K, NEVEČEREL H, ĐUKA A 2018 Fuel Consumption of Forwarders in Lowland Forests of Pedunculate Oak. *South-east Eur for* 9 (1): 73-80. DOI: https://doi.org/10.15177/seefor.18-07
9. PONSSE 2019 Harvester heads. URL: https://www.ponsse.com/products/harvester-heads#/ (2 May 2019)
10. SILVATEC 2019 Harvester heads manufacturer. URL: http://www.silvatecforest.com/home. (2 May 2019)
11. JOHN DEERE 2019 Harvesting heads. URL: https://www.deere.com/en/attachments-accessories-and-implements/forestry-attachments/harvesting-heads/ (2 May 2019)
12. BUDNIK PV 2012 Functional-technological analysis of harvester head (*in Russian*). *Science and Business: Ways of Development* 9 (15): 036-038
13. DEMCHUK AV 2012, Modernization of the technological equipment of harvester for improving the efficiency of delivery of logs. Engineering Bulletin of Don. Volume: 20. № 2: 542-546
14. №9232701 B1 US 2016 Four roller tree harvester head. ROBIN A. PETERSON, PORT ORANGE, FL (US)– 13/952164; appl. 26.07.2013; publ. 12.01.2016
15. № 2513415 C2 RU 2014 Feller device for felling and limbing on tree trunks and blade for limbing. KESKINEN JUKHO (FI), KINNUNEN KARI (FI), KHANNE KARI (FI) – 2011134264; appl. 15.01.2010; publ. 20.04.2014; Bul. of invent – No. 11
16. RUKOMOJNIKOV KP, VEDERNIKOV SV, GABDRAHMANOV MG 2018 A method for delimbing tree-trunks and a device for applying the method. *Journal of Applied Engineering Science* 16 (2): 263-266. DOI: https://doi.org/10.5937/jaes16-16442
17. № 2676139 RU 2018 Method of developing barked assortments and working body for implementation thereof. TSAREV EM, ANISIMOV SE, RUKOMOJNIKOV KP, KONOVALOVA YA, VEDERNIKOV SV, ZABOLOTSKIJ VM, ANISIMOV NS, ANISIMOV IS – RU 2017145977; appl. 26.12.2017; publ. 26.12.2018; Bul.of invent. – No. 36
18. №9999180 B2 US 2018 Timber - working head and method of operation. BRETT JAMES KAYE, TAURANGA (NZ) – 14/194314; appl. 28.02.2014; publ. 19.01.2018
19. № 6318425 B1 US 2001 Delimbing device and a method in a delimbing device. PETRI NIEMI, TAMPERE – FI 09/786838; appl. 10.09.1999; publ. 20.11.2001
20. №9591810 B2 US 2017 Harvester head assembly. CHAD BISBALLE, LAKE CITY, MI (US)– 14/141689; appl. 27.12.2013; publ. 14.03.2017
21. ASTASHEV VK, KRUPENIN VL 2016 Ultrasonic cutting as a nonlinear (vibro-impact) process. Engineering for rural development. Jelgava, 25-27 May 2016. Jelgava, pp 218-223
22. SINN G, ZETTL B, MAYER H, STANZL-TSCHEGG S 2005 Ultrasonic-assisted cutting of wood. *J Mater Process Tech* 170 (1-2): 42-49. DOI: https://doi.org/10.1016/j.jmatprotec.2005.04.076
23. ADIKOV SG 2007 Study of the effect of tangential ultrasonic oscillations of the instrument on the efficiency of the process of machining wood (*in Russian*). PhD thesis, Nizhny Novgorod, Russian Federation, 188 p
24. SABITOV AE 2016 Justification of parameters of perforator with shock system “piston-boom-bar” and dry blowdown (*in Russian*). PhD thesis, St. Petersburg Mining University, St. Petersburg, Russian Federation, 143 p
25. №2682037 C1 RU 2019 Method of pruning tree branches and design of mechanism for its implementation. RUKOMOJNIKOV KP (RU), VEDERNIKOV SV (RU), GABDRAKHMANOV MI (RU)– 2017145836; appl. 26.12.2017; publ. 14.03.2019
26. GOLYAKEVICH SA, GORONOVSKIJ AR 2015 Basics of designing forest machines and computer-aided design systems. Study Guide - Minsk: Belarusian State Technical University, Belarus, 126 p

SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

PROFESSIONAL PAPER

DOI: https://doi.org/10.15177/seefor.19-12

# Ecology and Management of Black Walnut (*Juglans nigra* L.) in Hungary

**Károly Rédei[1], Marianna Takács[1], Tamás Kiss[2], Zsolt Keserű[2]***

**(1)** University of Debrecen, Faculty of Agricultural and Food Sciences and Environmental Management Böszörményi Út 138., H-4032 Debrecen, Hungary; **(2)** National Agricultural Research and Innovation Centre, Forest Research Institute, Püspökladány Experimental Station, Farkassziget 3, H-4150 Püspökladány, Hungary

* **Correspondence:** e-mail: keseruzs@erti.hu

**Citation:** RÉDEI K, TAKÁCS M, KISS T, KESERŰ ZS 2019 Ecology and Management of Black Walnut (Juglans nigra L.) in Hungary. *South-east Eur for* 10 (2): 187-191. DOI: https://doi.org/10.15177/seefor.19-12

**Received:** 6 Mar 2019; **Revised:** 7 Jun 2019; **Accepted:** 23 Jun 2019; **Published online:** 15 Aug 2019

## ABSTRACT

**Background and Purpose:** Black walnut (*Juglans nigra* L.) was one of the first forest tree species introduced and acclimated from North America to Europe in the 17$^{th}$ century. Although native to North America, black walnut is now naturalized and widely planted throughout Europe. In Hungary, this species has played an important role in forest management. Black walnut can grow on various sites, but careful site selection and well-planned management practices are needed to produce successful plantations. Due to the increasing interest in black walnut growing in many countries this study complied with the aim of giving a summary on the base of research and improvement connected with the species over the past decades.

**Materials and Methods:** Black walnut produces a well-closing, favourably differentiated stand structure in consequence of the great genetic diversity of single trees. It utilizes well the leaks of the tending cuttings. In this manner, because of its quick height growth, the systematic, individual selective method can be favourably combined with more frequent stem number reduction. The objective of tending should be to produce a high proportion of good quality saw logs from stands of yield class I, II, III and IV, and some other smaller-dimension industrial wood from stands of yield class V and VI.

**Conclusions:** In Hungary, black walnut is one of the most valuable exotic tree species, mainly because of its wood excessively used in furniture industry. Black walnut is used in furniture industry both as solid wood and veneer. This species is among the most expensive furniture woods in the world due to its appealing surface figure and colour. Its wood is also used for making musical instruments, turned and carved ornaments, statues and marquetry. Black walnut stands are to be important in carbon sequestration, soil stabilization, and water quality protection as well.

**Keywords**: black walnut (*Juglans nigra* L.), stand establishment, tending operations and yield, diseases

## INTRODUCTION

Black walnut is one of the most valuable hardwoods in Hungary. Landowners have shown an increasing interest in growing black walnut for high-value timber products. Hungary has much experience in black walnut growing, as it was imported to the country in the eighteenth century [1]. Black walnut forests in Hungary have been established on high-quality as well as on medium-quality sites. The establishment of black walnut stands producing high-quality timber is possible only on sites with adequate moisture and well-aerated and preferably light soils, rich in nutrients and humus. It is a fast-growing species with frequent seed production and relatively high yielding potential. It has a durable and high quality wood, which is used for many purposes [2, 3]. This paper provides a practice-oriented review for black walnut plantation management based on the relevant Hungarian experiences and research results.

## AREA AND TREE CHARACTERISTICS

In Hungary, black walnut is one of the most valuable exotic tree species, mainly because of its wood excessively used in furniture industry [4]. It was introduced from North America to Europe in the 17$^{th}$ century, and appeared in the 18$^{th}$ century in Hungary. The first plantations of black walnut were established 100-110 years ago. The area of black walnut is approx. 8 000 ha (approx. 0.4% of the forested area) in the country. Important plantations of black walnuts are found in Tolna, Baranya, Somogy, Bács-Kiskun and Győr- Sopron [3] (Figure 1 and 2).

