www.seefor.eu

HRVATSKI ŠUMARSKI INSTITUT
CROATIAN FOREST RESEARCH INSTITUTE

SEEFOR

SOUTH-EAST EUROPEAN FORESTRY

Vol 9 No 2
pp 91-153
December 2018

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 9 No 2, pp 91-153, December 2018

SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

ORIGINAL SCIENTIFIC PAPER

DOI: https://doi.org/10.15177/seefor.18-17

First Record of *Dendrolimus pini* Outbreak on Aleppo Pine in Croatia and Severe Case of Population Collapse Caused by Entomopathogen *Beauveria bassiana*

Marta Matek[1], Milan Pernek[1]*

(1) Croatian Forest Research Institute, Division for Forest Protection and Game Management, Cvjetno naselje 41, HR-10450 Jastrebarsko, Croatia

* **Correspondence:** e-mail: milanp@sumins.hr

Citation: MATEK M, PERNEK M 2018 First Record of *Dendrolimus pini* Outbreak on Aleppo Pine in Croatia and Severe Case of Population Collapse Caused by Entomopathogen *Beauveria bassiana*. *South-east Eur for* 9 (2): 91-96. DOI: https://doi.org/10.15177/seefor.18-17

Received: 21 Nov 2018; **Revised:** 12 Dec 2018; **Accepted:** 14 Dec 2018; **Published online:** 22 Dec 2018

ABSTRACT

Background and Purpose: The pine-tree lappet moth, *Dendrolimus pini*, is a widely distributed pest in Europe that can cause serious needle defoliation on pines, with outbreaks occurring over large geographical areas. In Croatia the presence of *D. pini* was recorded only in the continental part, but not in a high level of abundance, and the outbreak of the population has never been recorded so far.

Materials and Methods: In autumn 2014 an unexpected and complete defoliation on Aleppo pine (*Pinus halepensis* Mill.) occurred in the vicinity of Skradin, near Šibenik, and was followed by defoliation in summer and autumn 2017 in Telašćica Nature Park, Dugi otok. Infested areas were inspected and overwintering larvae in soil surface were counted in order to estimate the population and assess whether the critical number of the population has been exceeded. Specimens were collected and transferred to the Laboratory for Entomological Analysis in the Croatian Forest Research Institute for further laboratory analysis.

Results: Since more than 10 larvae per m² of soil surface were found, it was concluded that an outbreak occurred at both localities. In both cases natural antagonists played an important role in lowering the pest population. In Skradin, entomopathogenic fungus *Beauveria bassiana* that occurred on the overwintering larvae broke the pest population, and in Dugi otok it was recorded, but to a much lesser extent and in combination with *Drino inconspicua* parasitoid. In both cases pines recovered very well in the following spring, with some bark beetle attacks mostly at the edge of the forest.

Conclusions: The outbreaks of *D. pini* resulting with a total defoliation of Aleppo pine stands, and the fact that they occurred in the Mediterranean region which is not an optimal area for its appearance, makes these events unusual. Also, this is the first record of *D. pini* population breakdown by some antagonist.

Keywords: antagonists, *Drino inconspicua*, Mediterranean, overwintering larvae, pine-tree lappet moth, *Pinus halepensis*

INTRODUCTION

The pine-tree lappet moth, *Dendrolimus pini* (L.) (Lepidoptera, Lasiocampidae), is a widely distributed pest in Europe [1, 2]. Its primary host is *Pinus sylvestris* L., but larvae can also feed on the needles of other species, mainly pines [3].

In July, after mating, each female lays 150-250 eggs on pine needles, twigs or bark in the canopy. Larvae begin to hatch within 1-3 weeks and start with autumn feeding which lasts until the occurrence of first frost, when they move down into the soil to find a proper site for hibernation. In spring, after overwintering, they climb into tree crowns where they feed on needles as well as the bark and buds of young shoots [2, 4]. One *D. pini* caterpillar can consume between 600 and 1000 pine needles through its development [5].

Spring feeding has a more damaging effect than the autumn one, and there are several reasons for that. First, the larvae at this stage are much bigger and consume a larger amount of needles. The second reason is that after complete defoliation, larvae can devour new needles that pines developed, and sometimes even parts of green shoots. This significantly weakens the vitality of the host, resulting in tree's dieback or the attack of secondary pests, most often bark beetles. Because of all this, it is extremely important to forecast a spring population, which is done by controlling the number of overwintering larvae (soil inspection and counting of hibernating larvae on a specific surface amount). Based on the empirical critical numbers, the answer is given whether suppressive measures are needed or not.

D. pini can cause serious needle defoliation, often followed by tree death, and its outbreaks can occur over large geographical areas [6]. It particularly happens at 30 to 60-year-old even-aged monocultures on warm and dry climatic conditions, where precipitation does not exceed 600 mm [7, 3].

First reports about mass outbreaks in Europe have been recorded at the beginning of the 18th century. Many areas dominated by Scots pine in Eastern and Central Europe have regular outbreaks of *D. pini* [1]. For example, between the year 1700 and 1929, 77 outbreaks were recorded in Germany [8], and several outbreaks have been documented since 1791 in Poland where more than 200 000 hectares were treated between 1946 and 1995 in order to control this insect [2]. In the period from 1812 to 1816 about 5 000 hectares were defoliated in Norway [9], with the outbreak recurring on 600 ha in the same area 85 years later [10, 11]. From 1938 to 40, an area of 700 ha, dominated by Scots pine, was defoliated in west central Sweden [12]. In 2012, on a small island called Furuskär in the Stockholm archipelago a severe *D. pini* outbreak was recorded where the largest parts of the island were heavily defoliated [2].

In Croatia, *D. pini* outbreaks have never been recorded so far, so unexpected total defoliation it caused on Aleppo pine (*Pinus halepensis* Mill.) and the fact it occurred at localities in the Mediterranean region where its presence has never been recorded make this events unusual.

MATERIALS AND METHODS

Outbreak in Skradin

In autumn 2014, several Aleppo pine stands in the vicinity of Skradin, near Šibenik, were seriously damaged by *D. pini* larvae feeding on needles. After inspection of an infested area, around 400 ha were found to be attacked, 20 ha of these being totally defoliated (Figure 1).

The first step was to estimate the population density, in order to decide whether suppressive measures are needed. Estimation of the population was conducted by soil surface inspection in order to find and count the hibernating larvae. The number of larvae per square meter of soil surface was assessed within the wooden frames 33.3×33.3 cm in size. The density of larvae was assessed by 108 samples (via wooden frames) with the minimum of 5 m distance between each, representing in total 12 m² of sampled surface. The critical population level number for this pest used in Central Europe is 10 larvae per m² (Dr. Katrin Möller, Brandenburg State Forestry Center of Excellence, pers. comm. in 2014).

Also, during the process of population assessment a large number of dead larvae was found. There were 306 collected larvae that were transferred to the Laboratory for Phytopathology Analysis of the Croatian Forest Research Institute for further laboratory inspection. To reveal the cause of death, each dead larva was placed on a moist filter paper disk in a sterile Petri dish to induce the potential sporulation of fungi. The larvae placed into a moist chamber were incubated at 24±1ºC, and a photoperiod L:D=16:8. After 3-4 days, fungi were isolated from each caterpillar on PDA medium, and inoculated Petri dishes were stored at controlled conditions described above. Within 2-3 weeks, all the cultures were microscopically examined. After morphological confirmation, the cultures were sent to Marta Wrzosek, Department of Molecular Phylogenetics

FIGURE 1. *Dendrolimus pini* outbreak in 2014 in Skradin, Šibenik.

and Evolution at Faculty of Biology, University of Warsaw, Poland, for molecular identification.

Outbreak in Dugi otok

After the inspection of the protected area of Telašćica Nature Park on Dugi otok, Croatia, in August 2017, around 150 ha of an Aleppo pine forest were found under the attack of *D. pini*, 30 ha out of which were totally defoliated. The same approach of population assessment was applied for the estimation of this population. Again, 12 m² of soil surface was sampled and the average number of larvae per square meter was assessed within the wooden frames.

In August 2017, 300+ larvae, and in September 2017, around 600 live and visually healthy 3rd and 4th larval instars were collected from Aleppo pine branches, trunks and the ground around trees in the infested area. Larvae were transferred to the Laboratory for Entomological Analysis in the Croatian Forest Research Institute, where they were incubated under laboratory conditions (L:D=16:8, 23±1°C). They were checked on a daily basis for the mortality and appearance of parasitoid larvae or fungi mycelium on cadavers, and were daily fed with fresh Aleppo pine needles.

Emerging parasitoids were counted, collected and sent to Hans-Peter Tschorsnig, Staatliches Museum für Naturkunde, Stuttgart, Germany, for the identification. Sporulating white mycelium on dead individuals was microscopically examined for the morphological taxonomical identification.

RESULTS

During the *D. pini* population assessment in Skradin, 306 larvae were found on 12 m², which means that the average number of larvae was 25.5 larvae per m². Since far more than 10 larvae per m² were found, the conclusion was that the outbreak level has been exceeded in this area, which would trigger the necessity for active suppression measures, if entomopathogenic fungus *B. bassiana* had not occurred in a large number of cases.

From 306 specimens collected and taken for further examination, morphological and molecular analyses confirmed the presence of entomopathogenic fungus *B. bassiana* on 301 dead caterpillars, i.e. 98.4% of the population. It was also found that one part of the population overwintered in the crown and was not attacked by *B. bassiana*, but during the control of the overwintering larvae in spring 2015, a new population collapse was recorded on the larvae infected with *B. bassiana* (Figure 2), while the Aleppo pine trees after full defoliation completely recovered (Figure 3).

The results from Dugi otok population estimation revealed that the average number of larvae per m² was 21, which again exceeded the known critical numbers for *D. pini* population, clearly visible in the field by total defoliation of Aleppo pines (Figure 4). In this case, larval infection with *B. bassiana* was low, and was recorded on around 1% of sampled larvae.

Parasitism rate on larvae collected in August was 2.8%, and it reached 5.6% on those collected in September. On average, 3 days after the caterpillar's death, parasitoid dipteran larvae were leaving its host and pupating. It took further 10 days on average for the adult flies to emerge. All

FIGURE 2. *Dendrolimus pini* larva covered with white mycelium of *Beauveria bassiana* fungus found on the soil surface.

FIGURE 3. Recovered Aleppo pine stand after *Dendrolimus pini* defoliation and *Beauveria bassiana* infestation on overwintering larvae in 2015 in Skradin, Šibenik.

FIGURE 4. *Dendrolimus pini* outbreak in 2017 around Salt Lake, Telašćica Nature Park, Dugi otok.

of the parasitoid individuals were identified as polyphagous tachinid fly *Drino inconspicua* Meigen (Diptera: Tachinidae).

The occurrence of superparasitism was recorded in 9 cases from *D. pini* larvae collected in September, where more than 2 parasitoid dipteran larvae emerged from one infested *D. pini* individual. From 5 *D. pini* individuals 2 of parasitoid dipteran larvae emerged, from 3 of them 3 parasitoid larvae emerged, and in one case there were 4 parasitoid larvae emerged from one *D. pini* individual.

DISCUSSION AND CONCLUSIONS

This research confirmed several unusual phenomena. Apart from the fact that Mediterranean Croatia does not represent the optimal area for the appearance of *D. pini*, Aleppo pine is not its primary host [3] and so far we had not witnessed an outbreak case. Another unusual phenomenon is the exceptionally high mortality of the overwintering *D. pini* larvae after Aleppo pine defoliation in the vicinity of Skradin.

In most cases it is hard to explain what triggers a certain outbreak, and why it happens in a specific time, place and level of severity. According to Lesniak [13], for the rapid spread of *D. pini* the most significant are the meteorological conditions, in terms of higher mean annual temperatures (particularly those during autumn and winter), lower wind velocities, less precipitation, fewer days with snow cover, greater duration of summer and vegetation season, and higher frequency of dry months. The results of his research also suggested that abiotic factors do not affect the pine moth directly, but rather the pine moth population dynamics indirectly, through the host plant.

In addition, high population density of *D. pini* can also be promoted by higher sunshine duration. Increased sunshine hours have a positive effect on egg development, as well as on larvae vitality due to the increase of feeding intensity. Higher survival rate as a result of earlier hibernation ending under favorable climatic conditions means avoiding certain risks related to overwintering in the soil (e.g. infestation with soil-borne fungi or bacteria) and can also be attributed to higher daily sun duration [14].

Skradin and Dugi otok are located in the middle of the Mediterranean region of Croatia (Figure 5), where hot-summer Mediterranean climate dominates, and is characterized by rainy winters and dry summers.

According to Croatian Meteorological and Hydrological Service, the year 2014 in Skradin was extremely warm and wet, with an extremely warm winter and higher precipitation than usual in autumn and winter. Dugi otok climate in 2017

FIGURE 5. Map of *Dendrolimus pini* outbreak locations.

was characterized by extremely warm weather with normal precipitation, but with extremely dry summer. In both cases we can conclude that extremely warm weather probably had a great impact on mass appearance of *D. pini*. Furthermore, the fact that both examined sites are dominated by monotypic Aleppo pine stands and that trees grown in such vegetation composition often do not possess the evolutionary developed ecological defense mechanisms to tolerate outbreaks of defoliators [15] should also be taken into account.

The role that natural antagonists played during these two mass outbreaks demonstrated their importance and posed some new questions. These relate to the possible mechanisms and triggers for the increase and breakdown of insect populations, such as weather conditions, natural enemies and diseases, lack of variability in forest composition or climate change.

In the case of Skradin, unusually high infestation of hibernating larvae with entomopathogenic fungus *B. bassiana* on the soil surface (98.4%) resulted in steep breakdown of *D. pini* population. The only comparably known collapse of some insect outbreak due to entomopathogenic fungi in Croatia is known in the case of gypsy moth (*Lymantria dispar* L.), where highly infectious fungal pathogen *Entomophaga maimaiga* Humber, Shimazu & R.S. Soper (*Entomophthorales*, *Entomophthoraceae*) caused death of thousands of *L. dispar* larvae [16]. In the case of Dugi otok *B. bassiana* appeared on dead *D. pini* larvae, but only in 1% of sampled larvae. The trigger for unusually high infestation of *B. bassiana* in Skradin probably lies in very wet conditions, which was not the case in Dugi otok, and therefore higher *B. bassiana* infection rates were not recorded. Larger numbers of larvae were infected with parasitoid *D. inconspicua*, with 5.6% of population being parasitized during the second larval sampling in September 2017. *D. inconspicua* is a polyphagous tachinid fly common in Europe and northern Africa. As a generalist parasitoid, it parasitizes various lepidopteran and several diprionid species feeding on a wide range of coniferous and deciduous trees. A few minutes after the deposition of eggs on the surface of host larvae, the tachinid larvae hatch and bore through the host integument. After 9-14 days, 3rd instars of *D. inconspicua* hatch from the host and pupate in the ground, and after 2-3 weeks, adult flies emerge [17-19]. In Croatia, this species was formerly found in Krka National Park, Skradin [20].

This research describes the first outbreaks and population collapse reported on *D. pini* so far in Croatia and might act as good reference point for future studies. At the same time it is restricted to a more accurate prediction of possible similar event that could occur in future. Wider area of the mass appearance of *D. pini* that was in focus through this research should be regularly monitored and its evaluation should not be left out.

Acknowledgments

We would like to thank Nikola Zorić, Ivana Mihaljević, Anica Dietz, Ivan Lukić and Blaženka Ercegovac for their help during field and laboratory work, and Valter Floigl for providing us with information and assisting in the field when needed. We would also like to thank prof. dr. sc. Cezary Tkaczuk for morphological confirmation of *Beauveria basssiana* and for connecting us with dr. Marta Wrzosek from Department of Molecular Phylogenetics and Evolution at Faculty of Biology (University of Warsaw, Poland), together with her team who did molecular identification, and we would like to thank them for that. Also, we would like to acknowledge dr. Hans-Peter Tschorsnig from Staatliches Museum für Naturkunde (Stuttgart, Germany) for the identification of tachinid *Drino inconspicua.* This research has been fully supported by the Diagnostic and Prognostic Service (IPP) of Croatian Forest Research Institute (Jastrebarsko).

REFERENCES

1. BJÖRKMAN C, LINDELÖW A, EKLUND K, KYRK S, KLAPWIJK MJ, FEDDERWITZ F, NORDLANDER G 2013 A rare event – an isolated outbreak of the pine-tree lappet moth (*Dendrolimus pini*) in the Stockholm archipelago. *Entomol Tidskr* 134 (1-2): 1-9
2. SIERPINSKA A 1998 Towards an integrated management of *Dendrolimus pini* L. *In*: McManus ML, Liebhold AM (*eds*) Proceedings: Population Dynamics, Impacts, and Integrated Management of Forest Defoliating Insects. USDA Forest Service General Technical Report NE-247, pp 129-142
3. RAY D, PEACE A, MOORE R, PETR M, GRIEVE Y, CONVERY C, ZIESCHE T 2016 Improved prediction of the climate-driven outbreaks of *Dendrolimus pini* in *Pinus sylvestris* forests. *Forestry* 89 (2): 230-244. DOI: https://doi.org/10.1093/forestry/cpw007
4. LE MELLEC A, MICHALZIK B 2008 Impact of a pine lappet (*Dendrolimus pini*) mass outbreak on C and N fluxes to the forest floor and soil microbial properties in a Scots pine forest in Germany. *Can J For Res* 38 (7): 1829-1841. DOI: https://doi.org/10.1139/X08-045
5. HYDÉN N 2006 *Dendrolimus pini* tallspinnare. *In*: Nationalnyckeln till Sveriges flora och fauna. Fjärilar: Ädelspinnare-tofsspinnare. Lepidoptera: Lasiocampidae-Lymantriidae. ArtDatabanken, SLU, Uppsala, Sweden, pp 135-137
6. MOORE R, COTTRELL J, A'HARA S, RAY D 2017 Pine-tree lappet moth (*Dendrolimus pini*) in Scotland: Discovery, timber movement controls and assessment of risk. *Scott For* 71 (2): 34-43
7. KOLK A, STARZYK JR 1996 The Atlas of Forest Insect Pests. The Polish Forest Research Institute. Multico Warszawa, Poland, 705 p
8. RITTER F 1929 Die in Deutschlands Waldungen aufgetretenen schädlichen Insekten. Ein Literaturnachweis für die Jahre 1449-1926. *Z Angew Entomol* 14: 561-563
9. SCHÖYEN WM 1880 Om furuspinderens (*Eutrichia pini*) optraeden i Norge i aarene 1812-1816. *Entomol Tidskr* 1: 39-42
10. MYHRWOLDT AK 1902 Om Furuspinderen (*Bombyx pini*, *Gastropacha pini*). *Tidskr Skogbrug* 10: 320-333

11. MEWES J 1903 Tallspinnaren. En hotande fara förvåra skogar. *Ent Tidskr* 24: 61-64
12. FORSSLUND KH 1940. Ett massuppträdande av tallspinnaren i Värmland. Skogen, 15 p
13. LESNIAK A 1976 Climatic and meteorological conditions of the pine moth (*Dendrolimus pini* L.) outbreaks. *Ekol Pol* 24 (4): 515-547
14. HENTSCHEL R, MÖLLER K, WENNING A, DEGENHARDT A, SCHRÖDER J 2018 Importance of Ecological Variables in Explaining Population Dynamics of Three Important Pine Pest Insects. *Front Plant Sci* 9: 1667. DOI: https://doi.org/doi.org/10.3389%2Ffpls.2018.01667
15. PRICE PW, BOUTON CE, GROSS P, MCPHERON BA, THOMPSON JN, WEIS AE 1980 Interactions among three trophic levels: influence of plants on interactions between insect herbivores and natural enemies. *Annu Rev Ecol Syst* 11: 41-65. DOI: https://doi.org/10.1146/annurev.es.11.110180.000353
16. HRAŠOVEC B, PERNEK M, LUKIĆ I, MILOTIĆ M, DIMINIĆ D, FRANJEVIĆ M, HAJEK A, LINDE A, PILARSKA D 2013 First record of the pathogenic fungus *Entomophaga maimaiga* Humber, Shimazu, and Soper (Entomophthorales: Entomophthoraceae) within an outbreak populations of *Lymantria dispar* (Lepidoptera: Erebidae) in Croatia. *Period Biol* 115 (3): 379–384
17. WEBBER RT 1932 *Sturmia inconspicua* Meigen, a tachinid parasite of the gypsy moth. *J Agric Res* 45: 193-208
18. HERTING B 1960 Biologie der westpalaarktischen Raupenfliegen (Dipt., Tachinidae). *Monogr Angew Entomol* 16: 1-188
19. ALTENKIRCH W, HUANG P 1986 Zur Prüfung der unerwünschten Nebenwirkungen von Pflanzenbehandlungsmitteln auf Raupenfliegen (Diptera, Tachinidae). *Nachr bl Dtsch Pflanzenschutzd* 38 (7): 97-99
20. TSCHORSNIG HP 2017 Preliminary host catalogue of Palaearctic Tachinidae (Diptera). http://www.nadsdiptera.org/Tach/WorldTachs/CatPalHosts/Cat_Pal_tach_hosts_Ver1.pdf

SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

ORIGINAL SCIENTIFIC PAPER

DOI: https://doi.org/10.15177/seefor.18-14

Winching Distance in Function of the Optimization of Skid Network

Darko Ljubojević[1], Milorad Danilović[2], Dane Marčeta[3*], Vladimir Petković[3]

(1) Public Forest Company "Šume Republike Srpske" a.d. Sokolac, FM "Prijedor", Vožda Karađorđa 4/2, BA-79101 Prijedor, Bosnia and Herzegovina; **(2)** University of Belgrade, Faculty of Forestry, Kneza Viseslava 1, RS-11030 Belgrade, Serbia; **(3)** University of Banja Luka, Faculty of Forestry, Stepe Stepanovica 75a, BA-78000 Banja Luka, Bosnia and Herzegovina

* **Correspondence:** e-mail: dane.marceta@sf.unibl.org

Citation: LJUBOJEVIĆ D, DANILOVIĆ M, MARČETA D, PETKOVIĆ V 2018 Winching Distance in Function of the Optimization of Skid Network. *South-east Eur for* 9 (2): 97-106. DOI: https://doi.org/10.15177/seefor.18-14

Received: 22 Aug 2018; **Revised:** 9 Nov 2018; **Accepted:** 12 Nov 2018; **Published online:** 10 Dec 2018

ABSTRACT

Background and Purpose: Optimisation of skid road network is very important in forest utilisation because transport is considered to be the most expensive part of timber production. Designing forest traffic infrastructure means positioning its location in the forest area using traditional or modern methods. Many factors influence the skidding costs, and winching distance is one of them. The use of modern techniques gives an opportunity to forest practitioners that simulate different network variants and choose the most appropriate ones.

Materials and Methods: The research object is Compartment 27, which belongs to Forest Administration Unit "Prijedor", with the area of 46.72 ha. Investigation is divided into the phase of field work and the phase of designing secondary forest road network variants in the office. Field work includes the traditional and Global Positioning System (GPS) marking of trees for cutting and the creating of Geographic Information System (GIS) database. In relation to spatial distribution of trees for cutting, skid roads and skid trail networks are laid by using the GPS. The new scondary road network is laid in the field and compared with three simulated variants of secondary road network that are laid by ArcGIS 10.3. Secondary road network is planned by using Network Analyst tools and Shortest path method that is based on Dijkstra's algorithm. These variants are simulated based on different average winching distances of 10, 20 and 30 m.

Results: The area of the compartment is divided into two transportation zones. Total length of the secondary road network designed in the traditional way is 4816 m, thus achieving the secondary openness of 103 $m \cdot ha^{-1}$. In simulated Variant I, with winch pulling distances of 20 m, the total length of secondary roads is 5590 m with costs of 14352.62 €, in Variant II with winching distance of up to 40 m length of secondary roads it is 3228 m with costs of 7426.78 €, and in Variant III with winch rope length of up to 60 m, the length of roads is 2219 m, with costs of 4400.89 €. The achieved mean skidding distances are relatively similar in all variants. When taking into account the average length of the winch rope, considering all three new-design variants, it can be said that there is almost no difference in productivity and skidding costs.

Conclusions: Mean winching distance has influence on skidding costs, but only in variants where mean skidding distance is decreasing. Smaller winching distance is justified only from the aspect of work humanization. Small differences in skidding costs between variants have no practical significance except for large quantities of wood assortments.

Keywords: skidding, simulation, rope length, Dijkstra algorithm

INTRODUCTION

In the mathematical sense, optimization means defining the minimal or maximal value of the real function. In sustainable forest management, from the point of timber usage, optimization means utilization of forests with minimal transport costs [1-3], while considering the rest of the forest users. Transport of timber is very important and the most expensive part of the timber production. According to Sokolović and Bajrić [4], transport costs amount to around 80% of total costs of the timber production and consist of the skidding costs and the costs of construction and maintenance of forest roads. The skidding costs are 20 to 30 times larger than the costs of long-disatnce transport [5]. The skidding costs consist of the costs of construction and maintenance of secondary forest roads and the unit costs of skidding. Secondary forest roads consists of skid roads and skid trails. Skid roads are constructed by excavation of soil with dozers or excavators. For the protection of skid road surface from erosion water bars are used, which are built diagonally over the skid road surface. Roadbed width of skid roads is 3.5 m. Longitudinal grade of skid road should be 16% in order to protect the road from erosion of its surface, while skid road gradient should not exceed 30%, especially when skidding uphill [6, 7]. Skid trails are not specially constructed, but only after they are designed all trees from the route of the skid trail are cut [5, 8, 9]. They make a forest temporarily accessible and they are used for the extraction of timber from the harvesting area to the landing on the forest road. Also, they do not exempt from the productive forest area. The most common way of timber extraction in Europe, and particularly in Bosnia and Herzegovina (BIH), is ground skidding with wheel skidders [10, 11].

The optimization of a secondary forest road network is very hard to present as mathematical or forest management problem. Dependence of the density of skid roads or other types of secondary forest roads on forest management can be observed as the targeted optimum. The density of secondary roads ranges from 100 to 200 $m \cdot ha^{-1}$ in BIH [5], depending on the forest management system which is applied for a certain category of forests. According to Rebula [12], secondary forest openness or needed density of skid roads and skid trails in young stands is around 250-300 $m \cdot ha^{-1}$, but in older stands, where trees are much more distant from one another, density is only 100-180 $m \cdot ha^{-1}$. In Slovenia the maximum allowable density of secondary forest roads depends of terrain configuration and amounts to 180 $m \cdot ha^{-1}$ for karst terrain, 150 $m \cdot ha^{-1}$ for hilly terrain, and 130 m $m \cdot ha^{-1}$ for mountainous terrain [13]. Pičman [14] stated that for hilly-mountainous areas 200 $m \cdot ha^{-1}$ represent good openness. In selective stands of Gorski Kotar the density of skid network is 150 $m \cdot ha^{-1}$ [15].

That task depends on the optimal density and spatial layout of forest roads, and the intensity of harvesting. Optimal density and spatial layout of forest roads influence relative forest accessibility, whose result is the defining of inaccessible forest areas. Relative forest accessibility depends on geometrical skidding distance. Also, the spatial layout of forest roads and terrain conditions defines the position of landings for timber. The intensity of harvesting depends on the number of marked trees and their quality. The extraction of timber is usually planned based on the assumption that timber is evenly distributed over the forest area, but as modern technologies are more widespread, tree marking by Global Positioning System (GPS) enables the planning of timber extraction based on the accurate position of marked trees [16].

Optimization of a secondary forest road network includes the designing of new skid roads and skid trails in parts of the compartment which are not accessible enough from the point of the extraction of marked trees. The design of secondary road network can be approached based on a traditional terrain job and vector or raster method [17]. The second and third approach of designing secondary roads are advanced methods based on using Geographic Information System (GIS) analysis.

Designing forest traffic infrastructure includes positioning of its location in the forest area by traditional or modern methods [18]. Traditional approach of designing a network of forest roads includes two different types of road network based on terrain conditions. It is recommended to use perpendicular secondary network on flat terrain and for the main parameter to be spacing. In steep terrain, the strategy of designing primary and secondary forest roads is based on defining the location of points which forest road or its segment has to connect. At this stage, forest road designing does not consider variability of forest stand conditions and harvesting technologies [19]. The modern approach of designing primary and secondary forest road networks consists of the vector, raster or graphic way of determination of forest road location [17, 20].

Vector approach is based on a computer algorithm which generates road networks from different factors that influence road designing. This method includes a sensitive analysis of affecting factors such as: total length of roads, the percentage of landings, slope, and horizontal and vertical alignment. This method improves the manual method of forest road designing, and it is suitable for strategic planning of forest road location [16].

Stückelberger *et al.* [21] developed an improved model of optimization of primary and secondary forest road network location based on connectivity of terminal points with shortest paths which were based on minimal transportation costs. Determination of shortest paths is carried out by using Dijkstra algorithm. These terminal points and links between them make a wire diagram. This model can determine suitable and the most cost-effective locations for forest roads in steep terrain.

Optimization of forest road location is carried out by heuristic algorithm, which should determine the most cost-effective location of forest roads for timber harvesting and the costs of production, skidding, construction and maintenance of forest roads. This method developed a tree-shape network of forest traffic infrastructure which evenly covers the forest area. It defines the variable costs as the unit skidding costs, while the fixed costs represent the costs of forest road construction and maintenance. Apart from information on the volume of timber in harvesting units, skidding and road network, and the landings by forest road or the saw mills, planning of forest road networks depends on terrain conditions such as slope and hydrology [23].

Najafi and Richards [24] have planned primary and secondary forest road network on the basis of minimal transportation costs, which provides cutting and transport activities by Mixed Integer Programming (MIP) method. Transportation costs were defined by the costs of construction and maintenance which were calculated based on segment length, terrain conditions, road standard, traffic volume and unit skidding costs. This research was based on the determination of cutting sites as points which will be connected with the least cost paths. Planning of primary forest road network was carried out by NETWORK 2000 software based on routes with minimal timber harvesting and extraction costs, for timber transport from harvest units to the sawmills or the market on the basis of the given link and sale data. These routes will be used for timber harvesting. Link data consist of information on primary forest road network, and fixed and variable costs. Sale data include information on timber harvesting units, timber destinations, volume and production year [25]. Suitability of forest area for construction of forest roads was determined on the basis of three influential factors: slope, soil and hydrology. Maps of these factors were divided into three categories which have high, moderate and low influence on construction costs of forest roads. The influence of these factors on the construction costs of forest roads was obtained on the basis of the experience of forest experts. The weight of slope is 0.63, for soil it is 0.29 and for hydrology 0.08. The designing of forest roads was conducted by PEGGER extension of ArcView, and it produced 9 alternatives [26].

Heinimann [19] has applied an optimal road strategy with a comprehensive spatial and statistical analysis of terrain and stand conditions of forest area and harvesting technology. Optimal road strategy depends on the definition of points which the forest road should connect. These points are cutting sites (compartments) from which timber should be transported with a skidder or cable yarder to landings on the forest road. They define timber volume, i.e. stand conditions of a forest area. Then, its strategy depends on the analysis of terrain conditions based on earlier field research, or the conditions derived from the Digital Terrain Model (DTM) or airborne Light Detection And Ranging (LiDAR) system.

Parsakhoo and Lotafalian [17] optimized skid road or trail network on the basis of the position of future landings and forest roads within the forest area by using weighted-graph optimization algorithm. This algorithm is based on minimization of skidding costs and construction costs of the forest road. The skidding costs showed optimal position of landings and optimal spatial layout of future forest roads. The construction costs of forest roads depend on their length and longitudinal grade, as well as terrain slope. The future landings are shown as points of cell size of DTM, and they are placed on the terrain with a slope of up to 10%. The future forest roads are presented as the links between points with maximum length of 75 m. The link connects the point with eight adjacent points, i.e. future landings.

The networks of the secondary forest road differ according to the winching distance which is achievable in certain terrain characteristics from the point of timber production costs. Winching is the phase of work in the roundwood extraction, or more precisely, in the skidding of roundwood. The most common way of roundwood extraction in BIH is skidding with wheel skidders [11]. In Croatia, wood bunching and extraction is performed by skidders equiped with one-drum or double-drum winches [27]. Bembenek *et al.* [28] showed that, during extration with tractors, the mean overal operational productivity was 30.05 $m^3 \cdot h^{-1}$, with an average od 1.8 m^3 of wood obtained from trees. Sabo and Poršinsky [29] established 11.6 $m^3 \cdot h^{-1}$ achived by Timberjack 240C in a mountainous fir stand where the volume per mean marked tree was 3.9 m^3, while by using a LKT 81T cable skidder in mountain conditions in an 82 year old fir stand productivity can reach 7.15 $m^3 \cdot h^{-1}$ [30].

The cost of winching and the total cost of roundwood production is lower with the reduction of winching distance, while winching productivity is higher. The reduction of winching distance requires an increase of the length and density of secondary forest road network.

The aim of this paper is to define the most appropriate network of secondary forest roads. The results of this investigation should show that it is possible to completely replace the methods used so far with those based on heuristic algorithms integrated into ArcGIS platform, as well as that the analysis of secondary forest road network, especially from the point of different winch rope length (winching distance), could lead to reduced costs. These tasks are the result of the assumption that with changes in winching distances in the unique distribution of trees marked for cutting, skidding costs will differ. Within this assumption, changing winch rope length will lead to changes in skid network density. Smaller winch rope length consequently causes larger density of secondary roads in the compartment and vice versa.

MATERIALS AND METHODS

Study Area

The research object is Compartment 27, which belongs to Forest Administration Unit "Prijedor". It is located between the latitude of 16°52'4.612" and 16°52'42.153" and the longitude of 45°3'42.255" and 45°4'16.017" (Figure 1). The area belongs to moderate continental climate. The area of Compartment 27 is 46.72 ha and it is covered by forests of beech and fir. Management system is group selection. Total volume per ha amounts to 365.94 $m^3 \cdot h^{-1}$, while volume increment is 8.34 $m^3 \cdot h^{-1}$. The cutting of marked trees is carried out by the assortment harvesting method.

Measurements

Investigation is divided into two phases, field work and the designing of secondary road network variants in the office. Field work includes traditional and GPS marking of trees for cutting (Figure 2) and creating a GIS database that contains tree species, Diameter at Breast Height (DBH) of trees, technical class of marked trees, volume of marked trees, volume of roundwood and the group to which a marked tree belongs. Volume of roundwood of marked trees is obtained from assortment tables based on total wood volume, tree species, technical class and DBH class [31]. Technical classes are determined by guidelines defined in Drinic *et al.* [31].

In relation to the spatial distribution of trees for cutting, skid road and skid trail network is laid using the GPS device. Routes are imported in the ArcGIS database, where they are assigned with numbers from 1 to n and their length. The aim of this investigation is related to the cost of secondary road network construction and the skidding cost. For the determination of mean winching and skidding distance the volume of roundwood is used.

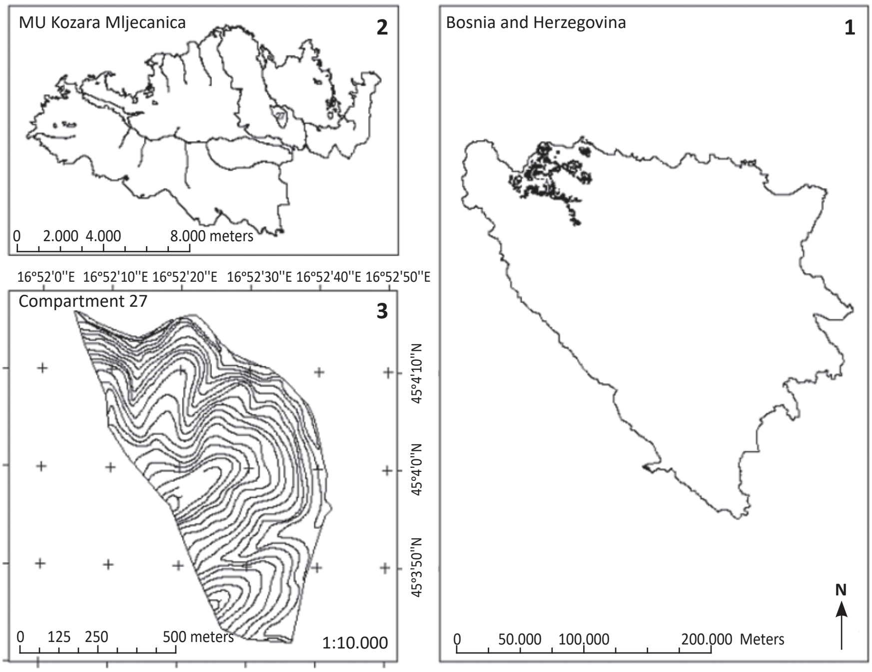

FIGURE 1. Area of research.

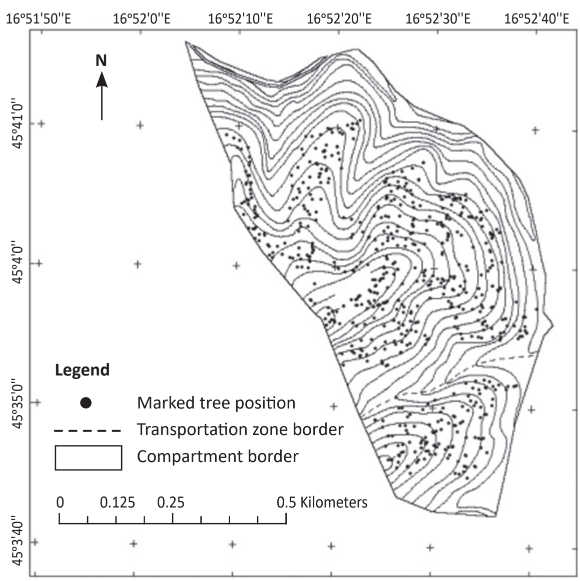

FIGURE 2. Position of marked trees in the investigated compartment

The unit cost of the construction of skid roads is determined on the basis of bulldozer productivity of 0.0475 $h \cdot m^{-3}$ and its labor cost of 35.90 €$\cdot m^{-3}$, thus amounting to 1.71 €$\cdot m^{-3}$ of soil [9]. Total cost of the construction of skid roads is the product of unit cost of the construction and the volume of earthwork. The volume of earthwork is determined on the basis of terrain slope at the station points of the skid road, which are laid at each 50 m of the road, and length of the skid road (Figure 3).

Calculation of Average Skidding Distance and the Costs of Wood Skidding

Winching distance is obtained by spatial analysis tools. Path distance tool is used to make a 3D raster of distance in the whole compartment, from each part of the secondary forest road network, and each marked tree is assigned a distance by the extract tool. On the basis of the distance of marked trees their affiliation is determined by a certain part of secondary forest road network, while the winching distance is calculated by Equation 1:

$$Sd_w = \frac{\sum L_{iw} \cdot V_i}{\sum V_i} \ (m) \quad (1)$$

where: Sd_w - average winching distance, L_{iw} - length of each winching, V_i - volume of winched roundwood.

Average skidding distance is defined as weighted average distance of all marked trees from skid roads or trails. For this task, Locate Feature Along Routes tool is used. Secondary forest road network is divided into gravitation zones. Gravitation zones include the parts of network leading to one landing, and skidding distance of the marked trees is determined between them and the landing (Equation 2):

$$Sd = \frac{\sum Li \cdot V_i}{\sum V_i} \ (m) \quad (2)$$

where: Sd - average skidding distance, L_i - length of skid road/trail, V_i - volume of skidded roundwood.

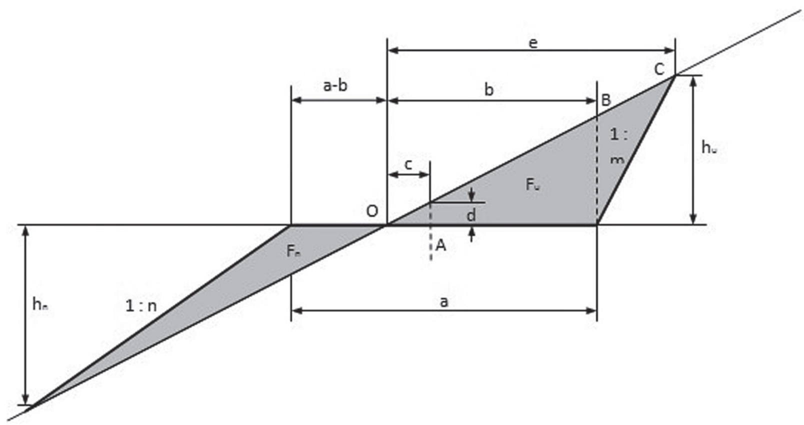

FIGURE 3. Cross section of the skid road.

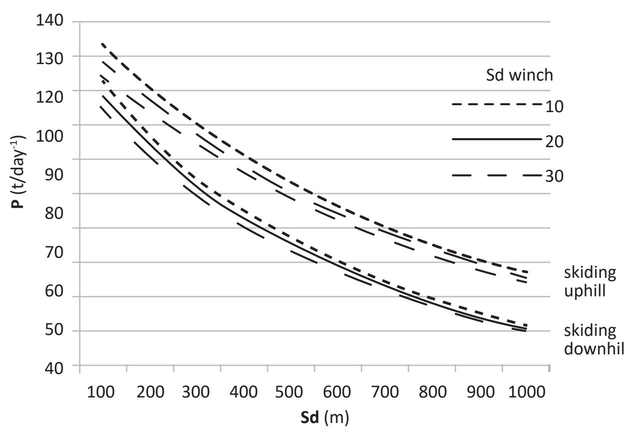

FIGURE 4. Diagram of productivity for different winching and skidding distances.

Determining of average skidding distances in this way is adapted to the application of the technical norms for wood skidding which are part of the Tables of Technical Standards in forest exploitation [32] (Figure 4).

According to these tables, the skidding costs are determined by the average skidding distance to the individual landings or for the entire compartment, whereby differences in productivity are the result of mean skidding distance, mean winching distance and skidding direction. In order to calculate work productivity, the tables for medium heavy articulated skidders were used in the dry to wet conditions of the soil and for skidding downhill or uphill. The average diameter of the marked tree is 51 cm and consequently the entry into the table used is the average piece volume of 1.00 m^3. As the performance rate was given in $t \cdot day^{-1}$, the transformation in $m^3 \cdot day^{-1}$ was performed using the ratio of 1:1.25 for fresh softwood and 1:1 for fresh beech.

Designing of Secondary Forest Road Network Variants

In this investigation the new secondary road network is laid in the field and it is compared with three simulated variants of secondary network that are laid by ArcGIS 10.3. These variants are based on different average winching distances of 10, 20 and 30 m.

Secondary forest road network is planned by using Network Analyst tools and Shortest Path method of the ArcGIS 10.3 software. The last method is based on Dijkstra's algorithm. Dijkstra's algorithm provides the shortest paths from a node to each of the other nodes of the graph [33]. In general, the shortest path is the problem of finding a series of road links connecting two nodes in a way that the sum of the weights on those edges is minimized [34].

The Network Analyst method intends to set up a network of points at a distance of 20 m in the digital map of the research area. These points are linked by lines that are potential parts of secondary forest road network. Every point is connected with neighboring points by 32 lines in the combination: 1+1, 1+2, 2+1, 1+3, 3+1, 2+3 and 3+2 (Figure 5). The aim of this method is to cover as large a research area as possible by potential routes of the secondary forest road network. This spatial layout of points achieved minimal length of 20 m and maximal length of 72.11 m of potential routes. The grade of every link between points is determined based on distance and height difference between them (Equation 3):

$$i = \frac{\Delta h}{d} \cdot 100\,(\%) \quad (3)$$

Height distance is the difference between altitudes of points, and their altitudes are obtained from DEM.

Djikstra's algorithm is used for the links whose slope is up to 30%, and this slope is maximal allowed for route of secondary forest traffic network. Regarding terrain slope, terrain with a slope of over 65% should be avoided during the marking of trees and setting up of skid roads or skid trails in the field. For laying different routes of secondary forest road network three points are used. The primary aim of laying secondary forest road network is to make all marked trees available for skidding and winching for the average or maximal length of rope. This is achieved by creating of 3D border zone around routes of the secondary forest road network. The additional routes of its transport network are laid in the case when a marked tree is out of the border zone.

RESULTS AND DISSCUSION

Marking Trees for Cutting and Real Skid Network

In the investigated compartment 642 trees of beech, fir and other hardwoods are marked for cutting. Total cutting volume is 2,397.01 m^3 with roundwood volume of 1,233.51 m^3. Cutting density in the whole compartment is 51.31 $m^3 \cdot ha^{-1}$. However, due to extremely steep slopes in some compartment areas, trees are marked only on 20.77 ha, or 44% of the total compartment area. This makes real cutting density of 115.41 $m^3 \cdot ha^{-1}$ or 59.39 m^3 of roundwood per unit area. The whole area of the compartment is spatially divided into two transportation zones from which roundwood is skidded in different directions on two landings, located on the forest roads. Downhill 956.24 m^3 are skidded, and uphill 277.27 m^3 from an area of 16.82 ha and 3.95 ha respectively.

Total length of the secondary road network (Figure 6a) designed in the compartment is 4,816 m, thus achieving the secondary openness of 103 $m \cdot ha^{-1}$. For their construction, according to an operational study, including the construction of new landings and clearing the existing ones, 392.64 € is needed. Small costs like this are the result of an already developed network of secondary roads from previous cutting cycles in the compartment. During the last cutting, only 170

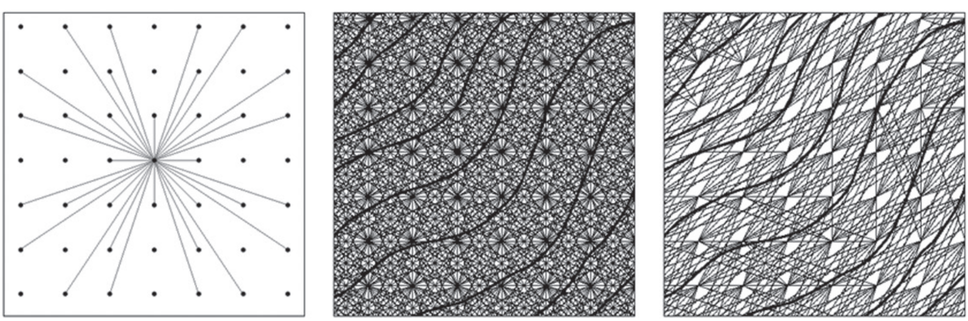

FIGURE 5. Connection pattern (left), whole network (mid), network of segments less than 30% (right).

m of new skid roads is added to the existing network. With the assumption that in the compartment an already built secondary road network does not exist, the length of skid roads for which it is necessary to calculate construction costs is 1,712 m, while 1,397.66 € is needed for the construction.

Designing Variants of the Skid Network

In the compartment, 1,173 points are interconnected with 20,777 segments of all slopes. Maximum slope for skid roads is defined by 30%, and the total number of segments used for the Dijkstra algorithm is 12,151.

Variant I

This variant (Figure 6b) of the secondary forest road network in the compartment is adjusted to the maximum winch pulling distances of 20 m, and as a result of that in this variant the total length of the secondary road network is projected to be 8,441 m, thus achieving an openness of 181 m·ha^{-1}. This network variant consists of 62 secondary roads. Fulfilling the conditions of the maximum length of the rope and the design of the secondary road on terrain slopes under 65%, and in order to ensure skidding of the total amount of wood, another landing was introduced in the transport zone from which wood is skidded downhill. In the category of skid roads, the total projected length is 5,590 m and the construction costs for this network are 14,352.62 €.

Variant II

The maximum planned winch rope length in this variant is 40 m, while the planned network consisted of 32 skid routes with 6,184 m in length, which gives an openness of 132 m·ha^{-1} (Figure 6c). In this variant of the network, the total amount of wood is skidded to the three landings. Total length of planned skid roads is 3,288 m and construction costs are 7,426.68 €.

Variant III

This variant of the secondary network is most similar to the actual network since the maximum allowable winch rope length is 60 m (Figure 6d). This variant guarantees the maximum distance between individual secondary roads and their minimum length at the same time. The planned network consists of only 18 secondary forest roads and has a length of 4,842 m and openness of 104 m·ha^{-1}. The construction cost of this variant amounts to 4,440.89 € for 2,219 m of skid roads.

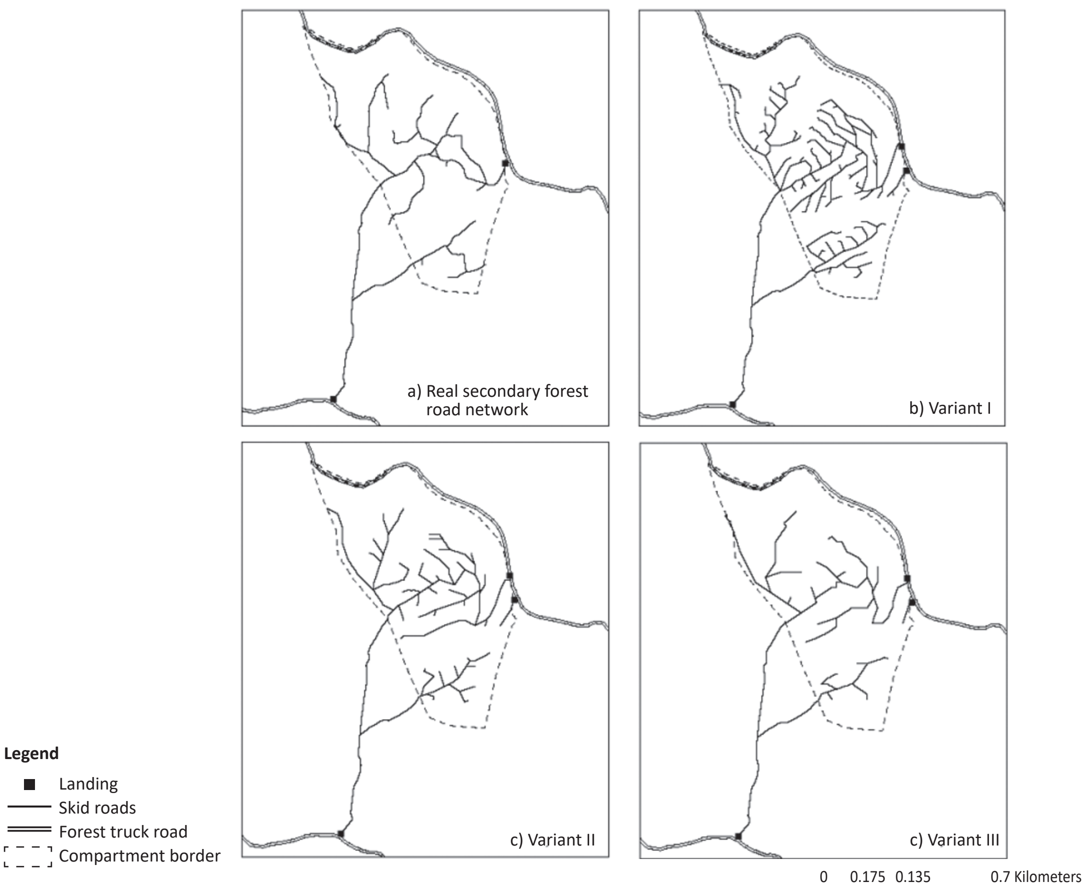

FIGURE 6. Secondary forest network designed in the field (a) and simulated in the office by ArcGIS (b, c, d).

TABLE 1. Mean skidding distance, productivity and skidding costs for the existing network and designed variants.

		Actual network	Variant I	Variant II	Variant III
Average skidding distance (m)	Downhill	690	760	740	710
	Uphill	990	920	910	920
Productivity ($m^3 \cdot day^{-1}$)	Downhill	83.89	83.57	82.92	82.90
	Uphill	55.71	59.99	59.50	58.26
Skidding costs ($€ \cdot m^{-3}$)	Downhill	6.85	6.88	6.93	6.94
	Uphill	10.32	9.58	9.66	9.87

Compared to the mean skidding distance for skidding with the wheeled skidder according to Pičman *et al.* [35], which amounts to 300 m uphill and 800 m (1000 m) downhill respectively, in this investigation in case of downhill skidding for all variants the mean skidding distances are twice longer. In general, extraction process in the compartment is relativelly unfavorable. Apart from long skidding in the downhill direction, when skidding uphill the mean skidding distance is almost 1000 m long, which produces high skidding costs. Petković *et al.* [36] stated that in such cases when different directions of skidding exist, minimum costs can be achieved by optimum skidding pattern.