Black walnut is a light-demanding tree species and develops straight, cylindrical trunks in close stands. The tree may grow 20-30 m tall, with a 15-18 m useful bole length. The average Diameter at Breast Height (DBH) can reach 0.3-0.4 m at the age of 80-90 years [5]. Longitudinal cracks appear on the greyish black bark even in young trees. Leaves are oddly pinnate, just like those of common walnut, but they are serrate with a less intensive odour. The large edible nut ripens in September or October of the same year and drops shortly after the leaves fall. Good seed crops are produced irregularly, perhaps twice in 5 years. Best seed production begins when the trees are about 30 years old and continues for another 40-50 years [5]. The initial root form of black walnut, with its rapidly growing juvenile taproot and wide spreading laterals, is characteristic of species that grow on deep, fine-textured soils [2, 6].

## SITE REQUIREMENTS

In Hungary, black walnut grows preferably on plains and thrives on moderately compact, nutrient-rich, moist soils (e.g. flood plains). It grows especially well on deep loams, loess soils, and fertile alluvial deposit. It also grows well on good agricultural soils, but it grows slower on sandy ridges. It tolerates winter frost well, but it is sensitive to early winter and late spring frosts [2, 3, 7].

In general, soils should be deep (at least 80-90 cm), well-drained, and should have a good moisture-holding capacity. Fertile loams and sandy loams with high organic matter and pH from 6.5 to 7.2 are usually best. Flooding can kill young walnut trees during the growing season. If water remains over the tops of trees for more than 2 days, the trees usually die. Flooding for 3 to 5 days during the dormant season is tolerated, but logs and other debris will often break or bend trees. Young trees recover rapidly from such treatment, but older trees may sustain permanent damage to bark, providing an avenue of entrance for decay [3, 6].

## PLANTATION ESTABLISHMENT

### Seedlings Management

In Hungary there are excellent nurseries to provide seedlings for artificial reforestation and afforestation. Seedling quality is generally good, and all seedlings are grown from walnuts collected in the country. Only larger seedlings with healthy root systems are sorted and planted. The grafts are relatively expensive, but provide a known, reproducible, genetic improvement over nursery seedling stock [2].

### Planting and Sowing Season

April and May are generally the most desirable months for planting bare-root walnut seedlings or sowing seeds. Seedlings should be planted after the danger of late freezes. Spring planting provides seedling with time to establish a root system before winter. Autumn planting (October, November) can also be proven successful under certain conditions. However, bare-root seedlings approaching the winter with little root growth and without adequate snow cover or mulch often suffer winter kill [2, 3, 7].

### Layout and Spacing

Recommended spacing for walnut plantations is 2.5-2.8 by 0.7-1.0 m (4000-5000 trees per hectare). This allows for mortality and thinning of undesirable trees during the rotation. Plantation layout is crucial to ease management operations in the future. Rows must be straight in at least one direction to facilitate mowing, spraying, and other silvicultural operations such as soil surface treatments between the rows. In case of sowing, normally 800-1000 kilos of seeds in shell are sown per hectare [2].

### Interplanting

In Hungary black walnut plantations are established as monocultures. Our growing trials with a mixture of black walnut and black locust have shown that black locust outgrows walnut and quickly smothers it [2]. Under no