When talking about absolute openess, achieved values in all variants including the existing network of secondary forest roads are in the interval defined by Jeličić [5]. According to Danilović and Ljubojević [37], average density of the secondary forest road network for nine analysed compartments in Management Unit "Prosara" amounts to 105 $m \cdot ha^{-1}$. Almost the same values are achieved in the third variant of the designed and the actual network of secondary roads. On the other hand, within defined sample Petković *et al.* [36] found that the density of secondary roads in MU "Prosara" is 119.7 $m \cdot ha^{-1}$and in MU "Kozara-Mlječanica" 96.5 $m \cdot ha^{-1}$. Differences between individual compartments are expected because density of skid roads and skid trails is not only a function of winch rope length.

In comparison with the actual position of secondary network in the compartment, where the length of the skid roads is only 35% of the total network length, in all simulated variants the skid road share is more than 60%, and in Variant I even 77%. The rest are skid trails. This is the main reason why the cost of building the actual network of skidding communications in the compartment is almost 3 times smaller than the cost of network construction in Variant III, although these two variants have almost identical overall length of the network. When designing field secondary roads, they mostly represent skid trails, such as the ones on the ridges or positioned perpendicularly on the contours. The slope of these trails often exceeds the 30% limit defined here, especially when it comes to skidding downhill.

The achieved mean skidding distances are relatively similar in all variants. This is somewhat expected since the road network in all variants leads to two or three landings. However, when taking into account average length of the winch rope, considering all three new-design variants, it can be said that there is almost no difference in productivity and skidding costs (Table 1). As network construction costs exponentially grow from Variant III to Variant I, without reducing the skidding costs, from an economical point of view the construction of this network is unacceptable. Imani *et al.* [38] compared the forest roads variants obtained by Dijkstra's method and the traditional method and found that by using the first method they obtained lower length and costs for 55% and 65%. Parsakhoo *et al.* [39] obtained shorter routes by 12.03% in average, by using Dijkstra's algorithm. In this investigation, by using the method of the shortest route, longer routes were obtained in relation to the existing network that is laid in a traditional way.

Sokolović *et al.* [40] state that the minimum transport costs could be achieved by using winch rope length of 40-60 m. It is not recommended to use longer rope in sense of labour humanization during skidding and residual stand damage. In Management Unit "Bovan-Jelar", Pičman *et al.* [41] during the improvement of the existing secondary forest road network and adjustment to demanding terrain conditions used winch rope length of 45 m.

Surface of the investigated compartment covered by secondary roads is between 3.6% and 6.3%, at road width of 3.5 m. Another topic for discussion could be load of each road network. In Figure 7 it is presented how each network variant is loaded depending on distance. It can be seen that secondary road network variants with shorter winching distances are less loaded than those with longer distances, and real network is closest to Variant III. This fact could have impact on durability and maintenance of the secondary road network.

CONCLUSIONS

Mean winching distance influences skidding costs, but only in variants where mean skidding distance is decreasing. For all three designed networks of secondary forest roads in the compartment, it has almost no effect on the reduction of mean skidding distance. Therefore, a dense network of secondary forest roads is justified only in those cases where smaller distance of winching is needed for some other reason, e.g. for a higher level of work humanization or ecological reasons. On the other hand, smaller winching distance requires more skid roads and skid trails, which is unfavorable from both the economic

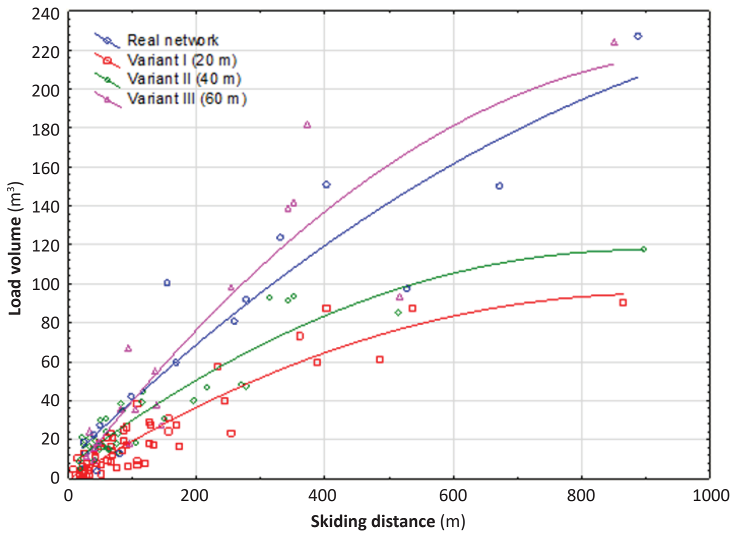

FIGURE 7. Load of skid network in different variants.

and ecological point of view, especially on steep slopes. In the end with the degree of density of secondary forest roads will be decided on the basis of archived average price of wood assortment and environmental guidelines. Small differences in skidding costs between variants have no practical significance except for large quantities of wood assortments. Spatial and network analysis tool is useful for secondary forest road network development and especially for large forest areas where there is a significant potential for this method. Another aspect is related to the primary and secondary openness of forest areas. Such tools, including network algorithms such as Dijkstra's algorithm, need greater attention in road network planning processes.

REFERENCES

1. IUFRO 1995 Forest work study. Nomenclature. Test Edition valid 1995-2000. International Union of Forestry Research Organisations WP 3.04.02, Swedish University of Agricultural Sciences, Department of Operational Efficiency, Garpenberg, Sweden, 16 p
2. DOBRE A 1995 Forest roads. Biotechnical faculty, Department for forestry and renewable forestry resources, Ljubljana, Slovenia, 70 p
3. POTOČNIK I 2004 Forest network. Manuscript, University of Banja Luka, Faculty of Forestry, Banja Luka, Bosnia and Hezegovina, 73 p
4. SOKOLOVIĆ DŽ, BAJRIĆ M 2013 Forest opening. University of Sarajevo, Faculty of Forestry, Sarajevo, Bosnia and Hezegovina, 250 p
5. JELIČIĆ V 1983 Forest roads and trails. SIC Education and training SRH. Zagreb, Croatia, 192 p
6. JELIČIĆ V 1977 Opening of cutting area with forest road network in forests of beech, fir and spruce. *Worksof the Faculty of Forestry University of Sarajevo*21 (1-2): 65-97
7. BOJANIN S 1983 Factors of optimal openness in secondary openings. *Mehanizacija šumarstva* 11-12 (8): 322-325
8. FAO 1998 A Manual for the Planning, Design and Construction of Forest Roads in Steep Terrain. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, 130,15 p
9. PUBLIC FORESTRY COMPANY "ŠUME REPUBLIKE SRPSKE" 2017 Rulebook about designing, construction, maintenance and reconstruction of tractor roads and trails. Banja Luka, Bosnia and Herzegovina, 18 p
10. DYKSTRA D P, HEINRICH R 1996 FAO model code of forest harvesting practice. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, 75 p
11. MARČETA D, PETKOVIĆ V, KOŠIR B 2014 Comparison of two skidding methods in beech forests in mountainous conditions. *Nova mehanizacija šumarstva* 35(1): 51-62
12. REBULA E 1983 Optimal density of skid trails. *Mehanizacija šumarstva* 8 (3-4): 317-321
13. URADNI LIST REPUBLIKE SLOVENIJE 2004 Rules on forest roads. Uradni list Republike Slovenije RS 104/2004 URL: https://www.uradni-list.si/glasilo-uradni-list-rs/vsebina?urlid=2004104&stevilka=4445
14. PIČMAN D 2007 Forest roads. University of Zagreb, Faculty of Forestry, Zagreb, Croatia, 460 p
15. ZDJELAR M 1990 The impact of skid road construction methods on work productivity and efficiency, tree damage and work load. *Mehanizacija šumarstva* 15 (1-2): 3-26
16. [31] PETKOVIĆ V, POTOČNIK I 2018 Planning forest road network in natural forest areas: a case study in Northern Bosnia nad Hrzegovina. *Croat J For Eng* 39 (1): 45-56

SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

ORIGINAL SCIENTIFIC PAPER

DOI: https://doi.org/10.15177/seefor.18-16

The Impact of Animal Logging on Residual Trees in Mixed Fir and Spruce Stands

Jelena Knežević[1*], Safet Gurda[1], Jusuf Musić[1], Velid Halilović[1], Dževada Sokolović[1], Muhamed Bajrić[1]

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

* **Correspondence:** e-mail: j.knezevic@sfsa.unsa.ba

Citation: KNEŽEVIĆ J, GURDA S, MUSIĆ J, HALILOVIĆ V, SOKOLOVIĆ DŽ, BAJRIĆ M 2018 The Impact of Animal Logging on Residual Trees in Mixed Fir and Spruce Stands. *South-east Eur for* 9 (2): 107-114. DOI: https://doi.org/10.15177/seefor.18-16

Received: 18 Oct 2018; **Revised:** 29 Nov 2018; **Accepted:** 6 Dec 2018; **Published online:** 22 Dec 2018

ABSTRACT

Background and Purpose: Logging is an example of the strongest human influence on forest environment because it causes damages to the forest soil and residual trees. The damages that occur during logging are more frequent in the skidding phase compared to the felling and processing phase.

Material and Methods: The research was conducted in mixed stands of fir and spruce in the area of eastern Bosnia and Herzegovina. Felling was conducted by chainsaw and extraction by animals, i.e. by two oxen. The following data were collected: tree species, diameter at breast height, pre-bunching zone (0-30 m or 30-60 m), presence of damages, presence of old damages, number of damages, type of damage, damage position and the size of damage.

Results: Damages were recorded on 3.32% of residual trees. The average number of damages per damaged tree was 1.08. The same percentage share of damages was recorded on butt end and root collar (38.46%), while damages on root have a share of 23.08%. Stem damages were not recorded. The most common type of damage was debarked tree (61.54%), then squashed bark (23.08%) and debarked and damaged tree (15.38%). It was recorded that the size of damages varied between 60 and 570 cm^2. The average size of damage was 222.54 cm^2. Statistical analysis using χ^2 test showed significant difference in the proportion of damaged trees among different pre-bunching methods, and did not show significant difference in the proportion of damaged trees between different pre-bunching zones.

Conclusions: It can be assumed that oxen logging causes insignificant damages to residual trees. The results of research will be used as a basis for future studies of residual trees' damaging during wood skidding.

Keywords: animal logging, oxen, damages, mixed fir and spruce stands

INTRODUCTION

Logging is an example of the strongest human influence on forest environment [1] because it causes damages to the forest soil and residual trees [2]. Tree felling and processing, as well as skidding of wood assortments, are the main phases of logging from the aspect of the extent of damage to stands and forest soil [3]. Damages to the forest ecosystem occur during felling and skidding operations, regardless of the technical means used in this process [1]. The problem of forest damages has become more and more important with the introduction of heavy mechanization in the phase of wood skidding and with the skidding of larger loads in the function of increasing productivity and economy of work [4].

Stand damaging depends on a series of different factors: work method, type of the machine used, machine characteristics and the manner of use, terrain and stand characteristics, and the relation of all participants in forestry production to forestry work and the forest itself [5]. The extent of damages is closely related to the adaptation of methods, instrumentality and organization of work to specific working conditions. In such a way, the size of damage increases with the power of the machine, the mechanization of work and larger lengths of skidded assortment [3].

Damages that occur during logging are more frequent in the skidding phase compared to the felling and processing phase. Tavankar *et al.* [6] found that percentage share of damages caused by a skidding operation with Timberjack 450 C tractor was about 73%, while damages caused by felling operations with chainsaw amounted to 27%. According to Martinić [3], wood skidding is a more common cause of tree damaging compared to the felling and processing of wood during thinning operations in young stands.

The largest damages to residual trees in the wood skidding phase are caused by tractors due to constant contact with the soil and movements per stand [3]. Zahirović *et al.* [7] found that the percentage share of damaged residual trees during tree felling with chainsaw and skidding with tractor was 35%.

The production of wood assortments on the territory of Bosnia and Herzegovina is partially mechanized. The main instruments of work in the skidding phase are tractors, primarily special forest tractors-skidders. Wood skidding by animals (horses and oxen) is also present [8]. Until the end of World War II in Bosnia and Herzegovina's forestry manual tools were used in the wood felling and processing phase, and animal skidding, waterways, chutes and tackles in the wood skidding phase. Technical roundwood was skidded by horses, and stacked wood (traditional one-meter long fuelwood) was skidded or carried out by horses as well. The work was done by unqualified workers organized into larger groups (about 10 workers) [9, 10]. The necessity of introducing more complex mechanization in the phase of wood pre-bunching and skidding in Bosnia and Herzegovina occurred because of more and more expensive animal work and smaller offer of private horses [11]. In addition to the above-mentioned reasons, for the replacement of manual labor and animal labor in forestry production, the following reasons were also mentioned: outdoor work, significant influence of meteorological conditions on working procedures, decisive influence of soil conditions on work, difficult and hazardous work within deadlines limited by time and technology due to biological and other conditions, and others [5]. A portion of harvestable area is usually inaccessible for skidding operations due to uneven and steep terrain. The animal skidding system is commonly applied in small cut-block areas and on uneven slope areas up to slopes of 50%, where limited timber volumes are available for transporting [12].

Animal skidding is the most rational skidding method in protected areas where low felling intensity is used and where there are no skid trails [13]. The integration of horse bunching with tractor skidding is a cost-effective solution for small wood extraction in steep terrain and in protected conservation areas. The result is a reduction in harvesting costs and skid trail density [14].

During animal skidding, products are typically transported along a common, designated skid-trail or the shortest path [12]. Steep terrains (>40%), terrain with soft soil (soil capacity <40 kPa) and uphill skidding (>8%) should be avoided [13]. It is recommended that horse skidding be applied at shorter distances, up to 250 m [15]. Magagnotti and Spinelli [14] notify that horse skidding is the cheapest alternative if the total extraction distance is shorter than 200 m.

According to Malatinszky and Fiscor [16], 26% of Forest Districts in Hungary apply animal logging regularly, using exclusively horses. Borz and Ciobanu [17] notify that tree felling using chainsaws followed by horse logging is a practice conducted in Romania, mostly applied in very young and dense stands where thinning operations are done. Non-mechanized wood extraction was used in 60% of forest operations and skidding in 35% of the cases in mountain areas of Bulgaria [18]. Toms *et al.* [19] report that animal logging is used in Alabama on small tracts, tracts with low timber volumes and harvests which use selective thinning. Verani and Sperandio [20] notify that the use of animals for hauling (mules and oxen) is still quite frequent in coppice harvesting in Southern Italy.

There is only light residual stand damage and soil compaction when using horse skidding [21]. In addition to decreasing the damages to residual trees during horse skidding, the density of the secondary forest communication network is also decreased [22]. Horse skidding of roundwood and hauling of one-meter long fuelwood caused twice less damages to residual trees in comparison to other skidding methods (adapted ZETOR 6945 tractor, adapted TORPEDO TD 75064 tractor) [3]. According to Martinić [3], skidding and hauling of wood by horses caused damages to 1.9% residual trees or every 52nd tree, which is statistically less significant in comparison to other skidding methods. Ficklin *et al.* [23] found that only 7% of residual trees of >5" (≈12.7 cm) diameter at the breast height were damaged by mule logging system in oak and pine stands (*Quercus velutina* Lain., *Quercus alba* L. i *Pinus echinata* Mill.), and 22% of residual trees were damaged by the skidder system.

Also, damages to regeneration when using animal (mule) logging method were significantly lower than when using the mechanized logging method by Timberjack C450 skidder [24]. Reduction in carbon emissions due to the absence of fossil fuel is another advantage of animal use in wood extraction [21].

Skidder logging causes higher soil compaction and lower soil porosity in comparison to animal skidding (mule skidding). Skidder compact both the depth of 0-10 cm and 10-20 cm, although mules mostly compact the top layer of the soil. Skidder disturbs larger area than mules during the extraction of the same wood volume [25].

Dudek and Sosnowski [26] explored the influence of different skidding technologies on tree damages in mountain area of Poland and found that two-horse skidding was the most environmentally friendly technology. Next were Larix 3T cable winch, agricultural MTZ 82 tractor, and a specialized skidder-type LKT 80 forest tractor.

Considering that animals are used for pre-bunching and skidding of the one part of felled wood in Bosnia and Herzegovina the aim of the research was to determine damages to residual trees in stands during oxen skidding. Horse is the most common and the most appropriate animal used for wood logging because of the best use of pulling force in accordance with its weight. Furthermore, it is able to increase the pulling force in a very short period of time, which is very important for wood logging. Horses are faster in comparison to oxen, but their purchase price, as well as feeding and maintance costs are greater. Oxen are more calm and secure during wood logging. Nontheless, because of the working method, front side of load is partially raised from the ground whereby traction resistance decreases, and load colletcs less amount of dirt, which is very important for processing in a sawmill.

MATERIALS AND METHODS

The research was conducted in eastern Bosnia and Herzegovina, in the area managed by Public Forest Enterprise "Šume Republike Srpske" a.d. Sokolac, Forest Management "Jahorina" Pale. The research object was Compartment 64, Forest Unit "Jahorina". Compartment area amounts to 86.41 ha, with altitude in the compartment ranging from 1360 to 1472 m. Average terrain slope is up to 15° with southeastern exposure. The compartment belongs to "High forest of fir and spruce or spruce on limestone soils" forest type. The share of species in the mixture is as follows: fir 37.09%, spruce 53.26%, beech 5.98%, and other broadleaved species 3.67%. The marking of trees for felling was conducted in 2016. The volume of marked trees was 2,746.19 m^3. The intensity of felling for coniferous and broadleaved trees was 10.26%.

Tree felling and extraction of wood assortments was carried out during 2017. Felling and processing were conducted by using a chainsaw. The extraction of wood assortments to the landing on the truck road was carried out by animals, i.e. by two oxen. Assortment processing method was performed. In earlier planning period wood extraction was carried out by animals and tractors as well, which is the reason why tractor skidding trails exist in the compartment. Animal paths and tractor skidding trails were used for skidding wood assortments from felling to landing on the truck road. Wood assortments were pre-bunched by oxen via animal paths from the felling site to the tractor skidding trail and then skidded by oxen via tractor skidding trail to the landing on the truck road. The slope of the tractor skidding trails used for animal skidding was less than 5%. The pre-bunching phase includes working operations of load forming and hauling of formed load to the tractor skidding trail, and the skidding phase includes wood skidding via tractor skidding trail to the landing on the truck road.

Damages to residual trees which occurred during animal logging were observed immediately after wood extraction, in August 2017. Only the damages which occurred during wood extraction were observed, while damages occurred during felling and processing were not the subject of analysis. Four stripe shape sample plots were set up in the compartment. Sample plots were set up in vertical direction to the central, longest tractor skidding trail. Sample plot 1 and sample plot 2 were located on the left side and on the right side of the tractor skidding trail respectively, at the distance of 500 m from the landing on the truck road. Sample plot 3 and sample plot 4 were located on the left side and on the right side of the tractor skidding trail respectively, at the distance of 100 m from the landing on the truck road with the aim of identifying skidding frequency influence on damage to residual trees. Sample plots were divided into two zones, with an area of 900 m^2 each. The first zone of every sample plot was set up at a distance of 0-30 m from the skidding trail, and the second zone at a distance of 30-60 m from the skidding trail. The zone width was 30 m (Figure 1).

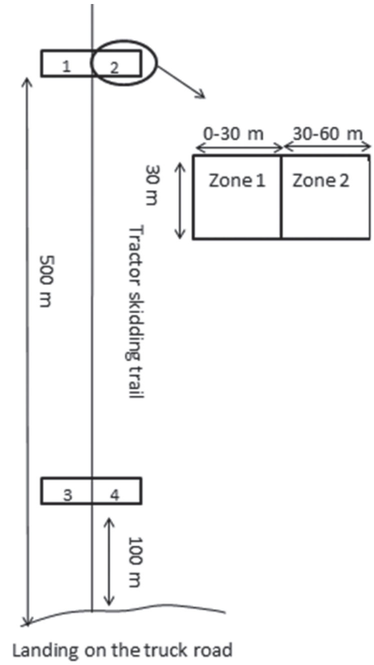

FIGURE 1. Schematic layout of sample plots.

Tree damages were determined using methodology applied by other authors [1, 3, 27-31].

At every sample plot, trees belonging to the sample were marked and recorded. Marginal trees were alternately taken and omitted from the sample. After the sample plots were set up, a detailed review of trees was conducted. Review included trees above taxation limit of 5 cm. For every tree belonging to the sample the following data were collected: tree species, diameter at breast height, pre-bunching zone (0-30 m or 30-60 m), presence of damages, presence of old damages, number of damages, type of damage, damage position, and the size of damage.

Damages were classified as: squashed bark, debarked tree, and debarked and damaged tree. Squashed bark is determined as a damage to the bark with invisible zone of cambium, and debarked tree is determined as a damage with visible zone of cambium [29]. Damages were classified according to the position of the damage as: stem damage, butt end damage, root collar damage, and root damage. To determine the position of tree damage a classification created by Meng [32] was used (Figure 2).

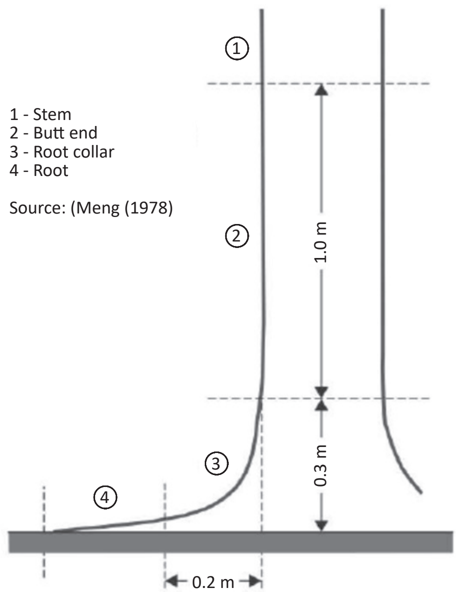

FIGURE 2. Classification of the position of tree damage.

Lengths were measured with a measuring tape, considering the terrain slope. The dimensions of damages were measured with a ruler in millimeters. The longest length and width, and the respective diameter in dependence of damage shape, were measured, and based on the measured values the damage area was calculated. Damages were classified into 4 groups according to damage size: <25 cm^2, 25-100 cm^2, 100-200 cm^2 and >200 cm^2 [30]. The damage position was determined by using a measuring tape, measuring the distance between the middle of the damage and the ground.

The following pre-bunching methods were determined at sample plots: flat terrain pre-bunching, downhill pre-bunching and uphill pre-bunching (Table 1).

TABLE 1. Pre-bunching method at the sample plot.

Sample plot	Pre-bunching zone	Pre-bunching method
1	0-30 m 30-60 m	Uphill pre-bunching
2	0-30 m 30-60 m	Pre-bunching on flat terrain
3	0-30 m 30-60 m	Pre-bunching on flat terrain
4	0-30 m 30-60 m	Downhill pre-bunching

STATGRAPHICS statistical package was used for data analysis.

RESULTS AND DISCUSSION

The research involved 361 trees of fir (*Abies alba* Mill.), spruce (*Picea abies* (L.) Karst.), beech (*Fagus sylvatica* L.) and sycamore maple (*Acer pseudoplatanus* L.). The damages were recorded on 3.32% of all inspected trees. The average number of damages per damaged tree was 1.08. One damage was recorded to 91.67% of damaged trees, and two damages were recorded to 8.33% of damaged trees.

The share of damaged trees (3.32%) was compared to the results of other studies. Melemez *et al.* [33] determined damages to 2.1% of residual trees in mixed beech-oak stands during animal skidding (by two oxen). Martinić [3] explored damages to residual trees during animal skidding and carrying out (by horses) in thinning operations of young stands, and determined that horse skidding and carrying out cause damages to 1.9% of residual trees, or to every 52nd tree. Ficklin *et al.* [23] found that 7% of residual trees with >5" (≈12.7 cm) diameter at the breast height were damaged by mule-logging system in oak and pine stands (*Quercus velutina* Lain., *Quercus alba* L. and *Pinus echinata* Mill.)

Statistical analysis using χ^2 test showed significant difference in the proportion of damaged trees among different pre-bunching methods (p=0.0008). The largest share of damaged trees was recorded during uphill pre-bunching (9%), then pre-bunching on flat terrain (1.58), while during downhill pre-bunching damages to residual trees were not recorded. According to Behjou [34], the probability of damages to residual trees increases with the increase of terrain slope. This ascertainment was confirmed.

Sample plots were divided into two pre-bunching zones with the aim of identifying the pre-bunching distance influence on damage appearance to residual trees. In pre-bunching zone of 0-30 m 2.79% damaged trees were recorded out of all trees belonging to the pre-bunching zone of 0-30 m. In pre-bunching zone of 30-60 m 3.85% damaged trees were recorded out of the all trees belonging to the pre-bunching zone of 30-60 m. Behjou [34] established that the probability of damages to residual trees decreases as the distance from the skidding trail increases. According to Kulušić [4], the most threatened are trees and regenerations located in the first third of the distance between the skid trail and the transport boundary. The research results did not confirm other authors' findings [4, 34]. Statistical analysis using χ^2 test did not show significant difference in proportion of damaged trees between different pre-bunching zones (p=0.5769).

Statistical analysis using χ^2 test did not show significant difference in proportion of damaged trees among different tree species (p=0.4375).

Two sample plots (3 and 4) were located at the distance of 100 m from the landing on the truck road and another two sample plots (1 and 2) were located at the distance of 500 m from the landing on the truck road. The aim of this spatial distribution of sample plots was the identification of skidding frequency influence on damage to residual trees. Trees belonging to the pre-bunching zone of 0-30 m were exclusively analysed. In total 4 damaged trees were recorded on sample plots located farther from the landing on the truck road, or 3.88% of all trees belonging to sample plots

TABLE 2. Chi-square test parameters.

Observed variables	Chi-square	Df	p - value
Pre-bunching method/presence or absence of damages	14.27	2	**0.008**
Pre-bunching zone/presence or absence of damages	0.31	1	0.5769
Tree species/presence or absence of damages	2.72	3	0.4375
Sample plot position/presence or absence of damages	1.03	1	0.31
Diameter at the breast height/presence or absence of damages	6.44	4	0.1684
Type of damage/pre-bunching method	2.44	2	0.2956
Type of damage/pre-bunching zone	0.76	2	0.6835
Damage position/pre-bunching method	6.24	2	**0.0442**
Damage position/pre-bunching zone	2.27	2	0.3214

1 and 2 and the pre-bunching zone of 0-30 m. On sample plots located nearer to the landing on the truck road one damaged tree was recorded, or 1.33% of all trees belonging to sample plots 1 and 2 and the pre-bunching zone of 0-30 m. According to Kulušić [4], the skidding frequency along the tractor road or animal path has an influence to stand damage in such a way that stand damages increase as skidding frequency increases. The research results did not confirm this ascertainment. Statistical analysis using χ^2 test did not show significant difference in proportion of damaged trees between the sample plot at different positions (p=0.32).

Statistical analysis using χ^2 test did not show a significant difference in proportion of damaged trees with different diameter at breast height (p=0.1684). The largest number of damaged trees belongs to the diameter class 5-10 cm, and least to the diameter class 51-80 cm. There were no recorded damaged trees in the diameter class 21-30 cm.

The damages which appeared during wood extraction in previous management periods („old damages") were recorded on the 9.42% of all surveyed trees. The presence of old and new damages was recorded on 1.11% of all surveyed trees, while new damages which appeared during current wood skidding were recorded on 2.21% of all surveyed trees (Figure 3). It is evident that more damages to residual trees occurred during wood extraction in previous management periods in comparison to current wood extraction in 2017.

The analysis of damages per type of damage showed that the largest percentage share of damages belongs to the category of debarked tree (61.54% of all recorded damages), followed by squashed bark (23.08%), and debarked and damaged tree (15.38%) (Figure 4). Martinić [3] found similar results in a research of felling and animal and tractor skidding during juvenile stands' thinning. The most common type of damage was squashed bark or debarked tree.

Statistical analysis using χ^2 test did not show significant difference in the proportion of damaged trees with different type of damage (squashed bark, debarked tree and debarked and damaged tree) between uphill pre-bunching

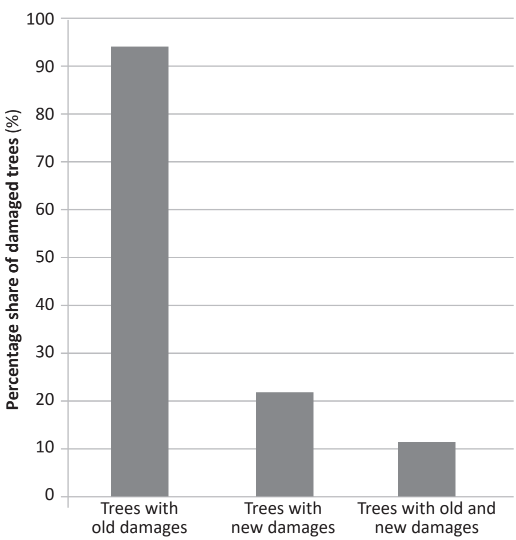

FIGURE 3. The distribution of damaged trees depending on the moment of damage occurrence.

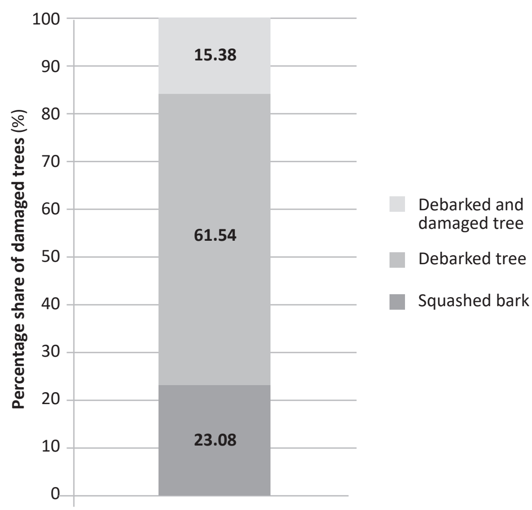

FIGURE 4. The distribution of damages depending on the type of damage.

and pre-bunching on flat terrain (p=0.2956). Also, statistical analysis using χ^2 test did not show significant difference in the proportion of damaged trees with different type of damage (squashed bark, debarked tree and debarked and damaged tree) between two pre-bunching zones (0-30 m and 30-60 m) (p=0.6835).

The analysis of damages per damage position showed that the same number of damages appeared on butt end and root collar (38.46%). The share of root damages in the total number of damages was 23.08% (Figure 5). Stem damages were not recorded. The result of research is similar to results of other researches [1, 27, 28] and showed that damages appear on the most valuable part of the tree. Gurda *et al.* [28] found that the largest number of damages appeared on the most valuable part of the tree, butt end (at the height bellow 1.3 m from the ground) during wood skidding with Timberjack 225A skidder. The largest number of damages on residual trees during wood skidding with LKT 81T appeared on the root collar and the lower part of stem, at the height bellow 1 m [1]. Danilović *et al.* [27] studied damages to residual trees during skidding with Timberjack 240C and found that the largest number of damages in the winching phase appear on root collar, and on butt end during the skidding phase.

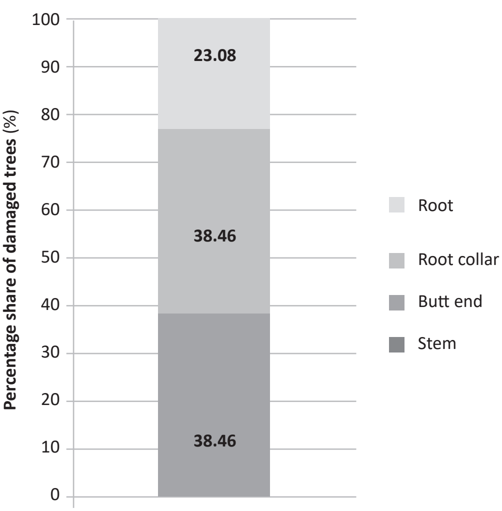

FIGURE 5. The distribution of damages depending on damage position.

Statistical analysis using χ^2 test showed significant difference in the proportion of damaged trees with different damage position (stem, butt end, root collar and root) between uphill pre-bunching and pre-bunching on flat terrain (p=0.0442). Root collar damages were exclusively recorded during pre-bunching on flat terrain, while during uphill pre-bunching root damages and butt end damages were also recorded. Statistical analysis using χ^2 test did not show significant difference in the proportion of damaged trees with different damage position (stem, butt end, root collar and root) between two pre-bunching zones (0-30 m and 30-60 m) (p=0.3214).

Damage size varied between 60 and 570 cm^2. The average size of damage was 222.54 cm^2 (Figure 6). The results are similar to the results found by Tsioras and Liamas [31], who investigated damages to residual trees during wood skidding with an adapted agricultural tractor (FIATAGRI Model 70.90) and mules in mixed beech and oak stands. The authors found that the largest share in all damages have damages larger than 200 cm^2. The determined average size of damage (222.54 cm^2) is greater than the average size of damage found by Martinić [3] in the analysis of wood felling and skidding with tractor and animals during juvenile stands' thinning (10-100 cm^2).

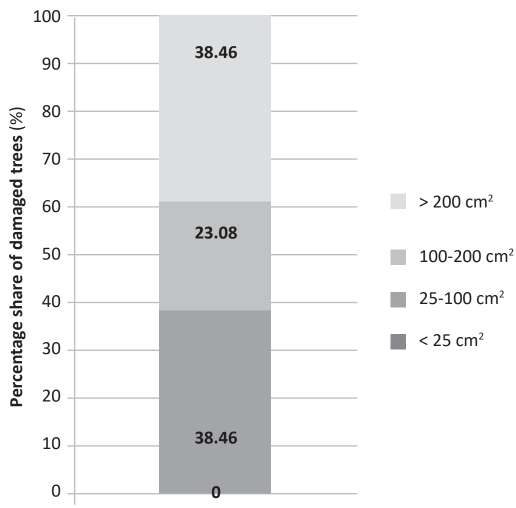

FIGURE 6. The distribution of damages depending on damage size

The average size of damage determined in this research is greater than the average size of damage found in other studies during skidding with a tractor. The average size of damage during skidding with Timberjack 240C varies between 50 and 200 cm^2 [27]. Gurda *et al.* [28] determined that the dominant damage on residual trees during skidding with Timberjack 225A was debarked tree on the area of 70 cm^2 on average. A large number of damages which appeared during tractor winching are caused by winch cable which is why they do not have a large area. During oxen pre-bunching damages are mostly caused by load impact to standing trees. Therefore, damages which appeared during oxen pre-bunching, although fewer of them, on average have greater area.

Damages larger than 200 cm^2 were in the largest percentage recorded at debarked and damaged trees (Figure 7). The smallest damages (25-100 cm^2) were in the largest percentage recorded at root damages (Figure 8).

Type of damage "debarked tree" was in the largest percentage recorded at root collar and root damages, while "squashed bark" was in the largest share recorded at butt end (Figure 9).

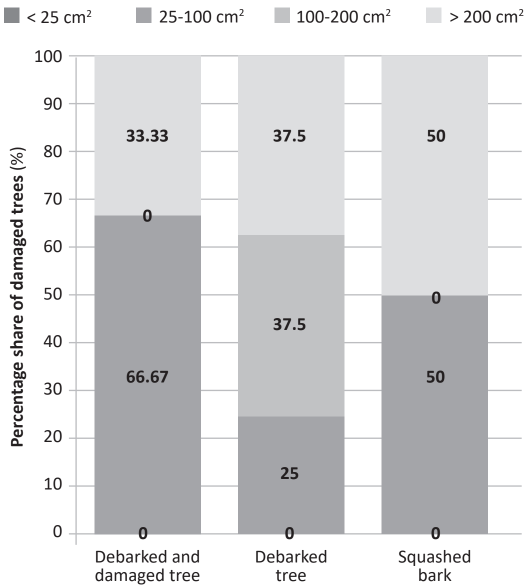

FIGURE 7. The distribution of different size damages depending on the type of damage.

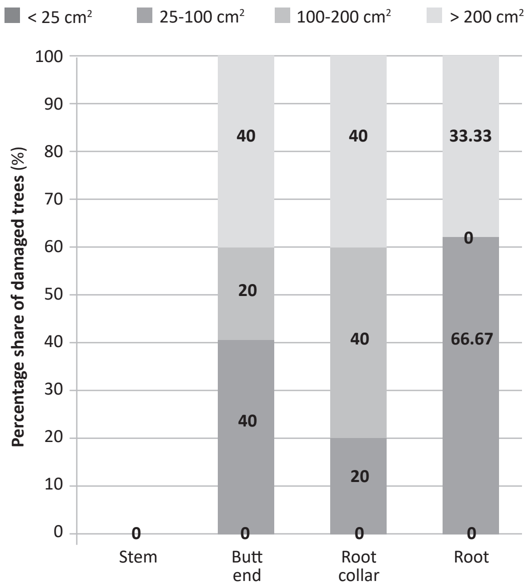

FIGURE 8. The distribution of different size damages depending on the damage position.

CONCLUSIONS

It can be concluded that oxen logging causes insignificant damages to residual trees. The result of research showed that damages appear on the most valuable part of the tree, the butt end (at the height bellow 1.3 m from the ground). The most common type of damage was debarked tree. Damages to residual trees can be reduced by organizational measures and appropriate planning of the felling site with visible marks on terrain, and also by preventive protection of the most threatened trees whose physical protection is done by setting the so-called protectors. In addition to above mentioned methods, the method of "sacrificed tree" is often used in practice. However, adequate control of forest harvesting is most important for high-quality work in forests. More intensive research of damages to residual trees during animal logging is planned to be conducted in the future, as well as the comparison between damages to residual trees during animal and mechanized logging.

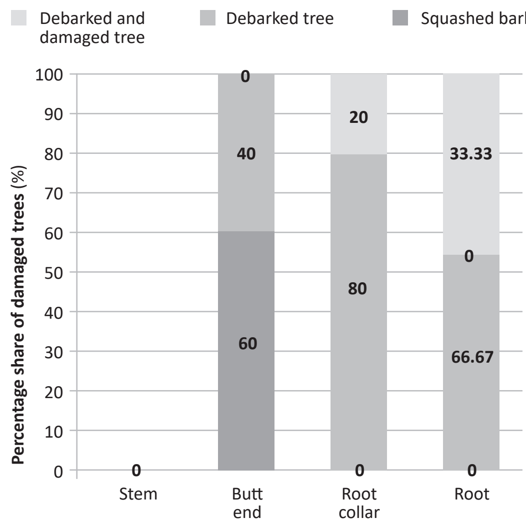

FIGURE 9. The distribution of different types of damages depending on the damage position.

REFERENCES

1. CUDZIK A 2017 Damage to Soil and Residual Trees Caused by Different Logging Systems Applied to Late Thinning. *Croat J For Eng* 38 (1): 83-95
2. NAGHDI R, BAGHERI I, LOTFALIAN M, SETODEH B 2009 Rutting and soil displacement caused by 450C Timber Jack wheeled skidder (Asalem forest northern Iran). *J For Sci* 55 (4): 177-183
3. MARTINIĆ I 1991 Damage to Stand of Trees in the Felling, Processing and Hauling of Timber (*in Croatian with English summary*). *Sumar list* 115 (1-2): 33-48
4. KULUŠIĆ B 2000 Manuscript – Forest Utilization. University of Sarajevo, Faculty of Forestry, Sarajevo, Bosnia and Herzegovina

5. MARTINIĆ I 2000 ENVIRONMENTALLY FRIENDLY USE OF MACHINERY IN FORESTRY - A SOAP BUBBLE OR A NEAR FUTURE (*in Croatian with English summary*). *Šumar list* 124 (1-2): 3-13
6. TAVANKAR F, NIKOOY M, PICCHIO R, BONYAD A, VENANZI R 2017-1 Effects of Logging Wounds on Caucasian Alder Trees (*Alnus subcordata* C.A. Mey.) in Iranian Caspian Forests. *Croat J Fort Eng* 38 (1): 73-82
7. ZAHIROVIĆ K, TREŠTIĆ T, MUJEZINOVIĆ O, HASKOVIĆ A 2016 INFLUENCE OF HARVESTING AND EXPORT OF WOOD MASS ON DAMAGE AND HEALTH CONDITION OF FIR AND SPRUCE TREES IN ZVIJEZDA MOUNTAIN AREA (in Bosnian with English summary). *Naše šume* 15 (44-45): 15-29
8. HALILOVIĆ V, MUSIĆ J, GURDA S, TOPALOVIĆ J 2015 Analysis of the means of forest harvesting in the Federation of Bosnia and Herzegovina. *Glasnik Šumarskog fakulteta*, Special issue 2015: 55-62. DOI: https://doi.org/10.2298/GSF15S1055H
9. BOJANIN S 1986 The situation on Development and Utilisation of Forests in SR. Croatia (*in Croatian*). *Šumari list* 110 (7-8): 323-332
10. ČOMIĆ R 1997 Ergonomy in Forestry. University of Banja Luka, Faculty of Forestry, Banja Luka, Bosnia and Herzegovina
11. MIHAĆ B 1977 Skidding, loading and transport of wood. *Works of the Faculty of Forestry and Institute for Forestry in Sarajevo* 21 (1-2): 3-63
12. EZZATI S, NAJAFI A, YAGHINI M, HASHEMI AA, BETTINGER P 2015 An optimization model to solve skidding problem in steep slope terrain. *J Forest Econ* 21 (4): 250-268. DOI: https://doi.org/10.1016/j.jfe.2015.10.001
13. LJUBOJEVIĆ S 2006 PRINCIPLES OF FOREST UTILIZATION IN PROTECTED AREAS AND IN SENSITIVE ECOSYSTEMS. *In*: Proceedings of Scientific conference: "Management of forest ecosystems in national parks and other protected areas", Jahorina-NP Sutjeska, 5-8 July 2006. Faculty of forestry University of Banja Luka, Banja Luka, Bosnia and Herzegovina, pp 479-484
14. N, SPINELLI R 2011 Integrating Animal and Mechanical Operations in Protected Areas. *Croat J Fort Eng* 32 (2): 489-499
15. GLUSCHKOV S, MARKOFF I, DJAMBASOVA M 2005 Timber haulage with horses in Bulgaria - economical, ecological and social aspects. *Forest Sci* 41 (1): 73-83
16. MALATINSZKY A, FISCOR C 2016 Frequency and Advantages of Animal-Powered Logging for Timber Harvesting in Hungarian Nature Conservation Areas. *Croat J For Eng* 37 (2): 279-286
17. BORZ SA, CIOBANU V 2013 Efficiency of motor-manual felling and horse logging in small-scale firewood production. *Afr J Agr Res* 8 (24): 3126-3135. DOI: https://doi.org/10.5897/AJAR2013.7306
18. ENACHE A, KÜHMAIER M, VISSER R, STAMPFER K 2016 Forestry operations in the European mountains: a study of current practices and efficiency gaps. *Scand J Forest Res* 31 (4): 412-427. DOI: https://doi.org/10.1080/02827581.2015.1130849
19. TOMS CW, DUBOIS MR, BLISS JC, WILHOIT JH, RUMMER RB 2001 A Survey of Animal-Powered Logging in Alabama. *South J Appl For* 25 (1): 17-24
20. VERANI S, SPERANDIO G 2005 Mechanization in firewood harvesting in southern Italy. *Forest@* 2 (2): 233-241. DOI: https://doi.org/10.3832/efor0290-0020233
21. BRAY DB, DURAN E, HERNANDEZ-SALAS H, LUJÁN-ALVAREZ C, OLIVAS-GARCIÁ M, GRIJALVA-MARTÍNEZ I 2016 Back to the Future: The Persistence of Horse Skidding in Large Scale Industrial Community Forest in Chihuahua, Mexico. *Forests* 7 (11): 283. DOI: https://doi.org/10.3390/f7110283
22. BOJANIN S, KRPAN A 1997 Adjustment of the Skidding Technology to Forest Protection. *Sumar list* 121(5-6): 243-252
23. FICKLIN RL, DWYER JE, CUTTER BE, DRAPER T 1997 Residual tree damage during selection cuts using two skidding systems in the Missouri Ozarks. *In*: Proceedings of the 11th Central Hardwood Forest Conference, Columbia, University of Missouri
24. NAGHDI R, LOTFALIAN M, BAGHERI I, JALALI AM 2009 Damages of Skidder and Animal Logging to Forest Soils and Natural Regeneration. *Croat J Fort Eng* 30 (2): 141-149
25. NAGHDI R, JALALI AM, GHAFFARIYAN MR, LOTFALIAN M 2009 Soil porosity and soil stress for skidder and mule logging sites. *Forest Sci* 45 (3): 103-113
26. DUDEK T, SOSNOWSKI J 2011 Evaluation of the environmental impact of selected timber extraction technologies used in mountain forests. *Sylwan* 155 (6): 413-420
27. DANILOVIĆ M, KOSOVSKI M, GAČIĆ D, STOJNIĆ D, ANTONIĆ S 2015 Damage to residual trees and regeneration during felling and timber extraction in mixed and pure beech stands. *Sumar list* 139 (5-6): 253-262
28. GURDA S, MUSIĆ J, SOKOLOVIĆ DŽ, BAŠIĆ M 2016 Damage on standing trees during wood skidding (winching phase) by cable skidder Timberjack 225 A. *Works of the Faculty of Forestry University of Sarajevo* 46 (1): 74-87
29. PORŠINSKY T, OŽURA M 2006 Damage to standing trees in timber forwarding. *Nova mehanizacija šumarstva* 27 (1): 41-48
30. TAVANKAR F, BONYAD AE, NIKOOY M, PICCHIO R, VENANZI R, CALIENNO L 2017 Damages to soil and tree species by cable-skidding in Caspian forests of Iran. *Forest Syst* 26 (1): e009. DOI: https://doi.org/10.5424/fs/2017261-09100
31. TSIORAS PA, LIAMAS DK 2010 Hauling damages in a mixed beech oak stand. *In*: Proceedings of 43th International Symposium on Forestry Mechanisation: Forest engineering: Meeting the Needs of the Society and the Environment, Padova, Italy, 11-14 July 2010
32. MENG W 1978 Baumverletzungen durch Transportvorgänge bei der Holzernte – Ausmaß und Verteilung, Folgeschäden am Holz und Versuch ihrer Bewertung. *Schriftenreihe der LFV Baden-Württemberg* 53: 159
33. MELEMEZ K, TUNAY M, EMIR T 2012 Investigation of some Extraction methods in Terms of Damages on Forest Stand. *In:* Pentek T, Poršinsky T, Šporčić M *(eds)* Forest Engineering - Concern, Knowledge and Accountability in Today's Environment, Proceedings of 45th International Symposium on Forestry Mechanization, Dubrovnik, Croatia, 8-12 October 2012. Forestry Faculty of University Zagreb, Zagreb, Croatia
34. BEHJOU FK 2014 Effects of Wheeled Cable Skidding on Residual Trees in Selective Logging in Caspian Forests. *Small-Scale For* 13 (3): 367-376. DOI: https://doi.org/10.1007/s11842-013-9259-x

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

ORIGINAL SCIENTIFIC PAPER

DOI: https://doi.org/10.15177/seefor.18-13

Valorisation of Waste Wood Biomass as Biosorbent for the Removal of Synthetic Dye Methylene Blue from Aqueous Solutions

Natalija Velić[1], Marija Stjepanović[1*], Lidija Begović[2], Mirna Habuda-Stanić[1], Darko Velić[1], Tamara Jakovljević[3]

(1) Josip Juraj Strossmayer University of Osijek, Faculty of Food Technology Osijek, Franje Kuhača 20, HR-31000 Osijek, Croatia; **(2)** Josip Juraj Strossmayer University of Osijek, Department of Biology, Cara Hadrijana 8/A, HR-31000 Osijek, Croatia; **(3)** Croatian Forest Research Institute, Division for Forest Ecology, Cvjetno naselje 41, HR-10450 Jastrebarsko, Croatia

*** Correspondence:** e-mail: marija.nujic@ptfos.hr

Citation: VELIĆ N, STJEPANOVIĆ M, BEGOVIĆ L, HABUDA-STANIĆ M, VELIĆ D, JAKOVLJEVIĆ T 2018 Valorisation of Waste Wood Biomass as Biosorbent for the Removal of Synthetic Dye Methylene Blue from Aqueous Solutions. *South-east Eur for* 9 (2): 115-122. DOI: https://doi.org/10.15177/seefor.18-13

Received: 30 Jul 2018; **Revised:** 16 Oct 2018; **Accepted:** 28 Oct 2018; **Published online:** 26 Nov 2018

ABSTRACT

Background and Purpose: Wood and wood processing industries are generators of a substantial amount of waste wood biomass, such as wood chips, shavings and sawdust. Such waste is often unused and its disposal can be a serious environmental problem. Different lignocellulosic waste materials have been successfully used as low-cost adsorbents (biosorbents) for the removal of synthetic dyes, as well as other contaminants, from wastewater. The aim of this study was to valorise the waste wood biomass of ten tree species, out of which seven are the most represented species of the Croatian growing stock, as biosorbents for the removal of synthetic dye methylene blue (MB) from model solutions.
Materials and Methods: The waste wood biomasses (shavings or sawdust) of ten tree species, namely common beech, pedunculate oak, sessile oak, common hornbeam, narrow-leafed ash, poplar, European silver fir, Norway spruce, European larch and Douglas fir, were dried and milled prior to characterisation and adsorption experiments. Characterisation of the biosorbents was performed by chemical analysis and Fourier transform Fourier transform infrared spectroscopy (FTIR). Upon characterisation, batch adsorption experiments were conducted in order to survey waste wood biomass as potential adsorbents for the removal of synthetic dye MB. The colour removal was monitored spectrophotometrically at predetermined time intervals. Further adsorption experiments were performed using poplar sawdust. The effects of contact time, biosorbent concentration, initial dye concentration, and pH on the adsorption process were investigated. The experimental data obtained by batch adsorption experiments were analysed using adsorption isotherm models (Freundlich and Langmuir).
Results: All the tested biosorbents were found to be very effective for the removal of MB from model dye solution, achieving high removal percentages ranging from 93.25 to 98.50%. Poplar sawdust proved to be the most effective. It was shown that MB adsorption process onto poplar sawdust could be interpreted in terms of Langmuir and Freundlich adsorption isotherm models.
Conclusions: Taken together, these results suggest that waste wood biomass has the potential to be used as a low-cost biosorbent for MB removal from aqueous solutions.

Keywords: adsorption, dye removal, Methylene Blue, poplar sawdust, waste wood biomass

INTRODUCTION

Wood is a natural renewable material that can have different purposes (e.g. construction material, fuel, etc.) and can be transformed into many different products. Depending on the geographical area, different tree species are prevalent in that specific area. The prevalent species of Croatian growing stock are the following: 36% common beech (*Fagus sylvatica* L.), 12% pedunculate oak (*Quercus robur* L.), 10% sessile oak (*Quercus petraea* (Matt.) Liebl.), 9% common hornbeam (*Carpinus betulus* L.), 8% European silver fir (*Abies alba* Mill.), 3% narrow-leafed ash (*Fraxinus angustifolia* Vahl) and 2% Norway spruce (*Picea abies* Karst.). All other tree species make up the remaining 20% [1]. Apart from the use of wood as fuel, there are four major sectors in the EU forest-based industries: woodworking, furniture, pulp and paper manufacturing and converting, and printing [2]. Since the industries that use forest wood are relatively heterogeneous, so are the resulting production waste streams. Wood processing residues (waste) remaining after processing logs and timber include bark, shavings, offcuts, sawdust, etc., and the amount of generated residues can be substantial. It can be converted into fuels in form of briquettes and pellets or can be used for the generation of electricity. Even though wood processing waste is available throughout the year and is relatively cheap, it often remains unutilised and its disposal can be a serious environmental problem. One of the possible uses of wood processing waste, besides its use as fuel, can be the use as low-cost adsorbents (biosorbents) for the removal of pollutants, such as synthetic dyes, from wastewater.