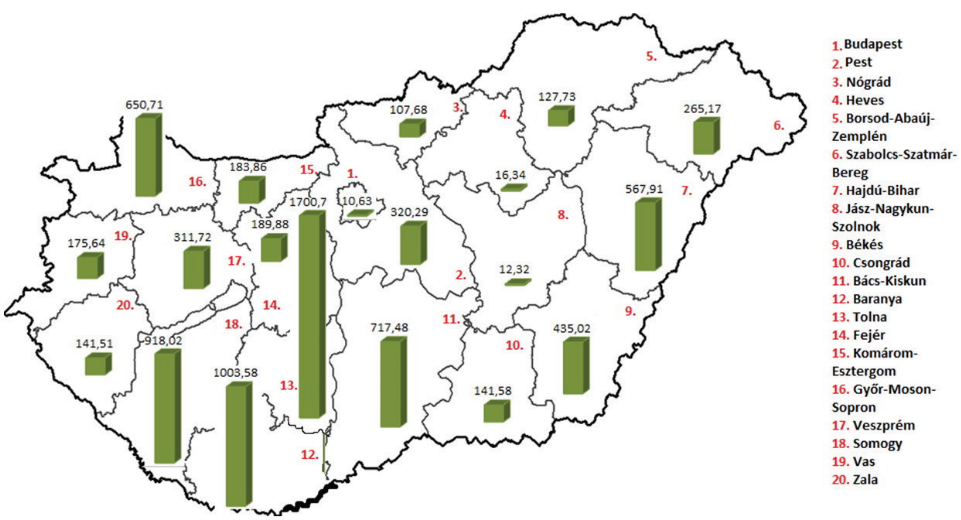


**FIGURE 1.** Covering of black walnut stands by counties (ha) (Source: Forest Service, 2015).

**FIGURE 2.** Black walnut plantation at the age of 60 years in Central Hungary (Photo: K. Rédei)

circumstances should livestock be grazed in a black walnut plantation. They will eat young trees; the bark of older trees may be stripped and soil compaction will reduce walnut growth. Deer and rabbits can provide forest owners with enough problems caused by animals [2, 6].

### Weed Control

Without weed control, black walnut plantations invariably fail or do not grow nearly to their potential. Weed control should be carried out both in the rows by hoeing and between the rows by disk. However, it must be emphasized that cultivation will be required twice during each growing season for trees up to four or five years old. Depth of cultivation must be shallow, because many walnut feeder roots are in the upper layers of the soil and are easily damaged [2].

### Pruning

Apart from weed control, the other important treatment to improve the quality and future value of black walnut is pruning. The purpose of pruning is to develop a straight single stem which will ultimately become a high-value veneer log. Black walnut has an overwhelming tendency to produce multiple shoots caused by insect or frost injury to the terminal bud. These shoots, if not reduced to the single straightest and/or tallest, will produce forks that limit the length of the future log. During carrying out the tending operations, it is necessary to reach a height of 8-10 metres of branch-free stem [2, 6]. It is known that proper pruning is the factor that a grower can use to greatly increase tree quality and hence the economic value of a walnut plantation. In fact, pruning may double the value of a plantation at harvest age.

## TENDING CUTTINGS AND YIELD

The first tending cutting should be made at about 8-10 years. Poorly formed trees with no potential for straightening, diseased, and very slow-growing trees should be removed. Sprouts should be mowed frequently until dead. Over 18 years thinnings are to be carried out. During the tending cuttings, it is important to take into consideration that populations consist of specimens of varied genetic value (genotypic). Black walnut produces a well closing, favourably differentiated stand structure in consequence of the great genetic diversity of single trees. It utilizes well the leaks of the tending cuttings. In this manner, because of its quick height growth, the systematic, individual selective method can be favourably combined at the more frequent stem number reduction (Table 1).

The most important stand structure parameters of black walnut stands at the age of 80 years old (Yield table: (5)) are shown in Table 2.

The objective of tending should be to produce a high proportion of good quality sawlogs from stands of yield class I, II, III and IV; and some other smaller-dimension industrial wood from stands of yield class V and VI. The mean volume increment, depending on the yield classes, varies between 3.1 and 14.2 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ [5]. The average rotation age for black walnut stands is 75-85 years [2, 5, 6].

## DISEASES

In Hungary, black walnut has no too many damages. A correct choice of species ensures that most black walnut

**TABLE 1.** Tending regime for black walnut plantations.

| Year | Stage/operation | Stem number·ha$^{-1}$ |
|---|---|---|
| 1 | Planting | 4000-5000 |
| 2-4 | Weed controls, replacing dead plants | 3500-4000 |
| 5-6 | "Completed stage" | 3000-3500 |
| 8-10 | Cleaning - respacing | 2000-2500 |
| 13-15 | Cleaning | 1200-1400 |
| 18-22 | Pre-commercial thinning | 800-1000 |
| 25-30 | Selective thinning | 300-400 |
| 50-60 | Increment thinning | 180-200 |
| 60-75 | Sanitary cutting (if necessary) | 120-150 |
| 75-85 | Harvest cutting | 100-150 |