Synthetic dyes are widely used in almost all industries, from textile to food industry. Since the excess dye left after the dyeing processes ends up in the industrial effluents, the dyes are recognised as the most common water pollutants that detrimentally affect the aquatic life [3]. They also exhibit recalcitrance towards removal/biodegradation by conventional biological wastewater treatment methods. The method most often employed for the removal of dyes is adsorption using conventional adsorbents, such as activated carbon [4]. However, despite their remarkable adsorption capacities, the application of conventional adsorbents is often limited by high price. It is, therefore, of great importance to find inexpensive (low-cost) adsorbents that could replace the costly conventional ones. By definition, the low-cost adsorbent is abundant in nature or is an industrial by-product or waste material that requires little or no processing [5]. Lignocellulosic waste materials originating from wood and agri-food industry have the potential to be used as low-cost adsorbents, among which sawdust is one of the most appealing materials when it comes to removing dyes from wastewater [6]. Sawdusts of different tree species were investigated as adsorbents for the removal of dyes: meranti wood for methylene blue removal [7], beech wood sawdust for direct brown removal [8], chir pine sawdust for Congo red and basic violet 1 removal [9], etc.

The synthetic dye used as a model in this study is a cationic (basic) dye methylene blue (MB) (Figure 1), widely used for cotton, silk and leather dyeing [10], as well as in microbiology for staining and in medicine for the treatment of hypotension, hypoxia, as antimalarial and more [11]. MB is not strongly hazardous, but it can still cause harmful effects in humans and animals.

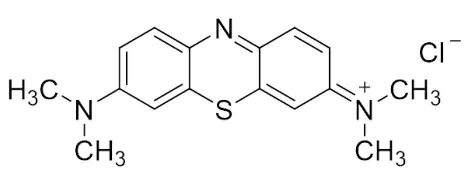

FIGURE 1. The chemical structure of methylene blue (MB).

The overall purpose of this study was to valorise the waste wood biomass of ten tree species of the Croatian growing stock as biosorbents for the removal of dye MB from aqueous solution. Upon survey of ten tree species, the aim was to further investigate the most efficient species (i.e. poplar) regarding different conditions for the adsorption of MB, namely contact time, biosorbent concentration, initial dye concentration and solution pH.

MATERIALS AND METHODS

Biosorbent

Waste wood biomass (wood shavings and sawdust) was kindly donated by Croatian Forests Ltd. Collected waste wood biomass included ten tree species, namely common beech, pedunculate oak, sessile oak, common hornbeam, narrow-leafed ash, poplar (*Populus euroamericana* Dode-Guinier), European silver fir (*Abies alba* Mill.), Norway spruce, European larch (*Larix decidua* Mill.) and Douglas fir (*Pseudotsuga menziesii* Mirb.).

The samples were oven dried at 323.15 K for 48 hours and ground using standard laboratory knife mill with 1 mm screen (MF10 basic, IKA Labortechnik, Germany) to ensure the particle size of adsorbent below 1 mm. No other chemical or physical treatments were applied prior to adsorption experiments.

Adsorbate

MB was purchased from Merck. A stock solution of 100 $mg \cdot dm^{-3}$ of dye was prepared daily, while the experimental solutions were obtained by diluting the stock solution to the desired dye concentration.

Adsorbent Characterisation

The elemental composition (C, H, and N) was performed using a CHNS/O elemental analyzer Seria II (Perkin Elmer, USA). The determination of ash content and extractives was described elsewhere [12]. The Kjeldahl method was used for protein content determination. Point of zero charge (pH_{pzc}) was determined according to the method given in Burevska *et al.* [13]. Crystalline cellulose content was determined according to Foster *et al.* [14].

The surface functional groups affecting the adsorption process were detected by Fourier transform infrared (FTIR) spectrometer (Cary 630, Agilent Technologies, USA). The spectra were recorded from 4000 to 500 cm^{-1}.

Adsorption Studies

A Survey of Waste Biomass of Different Wood Species for Adsorptive MB Removal

Batch adsorption experiments were carried out to investigate MB adsorption on different wood species' biomass by adding a fixed amount of biosorbent (0.25 g) to 25 cm^3 of 50 $mg \cdot dm^{-3}$ dye solution taken in a 100 cm^3 Erlenmeyer flask. The pH was not adjusted; however, it was measured at the beginning and at the end of the adsorption process using the pH-meter (Seven Easy, Mettler Toledo). The flasks were placed in the thermostatic shaker (SW22, Julabo) at 298.15 K and 150 rpm for 120 min, to ensure the equilibrium was reached. The samples were taken at predetermined time intervals for spectrophotometric determination of colour removal. The samples were filtered through Whatman filter paper No. 42 and then centrifuged at 6000 rpm for 5 min (IKA mini G). The dye concentrations in clarified supernatants were determined spectrophotometrically (Specord 200, Analytic Jena) at 664 nm. The percent of dye removal was calculated as follows:

$$\%\ \text{dye removal} = \left[\frac{(\gamma_0 - \gamma)}{\gamma_0}\right] \cdot 100$$

where γ_0 and γ (mg·dm^{-3}) are the initial dye concentration and dye concentration after predetermined contact time, respectively. The amount of dye adsorbed at equilibrium onto biosorbents, q_e (mg·g^{-1}), was calculated using the following equation:

$$q_e = \frac{[(\gamma_0 - \gamma_e) \cdot V]}{m}$$

where γ_e is the dye concentration at equilibrium, V is the dye solution volume (dm^3) and m is the mass of the biosorbent used (g).

Adsorption Studies using Poplar Sawdust as Biosorbent

Based on the results of a survey of different tree species as biosorbents for MB removal, poplar sawdust was used in further adsorption experiments. The effect of biosorbent concentration and pH on the amount of adsorbed MB was tested for different biosorbent concentrations ranging from 2 to 10 g·dm^{-3}. To study the effect of the initial dye concentration on the amount of adsorbed dye, the experiments were carried out at the temperature of 298.15 K, biosorbent concentration of 4 g·dm^{-3}, 150 rpm and pH=7 for 120 min. The initial MB concentrations were as follows: 10, 30, 50 and 100 mg·dm^{-3}. The effect of pH was tested in the pH range from 4.0 to 9.0, while all the other parameters were kept constant (initial dye concentration of 50 mg·dm^{-3}, biosorbent concentration of 4 g·dm^{-3}, 298.15 K, 150 rpm and 120 min). The pH was adjusted using 0.1 mol·dm^{-3} NaOH and 0.1 mol·dm^{-3} HCl solutions. The experimental data obtained by batch adsorption experiments were analysed using linear forms of Langmuir and Freundlich adsorption models.

All the experiments were performed in duplicate and were found reproducible.

RESULTS AND DISCUSSION

Biosorbent Characterization

The chemical composition of waste wood biomass of the surveyed tree species is given in Table 1. The results of the elemental analysis revealed that all used tree species have similar obtained C and H values ranging from 44.51 to 47.60% and 5.94 to 6.38%, respectively. This is in agreement with the research by Nacu [15] that reported similar values for total carbon and hydrogen. The chemical elements mentioned above, which are present in relatively large quantities, can form (along with oxygen and nitrogen) functional groups at the surface of sawdust that can serve as potential dye binding centres [16]. The nitrogen content varied from 0.07 to 0.44%, while protein content varied from 0.24 to 1.06%. Wood is comprised of major chemical components which are cellulose (40-45%), hemicellulose (30%) and lignin (20-30%), while extractives, ash, proteins and other components make up the rest [17]. The content of cellulose in this study was in the range from 31.66 to 44.27. Extractives include, amongst others, lipids, phenolic compounds, terpenoids, fatty acids, resin acids, steryl esters, sterol and waxes and their content generally varies between 2% and 5%, but can even reach 15% [18]. In this study, the content of extractives ranged from 1.31 to 3.94%. Ash is the inorganic residue remaining after water and organic matter have been removed, which provides a measure of the total amount of minerals within a sample. The ash content of wood biomass can vary between tree species and tree components [19]. High ash content can decrease the heating value of biomass [20]. Abdolali *et al.* [21] reported the average ash content of hardwood and softwood of less than 1%. However, in this study, the determined ash contents were higher and ranged from 0.81 to 1.9%.

The surface chemistry of adsorbents is determined by the acidic or basic character of their surface, or in other words, the net charge of the adsorbent surface can play a crucial role in the interactions occurring during the adsorption process. The pH at which the adsorbent surface net charge is zero is defined as the point of zero charge (pH_{pzc}). When solution pH is lower than pH_{pzc} the adsorbent surface is positively charged and can interact with anions, while at pH higher than pH_{pzc} the adsorbent surface is charged negatively and can interact with cations [22]. The pH_{pzc} of all used biosorbents was in the range from 5.25 to 7.10.

TABLE 1. The chemical composition of waste wood biomass.

Parameter	Common beech	Pedunculate oak	Cornish oak	Common hornbeam	Narrow-leafed ash	Poplar	European silver fir	Norway spruce	European larch	Douglas fir
C (%)	44.64	-	46.31	46.77	44.51	46.44	-	47.30	47.60	47.40
H (%)	6.38	-	6.33	6.23	5.94	6.29	-	6.35	6.34	6.22
N (%)	0.33	-	0.08	0.16	0.30	0.21	-	0.44	0.31	0.44
Extractives* (%)	1.41	3.48	3.94	1.64	3.18	2.45	1.72	1.31	1.36	2.41
Protein (%)	0.66	0.76	0.83	1.00	1.06	0.69	0.41	0.28	0.31	0.24
Ash (%)	1.14	1.12	0.81	1.40	1.50	1.43	1.80	1.90	1.45	1.60
Crystalline celulose (%)	31.66	-	32.91	39.89	33.04	40.53	44.27	38.00	32.18	43.06
pH_{pzc}	7.00	5.25	6.51	6.10	6.80	7.10	6.90	5.49	6.25	5.90

** ethanol/benzene (1:1)*

In order to investigate the functional groups present at the surface of used waste wood biomass, FTIR spectra were recorded for all samples. The spectrum for poplar sawdust, as a representative spectrum, is presented in Figure 2. As already mentioned, high contents of lignocellulosic polymers (i.e. cellulose, hemicellulose and lignin) are mostly responsible for a large number of hydroxyl groups available as binding sites for cationic dye molecules, such as MB. Hydroxyl groups, among others, are those mainly engaged in adsorption processes [21, 23]. The FTIR spectrum of poplar sawdust is dominated by the broad band at 3332 cm^{-1} representing hydroxyl groups. It can be ascribed to –OH stretching vibrations of polymers, e.g. cellulose and lignin, and it indicates free hydroxyl groups at the surface of the adsorbent. The band at 2899 cm^{-1} indicates the presence of $-CH_2$ aliphatic groups stretching. At 2102 cm^{-1} there is a band that can be assigned to –NH stretching. The bands from 1505 to 1423 cm^{-1} indicate the presence of branched-chain aromatic radicals [24]. The intense band at 1028 cm^{-1} is probably representing the polysaccharides, i.e. it could be ascribed to C-O, C=C and C-C-O stretching in cellulose, hemicellulose and lignin [25].

Adsorption Studies

A Survey of Waste Biomass of Different Wood Species for Adsorptive MB Removal

The results of a survey of the waste wood biomass of different tree species used as biosorbents for adsorptive MB removal are presented in Figure 3. The concentration of dye (50 $mg \cdot dm^{-3}$) was selected based on the dye concentrations previously reported in textile effluents that ranged from 10 to 50 $mg \cdot dm^{-3}$ [26, 27]. The results clearly show that all used biosorbents showed remarkable adsorptive capability for MB with high levels of dye removal (over 90% in all runs) under the applied experimental conditions. The initial stages of the adsorption process (first 30 min) were characterised by the higher MB removal rates, compared to later stages when the removal rate becomes slower (data not shown). This can probably be explained by the larger unoccupied surface area available for dye adsorption at the earlier stages of the experiment [28]. Similar results were reported for MB removal using different waste lignocellulosic material [25, 29].

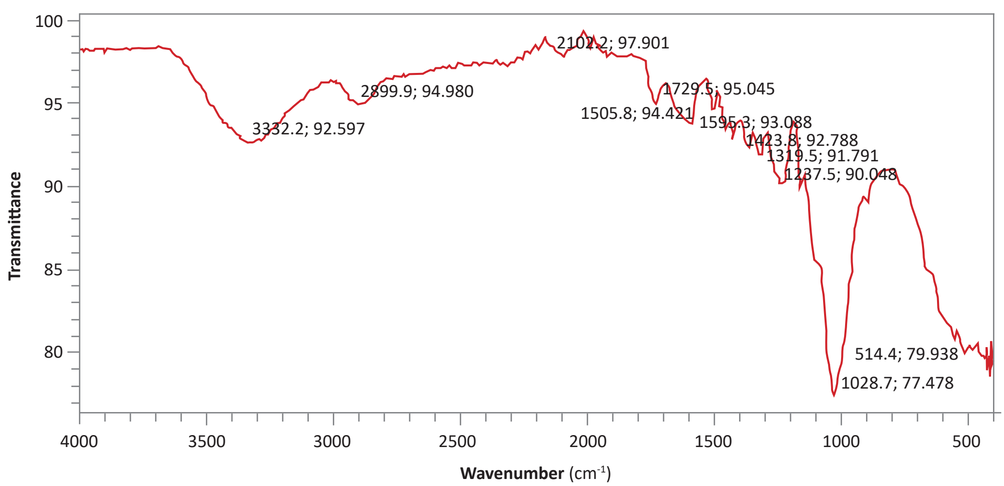

FIGURE 2. The FTIR spectral characteristics of poplar sawdust.

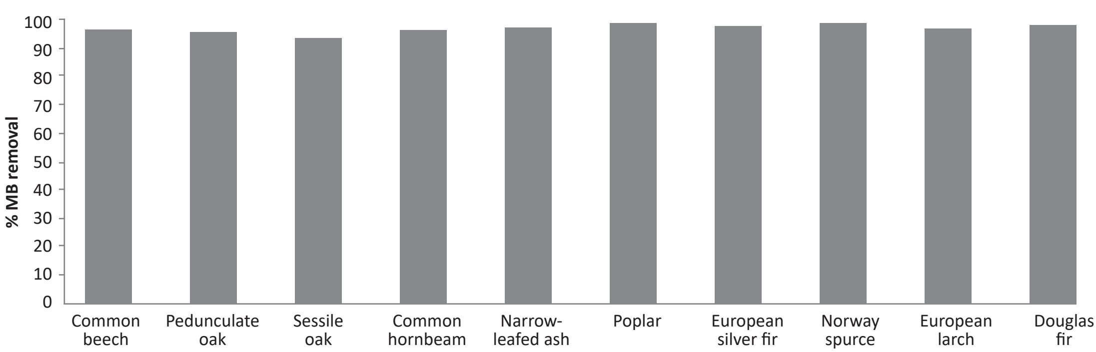

FIGURE 3. Adsorptive MB removal using different waste wood biomass as biosorbents (γ_{dye}=50 $mg \cdot dm^{-3}$, t=120 min, T=298.15 K, $\gamma_{biosorbent}$=10 $g \cdot dm^{-3}$, 150 rpm).

Adsorption Studies using Poplar Sawdust as Biosorbent

The adsorption process is usually strongly influenced by the adsorbent concentration because higher adsorbent concentration ensures higher surface area available for adsorption. The effect of adsorbent concentration on the adsorption of MB onto poplar sawdust is given in Figure 4. The results show that the percentage of MB removal increased from 62 to 97% with an increase of biosorbent concentration from 2 to 10 g·dm^{-3}. However, after the biosorbent concentration of 4 g·dm^{-3}, the percentage removal remained almost constant over the biosorbent range of 6-10 g·dm^{-3}, i.e. the further increase of biosorbent concentration did not markedly affect the adsorptive capacity. A similar behaviour was reported for MB removal using meranti sawdust as biosorbent [7].

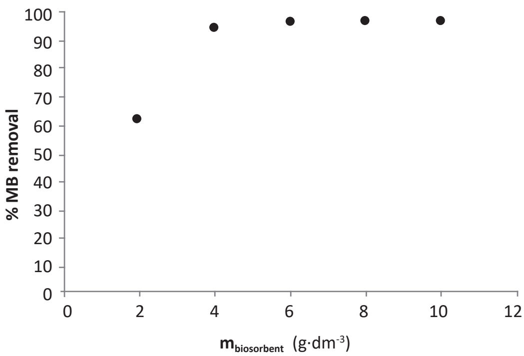

FIGURE 4. The effect of biosorbent concentration on the adsorption of MB onto poplar sawdust (γ_{dye}=50 mg·dm^{-3}, t=120 min, T=298.15 K, pH=7, 150 rpm).

The effect of contact time on MB adsorption is given in Figure 5. As already mentioned, the MB removal is rapid during the first stages and then gradually slows down until the equilibrium is reached. The equilibrium was achieved within 90 min and did not change with further contact time increase.

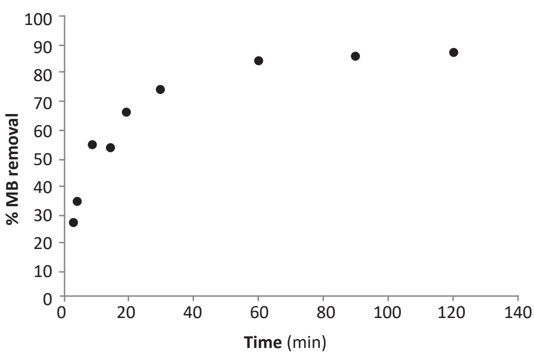

FIGURE 5. The effect of contact time on the adsorption of MB onto poplar sawdust (γ_{dye}=50 mg·dm^{-3}, $\gamma_{biosorbent}$=4 g·dm^{-3}, t=120 min, T=298.15 K, pH=7, 150 rpm).

Figure 6 shows the effect of the initial MB concentration on MB adsorption onto poplar sawdust.

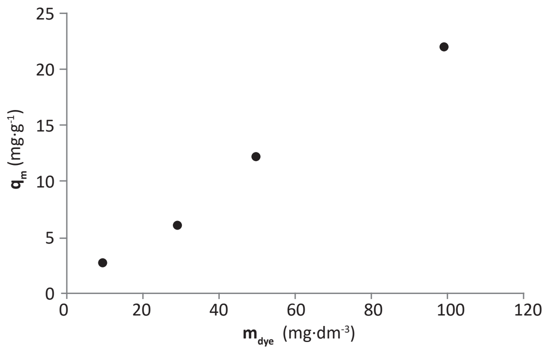

FIGURE 6. The effect of initial dye concentration on the adsorption of MB onto poplar sawdust ($\gamma_{biosorbent}$=4 g·dm^{-3}, t=120 min, T=298.15 K, pH=7, 150 rpm).

The amount of MB removed at equilibrium increased from 2.41 to 21.90 mg·g^{-1} when the initial MB concentration increased from 10 to 100 mg·dm^{-3}, which indicates that MB removal using poplar sawdust as biosorbent is concentration-dependent. This is in agreement with other studies using different waste lignocellulosic biosorbents, such as meranti sawdust [7], walnut sawdust [30] and modified Indian Rosewood sawdust [31]. Furthermore, the experimentally obtained adsorption capacities in this study are comparable to those reported by other authors, which can be seen from Table 2.

TABLE 2. Comparison of experimentally obtained adsorption capacities of various biosorbents for MB.

Sorption	Adsorption capacity (mg·g^{-1})	Reference
Formaldehyde treated rosewood sawdust	11.8 (50 mg·dm^{-3} MB) 46.1 (250 mg·dm^{-3} MB)	[33]
Chemically treated rosewood sawdust	12.49 (50 mg·dm^{-3} MB) 51.4 (250 mg·dm^{-3} MB)	[33]
Walnut sawdust	18.8 (100 mg·dm^{-3} MB)	[32]
Pyrrole modified walnut sawdust	33.2 (100 mg·dm^{-3} MB)	[32]
Mansonia sawdust	28.89 (120 mg·dm^{-3} MB)	[34]
Walnut sawdust	5 (50 mg·dm^{-3} MB)	[35]
Cherry tree sawdust	5 (50 mg·dm^{-3} MB)	[35]
Oak sawdust	5 (50 mg·dm^{-3} MB)	[35]
Pitch pine sawdust	5 (50 mg·dm^{-3} MB)	[35]
Meranti sawdust	98.4 (200 mg·dm^{-3} MB)	[7]
Poplar sawdust	21.9 (100 mg·dm^{-3} MB)	This study

One of the important parameters affecting the adsorptive removal of different contaminants from aqueous solutions (e.g. the complex matrix such as wastewater) is pH. The effect of pH on the amount of MB adsorbed onto poplar sawdust at equilibrium was studied over the pH range from 4 to 9 and the results are presented in Figure 7.

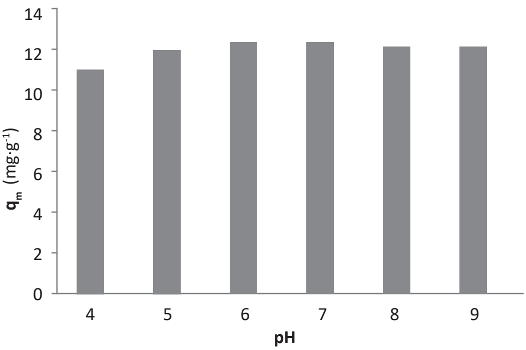

FIGURE 7. The effect of pH on the adsorption of MB onto poplar sawdust (γ_{dye}=50 mg·dm^{-3}, $\gamma_{biosorbent}$=4 g·dm^{-3}, t=120 min, T=298.15 K, 150 rpm).

The results show that the minimal amount of MB adsorbed was at pH=4, that it increased with pH and remained almost constant over the pH range of 7-9. Similar trends have been reported by other studies of MB removal using lignocellulosic materials [25, 34, 35]. The unfavourable effect of low pH on MB removal can probably be attributed to the presence of positively charged H^+ ions that compete with MB cations for adsorption sites. Furthermore, pH_{pzc} of poplar sawdust was found to be 7.1, so at pH higher than 7.1 its surface will be charged negatively and interact more readily with cationic dye MB.

Adsorption Behaviour of Poplar Sawdust (Isotherm Studies)

The adsorption isotherms describe the distribution of the adsorbate between the liquid and solid phase at the adsorption equilibrium at a constant temperature. They also offer insight into the adsorption capacity of the adsorbent for the removal of adsorbate from an aqueous solution. In this study, linear forms of Langmuir and Freundlich isotherm models were used to quantify the adsorption capacity of poplar sawdust.

Langmuir isotherm model is the most frequently used model and it presumes the occurrence of adsorption at specific adsorbent homogenous sites as a monolayer, single adsorption mechanism, uniform adsorption energy along the adsorbent surface and no interaction between the adsorbed molecules of the adsorbate [36]. The linear form of the Langmuir isotherm equation used is given by the following equation:

$$\frac{\gamma_e}{q_e} = \frac{1}{q_m} \cdot \gamma_e + \frac{1}{K_L \cdot q_m}$$

where γ_e (mg·dm^{-3}) is the equilibrium concentration, q_e (mg·g^{-1}) is the amount of adsorbed dye per unit mass of adsorbate, q_m (mg·g^{-1}) is the maximum amount of adsorbed dye (monolayer adsorption capacity) and K_L (dm^3·mg^{-1}) is the Langmuir constant related to the free energy of adsorption. q_m and K_L can be determined from the plot of γ_e/q_e against γ_e (Figure 8A). The Langmuir isotherm parameters are given in Table 3. The dimensionless constant called equilibrium parameter R_L indicates the type of isotherm to be unfavourable (R_L>1), favourable (0<R_L<1), linear (R_L=1) or irreversible (R_L=0) [7]. It can be calculated as follows:

$$R_L = \frac{1}{1 + K_L \cdot \gamma_0}$$

where γ_0 (mg·dm^{-3}) is the highest initial dye concentration.

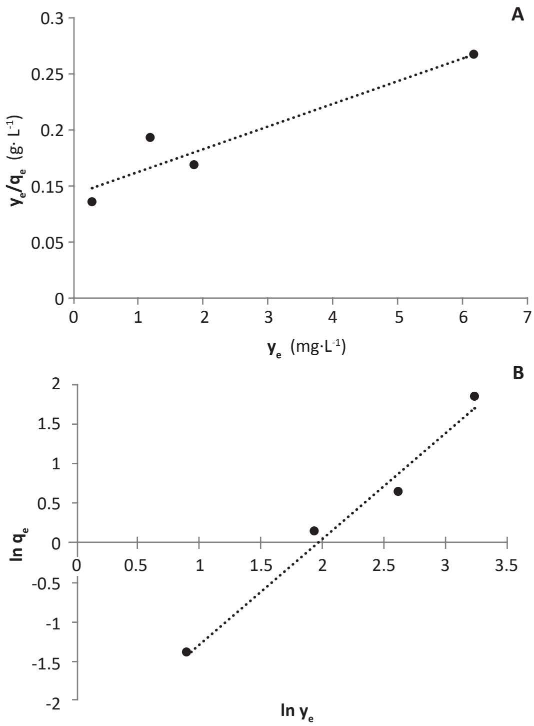

FIGURE 8. Langmuir (A) and Freundlich (B) isotherms of MB adsorption onto poplar sawdust at 298.15 K.

The R_L value in this study was 0.045, confirming that MB adsorption onto poplar sawdust under the studied conditions was a favourable process. When experimentally obtained q_{m_exp} values were compared to the q_{m_cal} values calculated based on the given Langmuir equation, a discrepancy could be seen. However, as already mentioned, experimentally obtained adsorption capacities (q_{m_exp}) in this study are comparable to those reported by other authors (Table 2).

TABLE 3. Isotherm parameters for the removal of MB by poplar sawdust at 298.15 K.

Isotherm model	298.15 K
Langmuir	
q_{m_exp} (mg·g^{-1})	21.900
q_{m_cal} (mg·g^{-1})	42.373
K_L (dm^3·mg^{-1})	0.213
R_L	0.049
R^2	0.893
Freundlich	
K_F (mg·g^{-1})(mg·dm^{-3})$^{1/n}$	0.075
n	0.744
R^2	0.979

The Freundlich isotherm model assumes the non-ideal adsorption on heterogeneous surfaces and multilayer adsorption and interaction between the adsorbed molecules [37]. The linear form of the Freundlich equation is given as:

$$\ln q_{\mathrm{e}} = \ln K_{\mathrm{F}} + \frac{1}{n} \ln \gamma_{\mathrm{e}}$$

where q_e (mg·g^{-1}) is the amount of dye adsorbed at equilibrium and γ_e (mg·dm^{-3}) is the equilibrium concentration of dye in the solution. Freundlich isotherm constants K_F and n indicate the adsorption capacity (K_F) and whether the adsorption process is favourable or not (n). The Freundlich constants are given in Table 3. The values of n indicate that the adsorption is linear when n=1, n<1 indicates that adsorption is a chemical process, while n>1 indicates favourable adsorption that is a physical process [38]. The results given in Figure 8B and Table 3 indicate that the adsorption of MB onto poplar sawdust is favourable and can be described in terms of the Freundlich isotherm model.

CONCLUSIONS

Waste wood biomass of ten tree species used in this study proved to be effective for the removal of synthetic dye methylene blue (MB) from an aqueous solution, achieving high removal percentage ranging from 93.25 to 98.50%. Poplar sawdust, the most effective of all tested tree species, was used in further adsorption experiments. The results showed that the percentage of dye removal increased with the increase of biosorbent concentration and contact time. The amount of MB removed at equilibrium increased from 2.41 to 21.90 mg·g^{-1} with the increase of initial dye concentration (10-100 mg·dm^{-3}). The effect of pH was investigated over the pH range from 4 to 9, whereas the minimal amount of MB adsorbed was at pH=4. After that, it increased up to pH=6 and then remained constant. The obtained equilibrium data were fitted to Langmuir and Freundlich isotherm models, and it was shown that the MB adsorption process could be interpreted in terms of both adsorption isotherms. However, the equilibrium data seem to be somewhat better fitted with the Freundlich isotherm equation. The overall results suggest that waste wood biomass represents a low-cost lignocellulosic adsorbent that has a potential to be used as an alternative to costly conventional adsorbents. However, further research should be undertaken to investigate the possibility of adsorption capacity improvement by different modification techniques, as well as the MB removal from synthetic and real wastewater samples.

Acknowledgments

The authors would like to thank Croatian Forests Ltd. for the kind donation of waste wood biomass.

REFERENCES

1. CROATIAN FORESTS LTD 2013 Forests in Croatia. URL: http://www.hrsume.hr/index.php/en/forests/general/forests-in-croatia (19 July 2018)
2. EUROPEAN COMMISION 2018 Forest-based industries. URL: https://ec.europa.eu/growth/sectors/raw-materials/industries/forest-based_en (19 July 2018)
3. ANNUAR MSM, ADNAN S, VIKINESWARY S, CHISTI Y 2009 Kinetics and energetics of azo dye decolorization by *Pycnoporus sanguineus*. *Water Air Soil Poll* 202 (1-4): 179-188. DOI: https://doi.org/10.1007/s11270-008-9968-5
4. HAMEED BH, AHMAD AA 2009 Batch adsorption of methylene blue from aqueous solution by garlic peel, an agricultural waste biomass. *J Hazard Mater* 164 (2-3): 870-875. DOI: https://doi.org/10.1016/j.jhazmat.2008.08.084
5. RAFATULLAH M, SULAIMAN O, HASHIM R, AHMAD A 2010 Adsorption of methylene blue on low-cost adsorbents: A review. *J Hazard Mater* 177 (1-3): 70-80. DOI: https://doi.org/10.1016/j.jhazmat.2009.12.047
6. SHUKLA A, ZHANG Y-H, DUBEY P, MARGRAVE JL, SHUKLA SS 2002 The role of sawdust in the removal of unwanted materials from water. *J Hazard Mater* 95 (1-2): 137-152. DOI: https://doi.org/10.1016/S0304-3894(02)00089-4
7. AHMAD A, RAFATULLAH M, SULAIMAN O, IBRAHIM MH, HASHIM R 2009 Scavenging behaviour of meranti sawdust in the removal of methylene blue from aqueous solution. *J Hazard Mater* 170 (1): 357-365. DOI: https://doi.org/10.1016/j.jhazmat.2009.04.087
8. DULMAN V, CUCU-MAN SM 2009 Sorption of some textile dyes by beech wood sawdust. *J Hazard Mater* 162 (2-3): 1457-1464. DOI: https://doi.org/10.1016/j.jhazmat.2008.06.046
9. KHAN TA, SHARMA S, KHAN EA, MUKHLIF AA 2014 Removal of Congo red and basic violet 1 by chir pine (*Pinus roxburghii*) sawdust, a saw mill waste: batch and column studies. *Toxicol Environ Chem* 96 (4): 555-568. DOI: https://doi.org/10.1080/02772248.2014.959017

10. RAMESH ST, GANDHIMATHI R, ELAVARASI TE, ISAI THAMIZH R, SOWMYA K, NIDHEESH PV 2014 Comparison of methylene blue adsorption from aqueous solution using spent tea dust and raw coir pith. *Global NEST J* 16 (1): 146-159. DOI: https://doi.org/10.30955/gnj.001248
11. GINIMUGE PR, JYOTHI SD 2010 Methylene blue: Revisited. *J Anaesth Clin Pharmacol* 26 (4): 515-520
12. VELIĆ N, TIŠMA M, JOZIĆ I, ZELIĆ B, SUDAR R, KELEKOVIĆ S, DOMAĆINOVIĆ A 2013 Solid-state fermentation of different lignocellulose substrates using *Phanerochaete chrysosporium*. *In*: Jukić A (*ed*) 14th Ružička days "Today science – tomorrow industry", Proceedings of 14th Ružička days "Today science – tomorrow industry", Vukovar, Croatia, 13-15 September 2012. Croatian Society of Chemical Engineers, Josip Juraj Strossmayer University of Osijek, Faculty of Food Technology Osijek, Zagreb and Osijek, Croatia, pp 187-192
13. BUREVKSA KA, MEMEDI H, LISICHKOV K, KUVENDZIEV S, MARINKOVSKI M, RUSESKA G, GROZDANOV A 2017 Biosorption of nickel ions from aqueous solutions by natural and modified peanut husk: equilibrium and kinetics. *Water Environ J* 32 (2): 276-284. DOI: https://doi.org/10.1111/wej.12325
14. FOSTER CE, MARTIN TM, PAULY M 2010 Comprehensive compositional analysis of plant cell walls (lignocellulosic biomass) part II: Carbohydrates. *J Vis Exp* 37: 1837. DOI: https://doi.org/10.3791%2F1837
15. NACU G 2015 Studies on the use of cellulosic waste to reduce environmental pollution. PhD thesis, Technical University "Gheorghe Asachi" of Iaşi, Iaşi, Romania
16. NACU G, BULGARIU L 2017 Sawdust – sustainable low-cost adsorbent for environmental remediation. *In*: Stefan E, Olaf K (*eds*) Sawdust Properties, Potential Uses and Hazards, Nova Science Publishers, Hauppauge, USA, pp 111-146
17. SJOSTROM E 1993 Wood Chemistry. Fundamentals and Applications, 2nd ed., Academic Press, San Diego, USA, 292 p
18. SHEBANI AN, VAN REENEN AJ, MEINCKEN M 2008 The effect of wood extractives on the thermal stability of different wood species. *Thermochim Acta* 471 (1-2): 43-50. DOI: https://doi.org/10.1016/j.tca.2008.02.020
19. VOIPIO R, LAAKSO T 1992 Chemical composition of the above-ground biomass of small-sized trees. *Folia Forestalia* 789: 1-22. URL: http://urn.fi/URN:ISBN:951-40-1202-X
20. HYTÖNEN J, NURMI J 2015 Heating value and ash content of intensively managed stands. *Wood Res* 60 (1): 71-82
21. ABDOLALI A, GUO WS, NGO HH, CHEN SS, NGUYEN NC, TUNG KL 2014 Typical lignocellulosic wastes and by-products for biosorption process sin water and wastewater treatment. A critical review. *Bioresour Technol* 160: 57-66. DOI: https://doi.org/10.1016/j.biortech.2013.12.037
22. FIOL N, VILLAESCUSA I 2009 Determination of sorbent point of zero charge: usefulness in sorption studies. *Environ Chem Lett* 7 (1): 79-84. DOI: https://doi.org/10.1007/s10311-008-0139-0
23. O'CONNELL DW, BIRKINSHAW C, O'DWYER TF 2008 Heavy metal adsorbents prepared from the modification of cellulose: A review. *Bioresour Technol* 99 (15): 243-250. DOI: https://doi.org/10.1016/j.biortech.2008.01.036
24. PISTORIUS AMA, DeGRIP WJ, EGOROVA-ZACHERNYUK TA 2009 Monitoring of Biomass Composition From Microbiological Sources by Means of FT-IR Spectroscopy. *Biotechnol Bioeng* 103 (1): 123-129. DOI: https://doi.org/10.1002/bit.22220
25. KEZERLE A, VELIĆ N, HASENAY D, KOVAČEVIĆ D 2018 Lignocellulosic Materials as Dye Adsorbents: Adsorption of Methylene Blue and Congo Red on Brewers' Spent Grain. *Croat Chem Acta* 91 (1): 53-64. DOI: https://doi.org/10.5562/cca3289
26. LAING IG 1991 The impact of effluent regulations on the dyeing industry. *Rev Prog Colouration* 21 (1): 56-71. DOI: https://doi.org/10.1111/j.1478-4408.1991.tb00081.x
27. SHELLEY TR 1994 Dye pollution clean-up by a synthetic mineral. *Int Dyer* 79: 26-31
28. WANYONYI WC, ONYARI JM, SHIUNDU PM 2014 Adsorption of Congo Red Dye from Aqueous Solutions Using Roots of *Eichhornia crassipes*: Kinetic and Equilibrium Studies. *Energy Procedia* 50: 862-869. DOI: https://doi.org/10.1016/j.egypro.2014.06.105
29. VELIĆ N, MARČEK T, JURIĆ T, PETRINOVIĆ K, HASENAY D, BEGOVIĆ L, SLAČANAC V 2015 A survey of different bioadsorbents for removal of malachite green and methylene blue dyes from aqueous solutions. *In*: Šubarić D, Jukić A (*eds*) 15th Ružička days "Today science – tomorrow industry", Proceedings of 15th Ružička days "Today science – tomorrow industry", Vukovar, Croatia, 11-12 September 2014. Josip Juraj Strossmayer University of Osijek, Faculty of Food Technology Osijek, Croatian Society of Chemical Engineers, Osijek and Zagreb, Croatia, pp 424-432
30. ANSARI R, MOSAYEBZADEH 2010 Removal of Basic Dye Methylene Blue from Aqueous Solutions Using Sawdust and Sawdust Coated with Polypyrrole. *J Iran Chem Soc* 7 (2): 339-350. DOI: https://doi.org/10.1007/BF03246019
31. GARG VK, AMITA M, KUMAR R, GUPTA R 2004 Basic dye (methylene blue) removal from simulated wastewater by adsorption using Indian Rosewood sawdust: a timber industry waste. *Dyes Pigm* 63 (3): 243-250. DOI: https://doi.org/10.1016/j.dyepig.2004.03.005
32. OFOMAJA AE 2009 Equilibrium sorption of methylene blue using mansonia wood sawdust as biosorbent. *Des Water Treat* 3: 1-10. DOI: https://doi.org/10.5004/dwt.2009.433
33. FERRERO F 2007 Dye removal by low-cost adsorbents: Hazelnut shells in comparison with wood sawdust. *J Hazard Mater* 142 (1-2): 144-152. DOI: https://doi.org/10.1016/j.jhazmat.2006.07.072
34. HAMDAOUI O 2006 Batch study of liquid-phase adsorption of methylene blue using cedar sawdust and crushed brick. *J Hazard Mater* 135 (1-3): 264-273. DOI: https://doi.org/10.1016/j.jhazmat.2005.11.062
35. BATZIAS FA, SIDIRAS DK 2007 Simulation of dye adsorption by beech sawdust as affected by pH. *J Hazard Mater* 141 (3): 668-679. DOI: https://doi.org/10.1016/j.jhazmat.2006.07.033
36. SOTO ML, MOURE A, DOMÍNGUEZ H, PARAJÓ JC 2011 Recovery, concentration and purification of phenolic compounds by adsorption: A review. *J Food Eng* 105 (1): 1-27. DOI: https://doi.org/10.1016/j.jfoodeng.2011.02.010
37. KATAL R, BAEI MS, RAHMATI HT, ESFANDIAN H 2012 Kinetic, isotherm and thermodynamic study of nitrate adsorption from aqueous solution using modified rice husk. *J Ind Eng Chem* 18 (1): 295-302. DOI: https://doi.org/10.1016/j.jiec.2011.11.035
38. SADAF S, BHATTI HN, NAUSHEEN S, NOREEN S 2014 Potential Use of Low-Cost Lignocellulosic Waste for the Removal of Direct Violet 51 from Aqueous Solution: Equilibrium and Breakthrough Studies. *Arch Environ Contam Toxicol* 66 (4): 557-571. DOI: https://doi.org/10.1007/s00244-013-9992-3

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

REVIEW PAPER

DOI: https://doi.org/10.15177/seefor.18-12

Capital Budgeting Applied to Serbian Poplar Plantations

Ljiljana Keča[1]*

(1) University of Belgrade, Faculty of Forestry, Kneza Viseslava 1, RS-11030 Belgrade, Serbia

* **Correspondence:** e-mail: ljiljana.keca@sfb.bg.ac.rs

Citation: KEČA LJ 2018 Capital Budgeting Applied to Serbian Poplar Plantations. *South-east Eur for* 9 (2): 123-130. DOI: https://doi.org/10.15177/seefor.18-12

Received: 14 Jul 2018; **Revised:** 26 Sep 2018; **Accepted:** 4 Oct 2018; **Published online:** 15 Oct 2018

ABSTRACT

Background and Purpose: Capital budgeting is the process in which a business determines and evaluates potential large expenses or investments. These expenditures and investments include projects such as building a new plant or investing in a long-term venture. In the case of poplar plantations in Serbia, a prospective project's lifetime cash inflows and outflows can be assessed in order to determine whether generated potential returns meet a sufficient target benchmark, also known as "investment appraisal". The purpose of this study is to show relative profitability of alternative courses of action in poplar plantations.

Material and Methods: The investigated plantations were established from *Populus* x *euramericana* cl. *I-214* on different soil types, situated in north-western part of Serbia, with planting spacing 6x3 m, differently aged, mainly for technical wood production. The data used in this study were collected from the management and materials books of the "Vojvodinašume" Public Forest Enterprise , which is the official owner of these stands. All of the plantations are state-owned. At the end the supply chain of poplar wood production is presented. Different capital budgeting techniques and different discount rates are employed to determine which types of poplar plantations, treated as separate projects, will or not will yield the most return over an applicable period of time.

Results and Conclusions: The financial effects for sample plot plantations were first evaluated with an external funder prerequisite of 12% discount rate, and continued with different investment appraisal discount rates. For the discount rate r=12%, all tested areas had a negative net present value (NPV). Average internal rate of return (IRR) is 5.63% and payback period is acceptable for the investor at 6% and less. The average benefit-cost analysis amount is 0.36 for all stands with a discount rate of r=12%.

Keywords: capital budgeting, strategy, discount rate, poplar, costs, revenues

INTRODUCTION

Financial appraisals in forestry are based on standard investment appraisal techniques. In such analysis we take into account the frequently long time period lapsing between initiating forest activities and obtaining returns from trees [1]. Forestry schemes are generally characterized by heavy initial costs, low recurrent costs (an advantage which will tend to be discounted relative to initial costs) and delayed benefits [2]. Poplar rotation is one of the shortest in European forestry, and production of poplar wood requires rational and well-planned management [3].

Capital budgeting is used to show the relative profitability of alternative courses of action [4]. The poplar plantations have been chosen because of the relatively short rotation period compared to other tree species [3, 5].

Yield classes in hybrid poplar plantations (*P.* x *euramericana* cl. *I-214)* are high in Serbia [6]. Preparation of the ground and soil for afforestation is the most expensive operation in the production cycle [7]. High costs are encountered at the stage of plantation establishment (chipping of tree stumps, ploughing, planting, protection, etc.) [3]. Major cuts in plantations of clone poplars belong to the group of clear felling [8]. "Marking of trees for cutting in restoration is carried out along the border line that is included in the area of clear cut. Harvesting is realized at a time when there is no risk of sudden arrival of high water, to effectively protect produced assortments during floods. When performing cuts there must be taken into account that felled trees do not intersect and the stump height does not exceed ¼ of diameter. Cutting of felled timber is adapted to market conditions, to achieve maximum financial effects (greater participation of technical wood in relation to the physical, waste is minimized) and performed by a qualified stuff" [9].

Costs are a very important element of an investment. When there is a significant lapse of time between the start of costs being incurred and the end of the period, such as in poplar plantations, in which all costs and benefits arise from the original expenditure, this is considered to be an investment [10]. "Structure of costs of major felling in cultures of clone poplars in Ravni Srem is composed of two segments of direct costs: costs of felling and work up and costs of extracted assortments. The costs of felling and work up are related to chainsaw and labor force. The second segment consists of the costs of extraction of produced assortments" [7].

The goals of the work reported in this paper were: (i) to apply capital budgeting to poplar plantations, based on the analysis of the present value of costs and revenues over a different time period, and (ii) to present the supply chain of poplar wood production and test the sensitivity of these values to possible changes in the levels of costs and revenues.

MATERIAL AND METHODS

There are four main groups of values identified in forestry: forestry values which derive from forest-related activities by forest managers and the upstream and downstream connections with other parts of the economy arising from such forestry activities; 'shadow' values arise as a result of other economic activities benefiting or experiencing loss as a result of forestry; non-market values are the external effects associated with forests and woodland; and social values [1, 11]. Critics of standard investment criteria based on discounting have argued that these introduce a bias in favor of investment projects which impose high private or social costs in the future, or after a long delay, but have lower capital costs at the present time or in the near future [2]. Forestry projects of all kinds will be disfavored relative to other types of projects of shorter term because of the inherently long gestation period involved in tree growth [13]. Generally, final goal of investment process is to maximize stakeholder wealth or value of the firm, making capital budgeting part of long term investment appraisals [14].

This paper identifies a number of different kinds of investment decisions in which a long-time horizon is involved and for which the application of the conventional, relatively high discount rates used in less developed countries creates problems.

The aim of the study was to conduct an analysis of costs and receipts of artificial poplar plantations on different fluvisols considering a span of rotation between 25 and 42 years, as well as in different discount rates (4-12%) [3]. The primary methods used are dynamic methods of investment calculation [15, 16]. These methods include net present value (NPV), internal rate of return (IRR), payback period (PBP), and cost-benefit analysis (R) [14, 17, 18].

The data used in this study were collected regarding costs during years 0-5 (soil preparation, planting, care and protection, etc.) obtained from the archives of "Vojvodinašume" Public Forest Enterprise, the forest enterprise which managed the studied plantations, according to the age established at the plantation [3, 5, 6] and expressed per unit area of 1 ha at the prices in force in January 2016. Land value was not taken into account since the objective of the study was not to determine optimal treatments and rotations for poplar [8, 19].

The investigated plantations were established from *Populus* x *euramericana* cl. *I-214* in the north-western part of Serbia, with planting spacing of 6×3 m (555 trees per ha), used for technical wood production. Thirteen study plots, i.e. 55 stands, aged 24-42 years, with a total area of 331.05 ha were assessed. The data collected are linked to different types of soil belonging to site classes I–V [3, 5, 6].

The level of the discount rate is of paramount importance in forestry owing to the large effects of a small change in rate when used to discount values over long periods of time [4]. The discount rate used in the public sector generally is related to the rate of return on capital in the private sector of the industry and commerce [20]. Discount rates of 3, 5 and 7% have been employed in an attempt to cover the range of real rates of return likely to be available from alternative investments open to private investors in forestry [10, 21, 22]. First in this research the discount rate of 12% was chosen, a traditional common choice for developing countries according to Gittinger [23]. Poplar plantations are not profitable at discount rates in the range of 10-15%, as it was still used some time ago in assessing funding opportunities in the economies of developing and transition countries [24]. The National Bank of Serbia discount rate was in 2005 at 8.8%, while today it is at 3.0%. Dinar loans for long-term lending of non-financial corporations nowadays are around 6%. Since the interest rates have decreased considerably since the financial crisis, in forestry it is most convenient to account for investment risk by adding a risk premium to the risk-free discount rate when computing present values of expected revenues which are uncertain [25]. After a review of the literature on the discount rate in economics and forestry, it is most useful to use IRR, while the opportunity cost of capital is considered in the establishment of a shadow price of investment [26].

Sensitivity Analysis is the calculating procedure used for prediction of the effect of changes of input data on output results of one model [27]. This procedure is often used in investment decision making, in the example of poplar plantations in this case, related to the investment project evaluation under conditions of uncertainty [28]. In this case sensitivity analysis [29] is a common way to consider uncertainty (by changing input variables and evaluating the effects on target variables) in poplar plantation studies.

RESULTS AND DISCUSSION

The financial effects for sample plot plantations were estimated using different discount rates (Table 1). For a discount rate r=12%, all tested areas had a negative NPV from -1 585.84 to -2 134.80 €·ha^{-1}, regardless of age and site quality. The discount rate of 6% can be accepted by shorter production cycles in younger stands (to the age of 28 years) on better sites (alluvial semigley) [3, 5]. The value of assortments by the price list of "Vojvodinašume" Public Forest Enterprise, which manages these forests, ranges from 11.088 to 23.676 €·ha^{-1} [9]. Cost, revenue and profit are three most important factors in determining the success of management in poplar plantations [30].

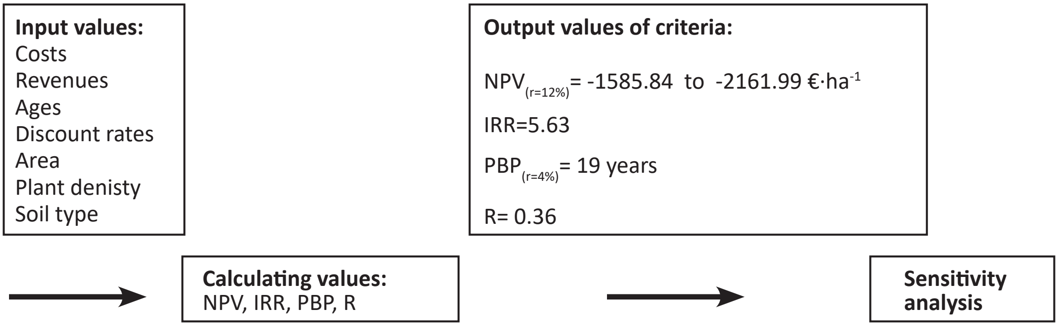

FIGURE 1. Calculation of individual criteria using input and output values.

TABLE 1. Capital budgeting on poplar plantation on sample plots in Serbia

Study plot no.	Soil Type	Site Class	Age (years)	Area (ha)	NPV p=12% (€·ha^{-1})	IRR (%)	PBP for p=4% (years)	R
1.	RC/HGL	IV	24	25.00	–1 743.02	5.20	19	0.421
2.	AS/ASG	I	26	36.75	–1 838.60	6.94	19	0.349
3.	AS/ASG	I	26	2.33	–1 700.41	5.83	19	0.467
4.	AS/ASG	I	26	9.87	-1 585.84	6.18	19	0.407
5.	AS/ASG	I	26	1.32	–1 746.22	6.12	19	0.430
6.	AS/ASG	I	28	32.57	–1 813.10	5.41	19	0.373
7.	AS/ASG	I	29	28.82	–1 872.78	5.84	19	0.351
8.	LC/HFL	III	29	33.81	–1 877.35	4.32	19	0.388
9.	LC/HFL	III	29	51.49	–1 791.41	5.36	19	0.390
10.	LC/HFL	III	31	58.15	–1 940.66	5.35	19	0.323
11.	ASG	I	37	5.80	–1 999.57	6.10	19	0.310
12.	ASG	I	42	6.62	-2 161.99	5.51	19	0.240
13.	α / β-β gley	V	42	38.52	–2 134.80	4.43	19	0.242
Total/ Average				331.05				0.36

RC - fossil hydromorphic black soil (humosemigley) on loess-alluvium; HGL – humogley; ASG - alluvial semigleyfossil hydromorphic black soil on loess-alluvium; HFL – humofluvisoil; α / β-β gley; p - discount rate; NPV - net present value; IRR - internal rate of return; PBP – payback period; R – benefit- cost analysis.

TABLE 2. Sensitivity analysis of NPV in relation to relative changes of T_p - costs and P_p - revenues (p=4 and 6%)

Study plot number	r = 6%		r = 4%		Acceptable or not for investment in r=6 and 4%
	T_p	P_p	T_p	P_p	
1.	-0.24	-0.24	0.94	0.94	+/-
2.	-0.41	-0.41	0.78	0.78	+/-
3.	0.58	0.58	2.39	2.39	+
4.	-0.09	-0.09	1.29	1.29	+/-
5.	0.10	0.10	1.60	1.60	+
6.	0.08	0.08	1.86	1.86	+
7.	-0.34	-0.34	1.06	1.06	+/-
8.	-0.36	-0.36	1.02	1.02	+/-
9.	0.06	0.06	1.76	1.76	+
10.	-0.40	-0.40	1.14	1.14	+/
11.	-0.12	-0.12	2.05	2.05	+/
12.	-1.10	-1.10	0.31	0.31	+/
13.	-1.03	-1.03	0.42	0.42	+/

By applying sensitivity analysis (Table 2) it can be concluded that "investment under calculation discount rate of 4% was financially justified in all study cases. The discount rate of 6% can be accepted by shorter production cycles in younger stands (up to the age of 26-29 years) on better sites (alluvial semigley)" [31]. That is directly connected to IRRs values. The results clearly show an inverse relationship between the IRR and plantation age, and also a direct proportion with the soil type, i.e. IRR are higher for plantations grown (Table 2) on stands suitable for poplar production (alluvial semigley) and for shorter rotations and vice versa [5].

IRRs varied in the range of 4.32-6.94% (average 5.63%). Internal rates were higher for plantations on good quality soil types and for shorter rotations, and vice versa. "The results clearly show the inverse proportion between discount rate and the age of the plantation, and also direct proportion with soil type, i.e. that discount rates are higher for plantations which are grown on stands suitable for poplar production (alluvial semigley) and for shorter rotations, and vice versa. Stands with higher IRR have priority in investment, and this research includes younger plantations, which refer the investors in poplar production to invest in stands with shorter rotations." [5, 32].