**TABLE 2.** The most important stand structure parameters of black walnut plantations at the age of 80 years.

| Yield Class | Height (m) | Diameter at breast Height (cm) | Volume (m$^3$·ha$^{-1}$) |
|---|---|---|---|
| I | 29.5 | 43.6 | 428 |
| II | 25.0 | 37.0 | 315 |
| III | 21.1 | 31.3 | 231 |
| IV | 17.2 | 26.4 | 170 |
| V | 15.1 | 22.4 | 125 |
| VI | 12.8 | 18.9 | 92 |

plantation schemes are successful. Frost damage appears in the form of suddenly blackened new leaves and shoots. Secondary buds will break and begin growing up and down the stem within a few days after frost. No permanent damage is caused except for the growth of multiple stems that require careful pruning [2]. *Dicerca alni* Fischer, *Hylesinus fraxini* Panzer and *Colotois pennaria* Linné can be mentioned, which may cause damages. Wild animals, mostly wild boar, can damage the fresh sowing, as well as deer and red deer, who can browse on new growth in young black walnut plantations. Fencing plantations against them is expensive but sometimes essential [2, 6].

## BLACK WALNUT WOOD CHARACTERISTICS AND MARKETING

Black walnut is an important source of hardwood lumber. The wood is close-grained, heavy and hard; it machines well and accepts a variety of finishes. Its most important wood properties are the followings [1, 4]:

- Density (kg·m$^{-3}$): air dry (12%MC) = 580-640-810, oven-dry = 560-580, green = 900-980;
- Shrinkage (%): radial = 4.8-5.5, tangential = 7.1-7.7; longitudinal = 0.4, volumetric = 12.0-13.3;
- Assortments: sliced veneer raw material; sawlogs; short and low quality logs; other industrial wood; firewood;
- Utilisation: Black walnut is used in the furniture industry both as solid wood and veneer. This species is among the most expensive furniture woods in the world for its appealing surface figure and colour. It is important for exquisite interior applications, such as for staircases, flooring and panelling. It is unique for manufacturing hunting arms because of its beauty and strength. The wood is also used for making musical instruments, turned and carved ornaments, statues and marquetry [4];
- Wood prices: There are no fixed prices. In the open-air market 1 m$^3$ black walnut wood material costs approx. 130.00 EUR.

## ECOSYSTEM SERVICES, INVASIVENESS

Black walnut stands are to be important in carbon sequestration, soil stabilization, and water quality protection [8]. They also have a special role in preserving wildlife and environment as a shelterbelt. Black walnut provides good cover and nesting sites for a wide variety of birds and mammals. Deer, red deer, wild boar and rabbits commonly browse leaves and young seedlings, while acorns are eaten by a wide variety of large and small mammals and birds. Black walnut is not considered to be an invasive tree species in Hungary [2, 6].

## CONCLUSION

In Hungary, black walnut plantations have not made a significant impact on the supply oftimber. However, if the volume of new plantations is increased, if the plantations are adequately managed and if they are planted on productive sites, the plantations have the potential to improve the future supply of black walnut wood fiber.

## REFERENCES


1. BABOS K, FILLÓ Z, SOMKÚTI E 1979 Useful tree species. Műszaki Könyvkiadó, Budapest, Hungary, 315 p (*in Hungarian*)
2. FÜHRER E, RÉDEI K, TÓTH B 2008 Plantation Forestry 2. Agroinform Kiadó, Budapest, pp 25-33 (*in Hungarian*)
3. RÉDEI K, ANTAL B 2017 Black walnut (*Juglans nigra* L.) as a valuable stand-forming tree species: growing techchnological rewiew. *Acta Agraria Debreceniensis* 69: 43-48 (***i**n Hungarian*)
4. MOLNÁR S, BARISKA M 2002 Wood species of Hungary. Szaktudás Kiadó Ház Budapest, Hungary, pp 102-105
5. PALOTÁS F 1973 Yield of black walnut stands. *Erdészeti Kutatások* 69: 191-199 (***i**n Hungarian*)
6. SÁRVÁRI J Forest from walnut trees. Mezőgazda Kiadó, Budapest, Hungary, 119 p (*in Hungarian*)
7. BONDOR A, GÁL J 1976 Production of forest propagation material. Mezőgazdasági Kiadó, Budapest, 226 p (*in Hungarian*)
8. SZENTKIRÁLYI P, KÁLLAY TAMÁSNÉ Walnut. 2006 Mezőgazda Kiadó, Budapest, Hungary, 203 p (*in Hungarian*)

## Contents



OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891