Based on the application of sensitivity analysis of IRR it was concluded that the most unfavourable situation is found in sample plots which are over-matured stands on unfavorable soil type for poplar production. On the other hand, the most favourable situation is found in the stands where the amounts of IRR are not considered to be higher than 12% in the observed changes of costs and receipts, and they are realized on the level below 70% of costs or above 130% of realized receipts [32]. There are commercial banks in Serbia, where one can get a loan with an interest rate of 5%. Private owners can be advised to invest in such a production of poplar wood. On the other hand, the state has interest regarding poplar plantations. Plantations are very efficient in CO_2 consuming, as shelterbelts, for flood control, etc. Therefore, the state can stimulate forest owners to invest in poplar production in river banks in the future. Plantations grown on more quality soil types such as alluvial semigley are more profitable [3, 5, 6, 32].

The analysis showed that PBP is practically unacceptable for the investor under the discount rate of 6%. The most favourable situation is with a discount rate of 2% in younger plantations. The conditions for having rotations up to over-aged stands are utterly unfavorable regarding the payback period, so the credit cannot be repaid under any conditions. This fact supports the conclusion that the production cycle period in poplar plantations should be shortened. In younger stands, the situation is fairly more favorable, so under special conditions the credit should be repaid [33]. Based on the sensitivity analysis for the method of payback period, it can be concluded that the change in receipts and costs in 5% steps can be represented by an exponential function and that PBP is between 1.3 and 4.6 years. For p=2% this ratio is the most favorable both in the case of the changes in receipts and the changes in costs [5, 6, 33].

Applying the method of cost-benefit it can be concluded that the average amount of R was 0.36 for all studied plots at 12% discount rate (Table 1) [5, 6, 34]. This means that the costs at a discount rate of 12% are about 2.8 times higher than the receipts. Based on the sensitivity analysis of the cost-benefit method, it can be concluded that cost benefit ratio for p=8-12% is below 1 within the study range of changes in costs and receipts, while for p=4-6% there are cases when this ratio is above 1, at certain degrees of decrease in costs, i.e. the increase in receipts [5, 34]. Nowadays, with the higher awareness of human impact on the environment, benefit/cost analysis is increasingly applied in the evaluation of forest social functions, wildlife conservation, impact on water resources (water supply, acidification and erosion control), landscape management, and greenhouse effect reduction. Forestry is often unable to valorize all of its products on the market, and therefore the social community should support forestry in a way, especially in the realization of the projects dealing with plantation forestry. One of the forms of support could be to enable the use of beneficial interest rates on the means invested in the establishment of new plantations, which are considerably lower than those in other production fields [34].

Based on the results presented above, it is clear that, in practice, it is necessary to improve the position of producers in getting the deficient financial means for investment in poplar cultivation, so as to stimulate the establishment of artificial poplar plantations, especially in the private sector (on private lands, which are unattractive for agricultural production). The investments can be directed to more efficient soil preparation (stump chipping, deep ploughing, etc.), the improvement of inter-row tilling, better plant protection against insect pests and phyto-pathogenic fungi (Figure 2) [31, 32].

Forest Management Plans prescribe the rotation period in poplar plantations on 25 years and thus also a certain time of the major harvest, the main income in the cultures of clone poplars. Major cuts in plantations of clone poplars belong to the group of clean felling, i.e. removing all trees from the selected area. The marking of trees for cutting in restoration is carried out along the border line that is included in the area of clean cut. Harvesting is realized at a time when there is no risk of sudden arrival of high water to effectively protect the produced assortments during floods. When performing cuts it must be taken into account that felled trees do not intersect and that stump height does not exceed ¼ of its diameter. Cutting of felled timber is adapted to market conditions to achieve maximum financial effects (greater participation of technical wood in relation to the physical, while waste is minimized) and performed by qualified staff. The assortments are brought out via forest roads, in the shortest possible time, to the forest stock where wood material is stored in an accessible place and is kept safe from flooding. Technical wood is exported to the forest road by machines (expenses of machine forwarder), while the cellulose wood carries the costs of loading, unloading and stacking (machine expenses - tractors and manpower - loader) [8].

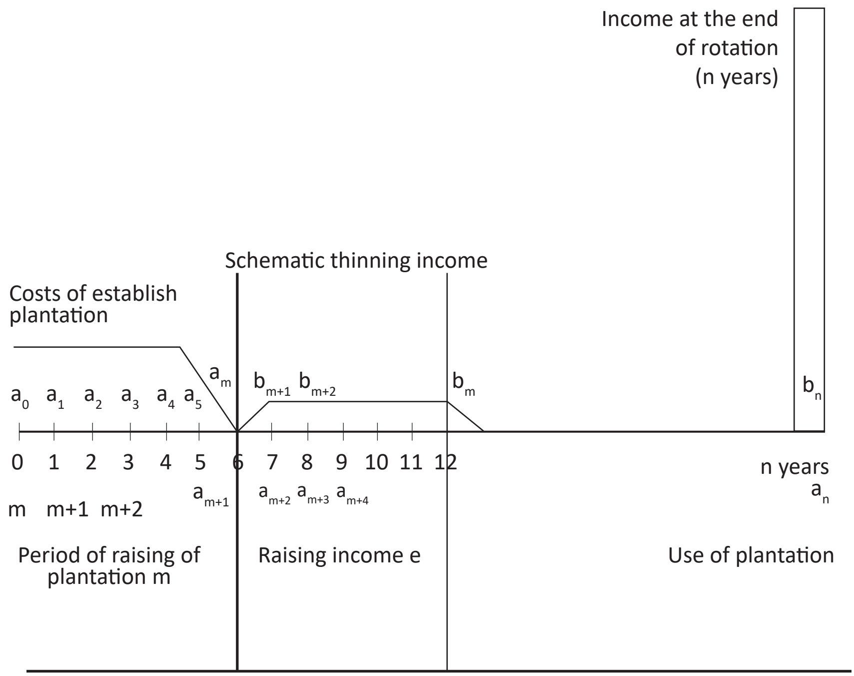

FIGURE 2. Developed model of investment in the establishment of multiannual plantations (Source: [34]).

One of the most significant changes in the paradigm of modern business management is that individual companies no longer compete as solely autonomous entities but rather as supply chains [35]. In Figure 3 the supply network structure, the supply chain business process, and the management process for poplar wood in Serbia are presented. In the Serbian market there is a strong need for F-class assortment of poplar and RII-class, which can lead to the conclusion that wood processing is oriented towards the production of various products of poplar wood, so the range of products from poplar wood expands, as directed for export and for domestic purposes [36]. All wood processing companies are privately owned in the sector of poplar production. All capacities on average amount to about 17,300 $m^3 \cdot yr^{-1}$ (3,000-100,000 $m^3 \cdot yr^{-1}$), and the utilization of the installed capacities is approximately 66% (30-90%) [36]. Wood processing companies are oriented towards the production of multiple products at the same time, such as: timber, boards, lumber, crates and veneer, fiberboard and particleboard [37], and produce approximately 350,000 m^3 of poplar wood per year [6]. Figure 3 shows the supply chain of the analyzed companies in poplar wood processing, from the purchase of raw materials, through the processing and sale of the final product.

In the future wood-processing organizations should be directed to better adapt to their operational and development plans of production in accordance with the planned cuttings in forestry and widening capacities. Plantations should be established to meet the demands of the market of poplar wood, especially in Serbia, and the markets in the region. For a long time there has been a great demand on the market for a veneer logs and saw logs, since the producers as a goal have the provision of these assortments [37].

CONCLUSIONS

Based on the analysis it is clear that it is necessary to improve the position of poplar production in Serbia in the soil types and age which are suitable for such a production, with appropriate site and climate conditions. It is both important for the public and private sector. Also in the future it would be useful to influence investments in cost reduction in poplar production on the one hand, and small and medium enterprises in the sector of wood production to intensify production of final products of poplar wood on the other hand. This is in line with the Common Agricultural Policy of the European Union and the endeavours of the Government of the Republic of Serbia to develop the bioenergy sector [36]. Market analyses are very important, particularly in the field of market supply. In that way they should direct influence production of wood in poplar plantations and shorten the rotation period. The obtained results are not very optimistic when a discount rate of 12% is applied, but by applying sensitivity analysis the circumstances in which such a production is profitable are emphasized. During the past decade, the interest rates have decreased considerably since the Financial Crisis of 2007-2008, also affecting Serbia. On the other hand, poplar plantations are very efficient in flood control and shelterbelt and in that way have not just an economic, but also an ecological function.

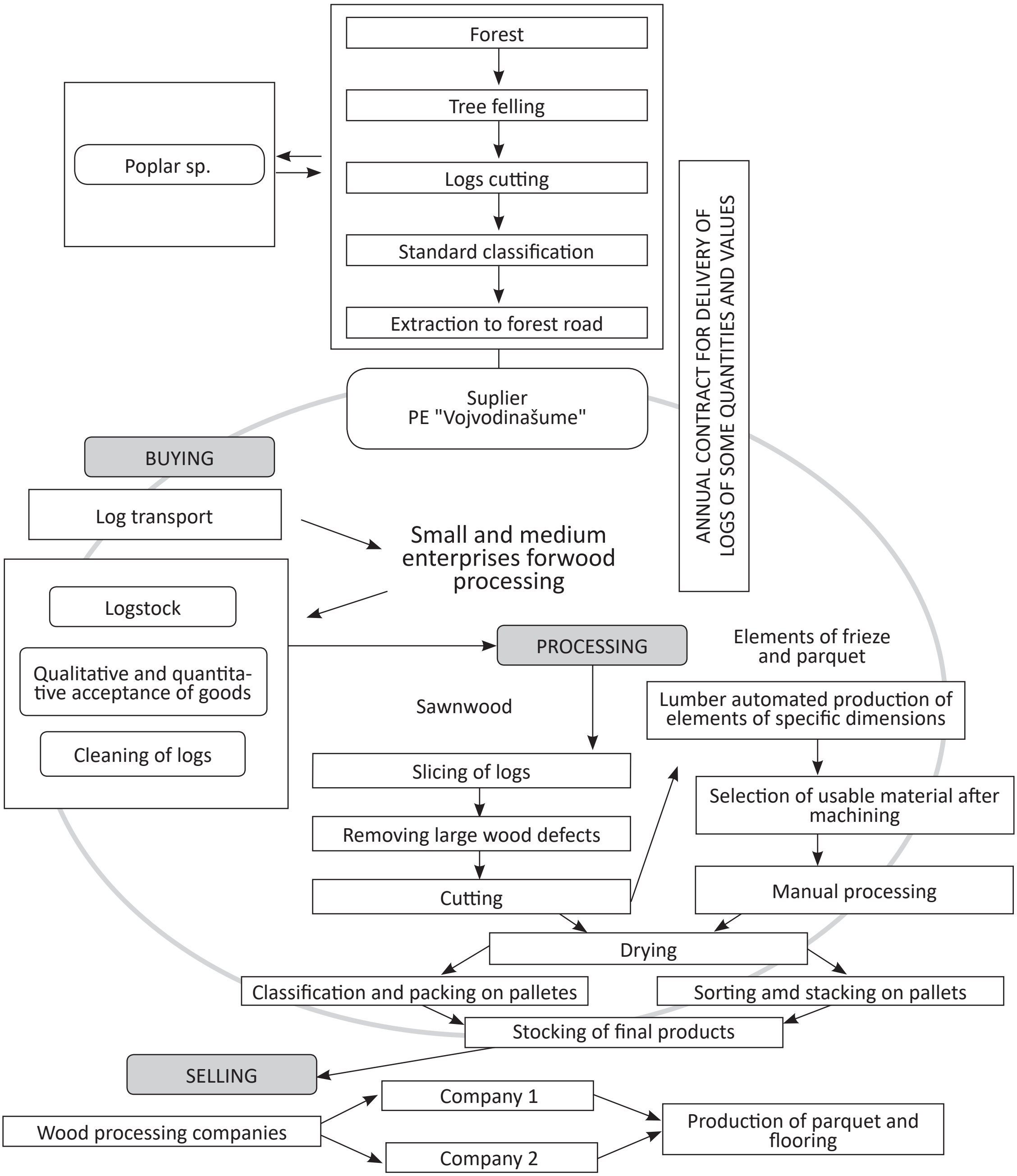

FIGURE 3. Supply chain in poplar wood production (Source: Marčeta M. (unpublished), adapted by Keča Lj.).

Acknowledgment

This research was presented on the International Conference SUSTAINABLE FOREST MANAGEMENT FOR THE FUTURE - the role of managerial economics and accounting, IUFRO Unit 4.05.00 – Managerial economics and accounting in Zagreb (10-12 May 2018). The research was supported by a grant from the Ministry of Education and Science of the Republic of Serbia, projects: "Sustainable management of total forest potential in the Republic of Serbia" (TR 37008) and "Forest plantations as the indicator of increasing afforestated areas of Serbia" (TR 31041). The author would also like to thank CA COST ACTION CA 15206 - Payments for ecosystem services - PESFOR-W, COST TN 1401 - CAPABAL and COST ACTION FP 1403 - NNEXT.

REFERENCES

1. SLEE B, ROBERTS D, EVANS R 2004 Forestry in the rural economy: a new approach to assessing the impact of forestry on rural development. *Forestry* 77 (5): 441-453. DOI: https://doi.org/10.1093/forestry/77.5.441
2. LIVINGSTONE I, TRIBE M 1995 Projects with long time horizons: their economic appraisal and the discount rate. *Project Appraisal* 10 (2): 66-76. DOI: https://doi.org/10.1080/02688867.1995.9726978
3. KEČA LJ, KEČA N, PAJIĆ S 2011 Investment Appraisal of Poplar Plantations in Serbia. *Baltic For* 17 (2): 268-279
4. BUSBY RJN, GRAYSON AJ 1981 Investment appraisal in forestry. Forestry Commission Booklet 47, London, UK, 90 p. URL: https://www.forestry.gov.uk/PDF/FCBK047.pdf/$FILE/FCBK047.pdf
5. KEČA LJ, KEČA N, PANTIĆ D 2012 Net Present Value and Internal Rate of Return as indicators for assessment of cost-efficiency of poplar plantations: a Serbian case study. *Int For Rev* 14 (2): 1-12. DOI: https://doi.org/10.1505/146554812800923345
6. KEČA LJ, KEČA N 2012 Commercial Profitability of Poplar Plantation with Reference to the Damages Caused by Fungi. *South-east Eur for* 3 (1): 23-31. DOI: https://doi.org/10.15177/seefor.12-03
7. KEČA LJ, KEČA N 2014 Investment Appraisal in poplar Plantations in Serbia and it's Relations with Sustainable Land Management. *In*: Zlatić M, Kostadinov S (*eds*) Challenges: Sustainable Land Management - Climate Change. Advances in Geoecology 43, Catena Verlag GMBH, pp 287-297
8. KEČA LJ, PAJIĆ S 2010 Financial Aspects of Restoration in Poplar Plantations with Technology of Full Ground and Soil Preparation. International Conference "Land Conservation"- LANDCON 0905, Tara Mountain, Serbia, 26-30 May 2009. *In*: Zlatić M (*ed*) Global Change Challenges for Soil Management. Advances in Geology 41, Catena Verlag GmbH, pp 321-334
9. KEČA LJ, PAJIĆ S 2015 Costs and revenues in poplar plantations established using full ground and soil preparation in Serbia. *In*: Ivetić V, Stanković D (*eds*) Proceedings: International conference Reforestation Challenges. 03-06 June 2015, Belgrade, Serbia. Reforesta, pp 234-241
10. PRICE C 1993 Time, Discounting and Value. Blackwell, Oxford, UK
11. THOMPSON W A, VAN KOOTEN G C, VERTINSKY I 1997 Assessing timber and non-timber values in forestry using a general equilibrium framework. *Critical reviews in environmental science and technology* 27 (S1): 351-364
12. GILLIS A M 1990 The new forestry. *BioScience* 40 (8): 558-562
13. SNOWDON P, HAROU P 2014 Guide to Economic Appraisal of Forestry Investments and Programmes in Europe. EFI Technical Report 94, European Forest Institute, 31 p. URL: https://www.efi.int/sites/default/files/files/publication-bank/2018/tr_94.pdf
14. DAYANANDA D, HARRISON S, IRONS R, HERBOHN J, ROWLAND P 2002 Capital budgeting: financial appraisal of investment projects. Cambridge University Press, 344 p
15. GREGERSEN HM, CONTRERAS AH 1979 Economic analysis of forestry projects. FAO Forestry Paper 17, Rome, Italy, 193 p
16. SHARPE WF 2011 Investors and markets: portfolio choices, asset prices, and investment advice. Princeton University Press, Princeton, New Jersey, USA
17. LUMBY S 1988 Investment Appraisal and Financing Decisions. Third Ed. Van Nostrand Reinhold Co. Ltd, England
18. BRUEGGEMAN WB, FISHER JD 2011 Real estate finance and investments. McGraw-Hill Irwin (5-6), New York, NY, USA
19. ALIG RJ, ADAMS DM, MCCARL BA 1998 Impacts of incorporating land exchanges between forestry and agriculture in sector models. *Journal of Agricultural and Applied Economics* 30 (2): 389-401. DOI: https://doi.org/10.1017/S1074070800008373
20. PIKE RH, WOLFE MB 1988 Capital budgeting for the 1990's: a review of capital investment trends in larger companies. Chartered Institute of Management Accountants
21. ROW C, KAISER HF, SESSIONS J 1981 Discount rate for long-term Forest Service investments. *J Forest* 79 (6): 367-376. DOI: https://doi.org/10.1093/jof/79.6.367
22. BRUKAS V, THORSEN B J, HELLES F, TARP P 2001 Discount rate and harvest policy: implications for Baltic forestry. *Forest Policy Econ 2* (2): 143-156. DOI: https://doi.org/10.1016/S1389-9341(01)00050-8
23. GITTINGER P 1972 Economic Analysis of Agricultural Projects. The Economic Institute, International Bank for Reconstruction of Development, The John Hopkins University Press, Baltimore-London
24. 2005. Serbia and Montenegro: Selected Issues and Statistical Appendix. IMF, Country Report No. 05/232, Washington D.C., USA, 127 p
25. KLEMPERER WD, CATHCART JF, HÄRING T, ALIG RJ 1994 Risk and the discount rate in forestry. *Can J Forest Res* 24 (2): 390-397. DOI: https://doi.org/10.1139/x94-052
26. HAROU PA 1985 On a social discount rate for forestry. *Can J Forest Res* 15 (5): 927-934. DOI: https://doi.org/10.1139/x85-149
27. JOVANOVIĆ P 1999 Application of sensitivity analysis in investment project evaluation under uncertainty and risk. *Int J Project Man* 17 (4): 217-222. DOI: https://doi.org/10.1016/S0263-7863(98)00035-0
28. SQUIRE L, TAK HG 1979 Economic Analysis of Project. J. Hopkins, Baltimore, USA
29. CUBBAGE F, MAC DONAGH P, SAWINSKI J JR., RUBILAR R, DONOSO P, FERREIRA A, HOEFLICH, V, MORALES OLMOS V, FERREIRA G, BALMELLI G, SIRY J, NOEMI BAEZ M, ALVAREZ J 2007 Timber investment returns for selected plantations and native forests in South America and the Southern United States. *New Forests* 33 (3): 237-255. DOI: https://doi.org/10.1007/s11056-006-9025-4

30. HARDESTY SD, LEFF P 2010 Determining marketing costs and returns in alternative marketing channels. *Renew Agr Food Syst* 25 (1): 24-34. DOI: https://doi.org/10.1017/S1742170509990196
31. KEČA LJ 2010 Estimation of cost-effectiveness of poplar wood production in Ravni Srem by applying the net present value method. *Bulletin of the Faculty of Forestry University of Belgrade* 101: 81-100
32. KEČA LJ 2010 Assessment of cost-efficiency for wood production in poplar plantations in Ravan Srem, based on internal rate of return. *Bulletin of the Faculty of Forestry University of Belgrade* 102: 25-40
33. KEČA LJ 2011 Estimation of cost-effectiveness of poplar wood production in poplar plantations in ravni srem based on the method of pay back period. *Bulletin of the Faculty of Forestry University of Belgrade* 103: 41-56
34. KEČA LJ 2011 Estimation of cost-effectiveness of poplar wood production in poplar plantations in Ravni Srem based on the cost-benefit method. *Bulletin of the Faculty of Forestry University of Belgrade* 104: 81-96.
35. LAMBERT DM, COOPER MC, PAGH JD 1998 Supply chain management: implementation issues and research opportunities. *Int J Log Manag* 9 (2): 1-20. DOI: https://doi.org/10.1108/09574099810805807
36. KEČA LJ, KEČA N 2015 Market potential dynamics for plantation-grown poplar forest products in Serbia. *In*: Ivetic V, Stankovic D (*eds*) Proceedings of the International Conference Reforestation Challenges, Belgrade, Serbia. 3-6 June 2015,
37. KEČA LJ, KEČA N, AVDIBEGOVIĆ M 2014 Development of marketing activities in production of logs in Serbia. *In*: Parrotta JA, Moser CF, Scherzer AJ, Koerth NE, Lederle DR (*eds*) Proceedings of XXIV IUFRO World Congress "Sustaining Forests, Sustaining People: The Role of Research", Salt Lake City, Utah, USA 5-11 October 2014 ,

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

PRELIMINARY COMMUNICATION
DOI: https://doi.org/10.15177/seefor.18-15

The New Natural Distribution Area of Aspen (*Populus tremula* L.) Marginal Populations in Pasinler in the Erzurum Province, Turkey, and its Stand Characteristics

Halil Barış Özel[1], Sezgin Ayan[2]*, Serdar Erpay[1], Bojan Simovski[3]

(1) University of Bartın, Faculty of Forestry, TR-74100 Bartın, Turkey; **(2)** Kastamonu University, Faculty of Forestry, TR-37100 Kuzeykent, Kastamonu, Turkey; **(3)** Ss. Cyril and Methodius University in Skopje, Faculty of Forestry, Aleksandar Makedonski bb, MK-1000 Skopje, Republic of Macedonia

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

Citation: ÖZEL HB, AYAN S, ERPAY S, SIMOVSKI B 2018 The New Natural Distribution Area of Aspen (*Populus tremula* L.) Marginal Populations in Pasinler in the Erzurum Province, Turkey, and its Stand Characteristics. *South-east Eur for* 9 (2): 131-139. DOI: https://doi.org/10.15177/seefor.18-15

Received: 18 Oct 2018; **Revised:** 2 Dec 2018, 6 Dec 2018; **Accepted:** 9 Dec 2018; **Published online:** 22 Dec 2018

ABSTRACT

Background and Purpose: Genetic diversity is the basis for adaptation and survival of tree species under changing environmental conditions, representing the key issue of stability and productivity of forest ecosystems. This paper studies the marginal population characteristics and stand dynamics of aspen tree (*Populus tremula* L.) in natural, pure and mixed forest stands with Scots pine (*Pinus sylvestris* L.). These populations were observed on founding sites between Timarli Valley and Timan Plateau located in Pasinler in the Erzurum Province in Turkey.

Materials and Methods: Three replicated sample sites were established according to a randomised block design with a spacing of approximately 200 m in altitude starting from 1,890 m, which is the natural distribution area of *P. tremula*, up to 2,460 m, above which this species can no longer thrive. Timarlı Valley, Pasinler Erzurum Province, which is the area of research, is located enroute to Timan Plateau, where Scots pines form the alpine tree line ranging up to 2,680 m a.s.l.

Results: In this context, aspen trees in this region are the second closest tree species to the tree line after Scots pine, which are found in the subalpine and war zones. In addition, as a result of this study, it has been found out that this species, notwithstanding its natural area of occupancy across Turkey, could thrive up to 2,460 m in altitude and extent of occurrence.

Conclusions: A new marginal natural population related to aspen has been found in Pasinler in the Erzurum Province, Turkey, which at the same time indicates that the timberline value in the vertical natural distribution of these species should be updated. Aspen trees, which as pioneer trees play a vital role in the rebuilding or restoring of the ecological balance in forests that over time become degraded because of excessive cutting of trees and erroneous silvicultural interventions should be used in the reclamation of broadleaved and mixed forests in a planned manner. Genetic resources that represent marginal and peripheral populations, both within and outside the natural distribution area, should be established and protected.

Keywords: Aspen, Scots pine, stand characteristics, natural distribution, elevation, marginal population

INTRODUCTION

According to the latest statistics, forest area in Turkey covers up to 22.7 million ha [1]. It has been observed that many broadleaved and coniferous forest tree species in a forest area of this size have formed a wide geographical variation according to their natural distribution inclinations in different ecological conditions [2, 3]. The most prominent species in this wide geographical variation is aspen (*Populus tremula* L.). This tree species has a wide distribution area across Europe, West Asia and North Africa. *P. tremula* trees have cylindrical trunks, dense branches and wide conical crown, and they can grow up to 25 metres in height [4, 5]. Being one of the many pioneer species, aspen trees demonstrate fast growth followed up by strong root suckers. Although there are not many studies about aspen trees in Turkey, this species is reported to have a natural range all around Turkey where it forms mixed forests with broadleaved and coniferous species such as Scots pine, larch and fir at 2,000-2,350 metres a.s.l., excluding the steppes of Southeastern and Central Anatolia [4, 6]. Previous research on *P. tremula* also indicated that there are pure stands of this species across regions of Çanakkale-Yenice, Sarıkamış, Göle, Lake Van, Kayseri-Erciyes Mountain, Kahramanmaraş and Isparta. [7-9].

The limited number of studies conducted in Turkey, literature on forest trees in Europe, and especially EUFORGEN programme concerning the natural distribution area of these species did not record any information regarding aspen trees forming pure or mixed stands with Scots pine between 1,890-2,460 metres in the area of Timarlı Valley and Timan Plateau located in Pasinler in the Erzurum Province (Figure 1). In this research, the aim was to determine the stand characteristics of the marginal populations of pure and mixed forest stands with Scots pine of aspen trees found in Timarlı Valley and Timan Plateau. Additionally, a new natural distribution area of the aspen tree has been discovered.

MATERIALS AND METHODS

Material

The research was carried out in Timarlı Valley and Timan Plateau, on an altitude ranging from 1,890 to 2,460 m a.s.l. in Pasinler in the Erzurum Province. Coordinates of the investigation area are as follows: 40° 04ꞌ 25ꞌꞌ - 41° 43ꞌ 45ꞌꞌ and 40° 08ꞌ 24ꞌꞌ - 41° 44ꞌ 45ꞌꞌ (Figure 2).

The long-term climate data of 50 years of the research site have been analysed. As a result of the analyses, it was found that the lowest temperature at the research site was -23.6°C in January and the highest temperature 27.9°C in July. In addition, precipitation at the research site was measured as 69 mm in August (lowest) and 658 mm in May (highest). Vegetation period of the research site is five months (May-September) [10]. When the soil structure of the study area was examined, it was determined that the geological structure was formed mainly of metamorphic rocks from the Triassic-Cenomanian periods with varying age ranges. The stoniness rate of the surface of the research site is rather high with 73.2%, and the soil is of medium depth. Limestone is very common in this area and the rate of organic matter in the soil is rather low. Furthermore, the structure of the area is detrital and the soil texture is clayey-sandy-loamy. Both the soil consolidation and surface flow rating are higher on topsoil in this area [11].

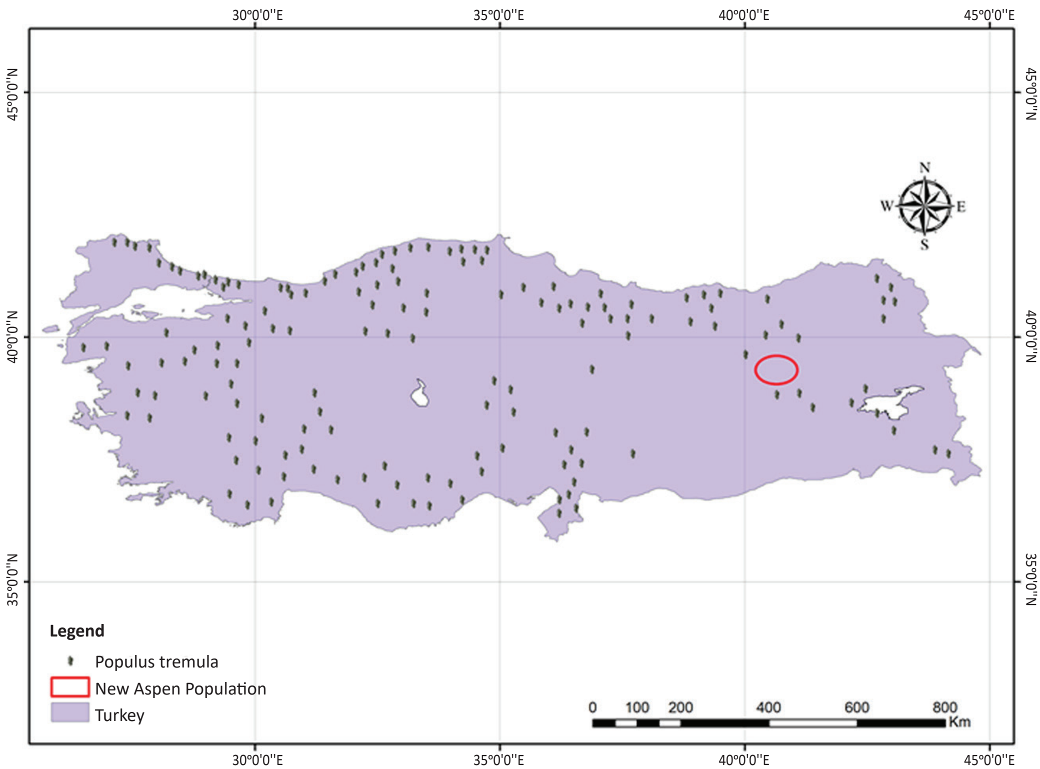

FIGURE 1. Natural distribution area (extent of occurrence, marked with red ellipse) of *Populus tremula* in Turkey [4].

FIGURE 2. Investigation area.

Method

The structural characteristics of both pure and mixed aspen - Scots pine stands have been investigated on four different altitudes, starting from Timarli Valley at 1,890 metres and ending with Timan Plateau at 2,460 metres in Pasinler in the Erzurum Province. In this context, three replicated sample sites, which consisted of pure *P. tremula* and mixed stands with Scots pine, were established according to randomised block design at 200 m intervals with 25x40 m spacing. The locations of the trees sample sites were determined with GPS devices and stand profile was prepared using Vector Packet Program. On the other hand, the physiographic conditions such as elevation, slope and aspect of stands on the sample sites were also determined with GPS devices. Furthermore, both aspen and Scots pine trees on the sample sites were measured with digital tree callipers and metres. Canopy cover value in the sample sites was measured with a spherical densitometer. The frequency of stands, site index and volume values were determined with the help of volume tables for aspen and Scots pine, presented by Bayburtlu [12] and Pehlivan [13] respectively. The increment core of one of the trees in the middle of the sample sites was removed just above the ground level to estimate the average age of the species (tree rings). Three replications in each altitude level were applied to determine tree age.

RESULTS AND DISCUSSION

During the research conducted in the investigation area, detailed data were collected from the sites. Table 1 presents the collected data of the four established sample sites with specific characteristics of both pure aspen and mixed forest stands with Scots pine.

TABLE 1. The characteristics of pure aspen and mixed forest stands with Scots pine in Pasinler in the Erzurum Province.

Sample stand	Altitude (m)	Aspect	Slope (%)	Canopy	Stand density	Site index	Average tree height (m)	Tree number (trees·ha^{-1})	Diameter (cm)	Mean volume (m^3·ha^{-1})
1st: Pure Aspen	1,890	NW	35.6	0.6	0.5	III	6.2	4,123	14.8	23.9-90.7
2nd: Pure Aspen	2,100	NE	47.2	0.7	0.5	III	4.7	3,080	12.8	21.8-43.2
3rd: Mixed Aspen & Scots pine	2,270	N	45.7	0.5	0.3	III	4.2 5.6	2,976	8.3 11.7	14.6-20.2 21.8-49.4
4th: Mixed Aspen & Scots pine	2,460	N	41.6	0.8	0.7	III	4.5 5.3	3,150	6.7 9.2	9.2-14.3 28.6-62.5

The first sample site designated for this research consisted of pure stands of aspen trees formed at 1,890 metres (Figure 3). This stand was located on a middle slope position. It was a single layered stand, and the average age of even-aged aspen individuals was 23.

Mean volume of pure aspen stands with poor yield rating in a similar sample site with extreme habitat conditions located in Norway at 1,910 metre altitude was reported to be between 19.8-126.7 $m^3 \cdot ha^{-1}$ [14]. According to this comparative analysis, the state of development of the pure aspen stand studied in this research area at the mentioned altitude level, notwithstanding the prevailing extreme habitat conditions of the area, could be said to be satisfactory.

The second sample site designated for this research was established at 2,100 metres, 200 m higher in altitude than the first sample site (Figure 4). This stand was located on a steep slope position on north-east aspect (Table 1). It was a single layered stand, and the average age of even-aged aspen individuals was 15 years.

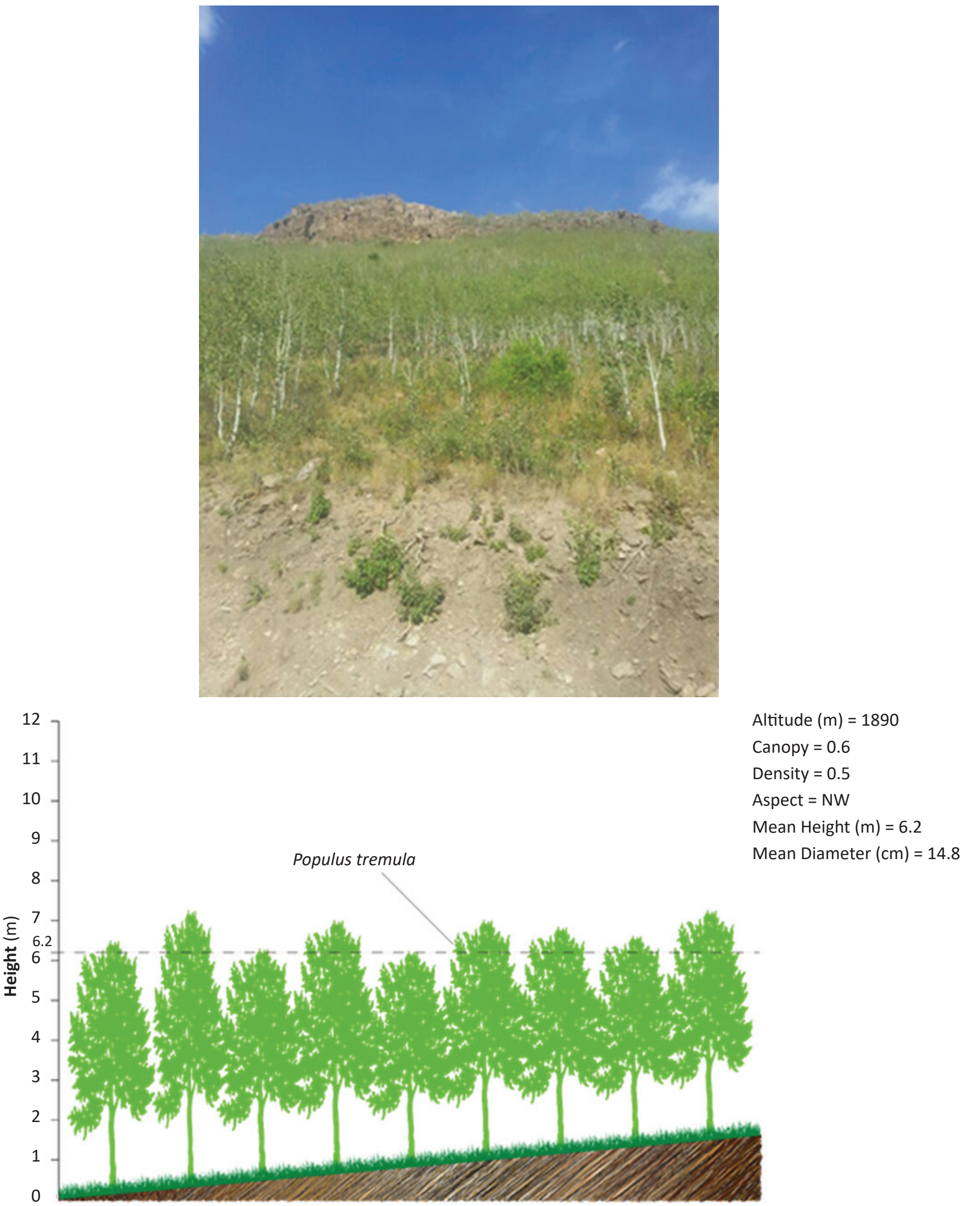

FIGURE 3. Profile of pure *Populus tremula* stand at the first altitude level (1,890 m.a.s.l.).

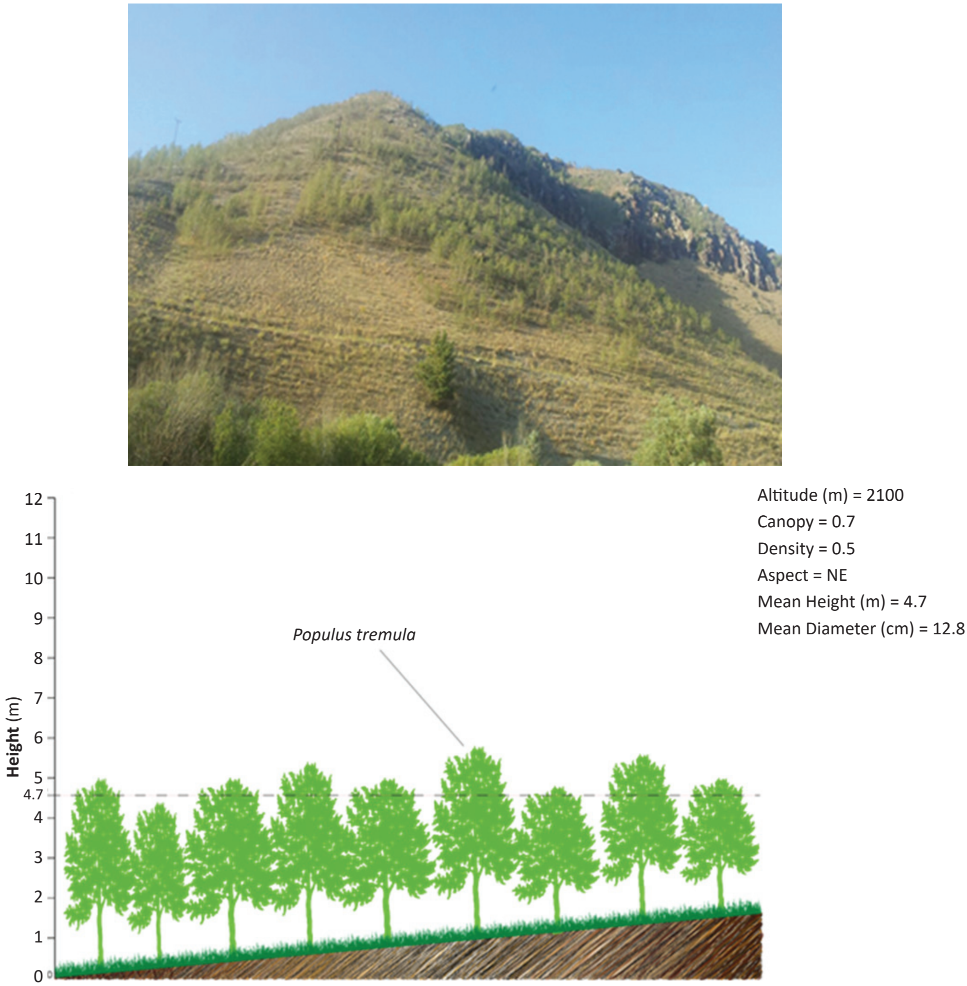

FIGURE 4. Profile of a pure *Populus tremula* stand at the second altitude level (2,100 m.a.s.l.).

The average volume of aspen trees in a research conducted in Russia at 2,165 metres altitude was reported to be between 17.4-56.7 $m^3 \cdot ha^{-1}$. According to this research, high winds in the mentioned altitude and a large portion of snowfall in the region caused the trees to split and fall on. Therefore, they had intense negative effects on the remaining aspen stand in the sample site [15]. Similar to this research, it has been found that in the current sample site, above 2,000 m, especially at 2,100 m, there was a significant increase in the number of fallen trees. In addition, a sudden decline in the soil depth has been observed, and the parent material has been found too close to the surface at many points. Even in these negative circumstances, the protection, resistance and vitality of the pure aspen stand was found to be very satisfactory. Even though the volume of this stand is rather low, it plays a vital role in the prevention of landslides, erosion and avalanches that might occur at 2,100 m a.s.l., considering the high slope of the terrain.

The next sample site was established at 2,270 m a.s.l. (Figure 5).

Scots pine trees form a mixed stand with aspen trees on an individual basis starting from 2,180 m. However, the altitude at which they join up with aspen trees as clusters and groups at a rate of 10% or higher is at 2,270 m. The stand was located on a medium slope position. Average ages of the aspen and Scots pine trees were 18 and 24 years, respectively. The mean number of Scots pine in the site was 1,584 (Table 1). It was as double layered stand with Scots pine on the top, and aspen trees in the intermediate layer. The volume of aspen trees at this altitude level was measured between 14.6-20.2 $m^3 \cdot ha^{-1}$. The volume of Scots pine trees at the same site was between 21.8-49.4 $m^3 \cdot ha^{-1}$. This indicates that aspen trees, while being among pioneer species, have started to lose their dominance to Scots pine in the mixed stand. Moreover, a research conducted in the forests mixed with European spruce trees (*Picea abies* (L.)

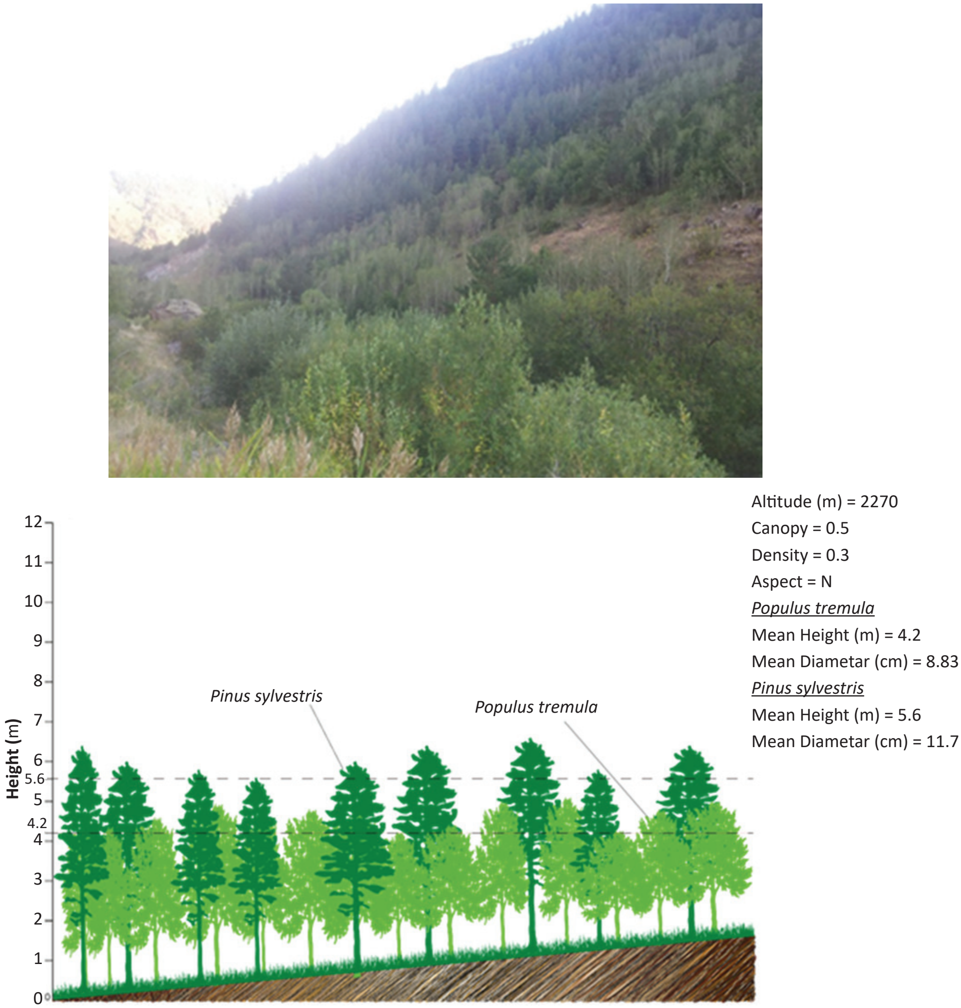

FIGURE 5. Profile of *Populus tremula* and *Pinus sylvestris* stands at third altitude level (2,270 m a.s.l.)

Karst) in Lithuania has shown that the number and density of aspen trees decreased significantly at 2,300 m and at higher altitudes when they became part of a mixed stand with European spruce trees. The average number of aspen trees were reported to be between 2,856-3,579, lesser than that of European spruce trees. The research in question has also revealed that in regions where double-layered structures were often predominating, the European spruce trees started to gain dominance over other trees from an early age, thanks to their fast growth rate [16].

The last sample site was established on Timan Plateau at 2,460 m a.s.l. (Figure 6).

The highest and last altitude, at which a sample site was established according to 200 m altitude intervals determined within the context of this research, was 2,460 m. It was located on a high slope position (Table 1). Average tree ages of aspen and Scots pine were 13 and 19 years, respectively. The mean number of aspen and Scots pine at the site was 1,016 and 2,134. It was structured as a double-layered stand with Scots pine on top, and with aspen trees in the intermediate layer. Scots pine trees alone form the alpine tree line on Timan Plateau, at 2,680 m.

In this context, the aspen trees in this region are the second closest tree species to the tree line after Scots pines, which are found in the subalpine and war zones. Indeed, according to a number of studies concerning the silviculture of trembling aspen trees, it was reported that this species of aspen trees, thanks to their resilient nature, are able to form tree lines in their natural distribution areas or grow up to subalpine layers [17-19]. Similarly, a research carried out in Canada concerning a forest with broadleaved trees at 2,532 m has shown that aspen trees are able to thrive in war zones, and that they could grow up to the subalpine layer. The number of aspen trees per ha in this region was reported to be between 897 and 1,153. In this research, as is the case in our research as well, aspen trees were found to retreat into the intermediate layer, and their trunk and top structures began to deform [20, 21]. In the light of these evaluations, a new natural distribution area of trembling aspen trees, one that has no mention in literature concerning this specific species in Turkey, has been discovered in the area between Timarlı Valley and Timan Plateau, at varying altitude levels. Stand statistics and stand profiles of pure and Scots pine mixed stands of aspen trees in this new natural distribution area were drawn.

As a result of this study, a cross-section of pure aspen and Scots pine mixed stands of aspen trees between Timarlı Valley and Timan Plateau has been made (Figure 7).

As it can be seen in Figure 7, aspen trees form pure and Scots pine mixed stands all around the sample site. In addition, when the literature on aspen trees in Turkey is analysed, it can be seen that the vertical altitude level of these species is between 2,200 (lowest) and 2,350 (highest) [4, 5, 22]. Also, as a result of this study, it has been found out that aspens, notwithstanding their natural distribution areas across Turkey, could thrive up to 2,460 m in altitude.

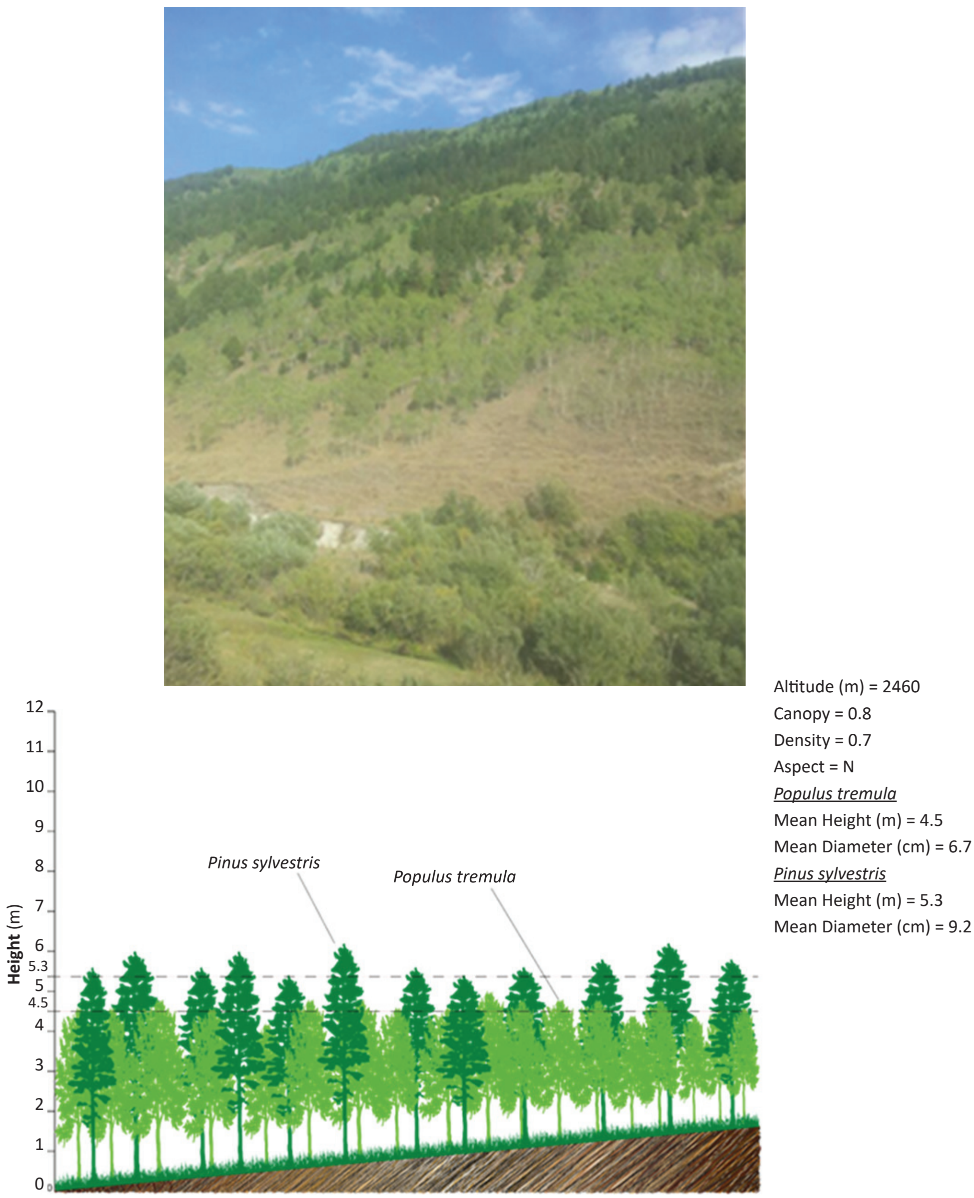

FIGURE 6. Profile of *Populus tremula* and *Pinus sylvestris* stands at fourth altitude level (2,460 m.a.s.l.).

This shows that a new marginal natural population related to aspen trees has been detected in Pasinler in the Erzurum province, which at the same time indicates that the upper limit value in the vertical natural distribution of these species should be updated. In this context, an important contribution has been made to updating the research-based information concerning aspen trees [23, 24], which is an important forest tree species in Turkey, and which has important features such as fast growth and strong root shoots, as well as being one of the pioneer species.

CONCLUSIONS

As a result of this study, a new natural distribution area of aspen, one that was not mentioned in previous and recent research in Turkey, has been discovered in the area between Timarlı Valley and Timan Plateau in Pasinler in the Erzurum province. Furthermore, the upper limit of the altitude, where this specific species of aspen could thrive, was updated to 2,460 ms. Considering the insufficient forest percentage in the region, the extreme climate and conditions of the habitat and landslide, erosion and avalanche risks that may arise therefrom, the use *P. tremula* is of utmost importance for the protection of residential and agricultural areas in the region, and for ensuring the conservation and continuity of aspen trees. In this context, it can be seen that *P. tremula*, which has a wide geographic variation, is a very robust species of aspen that can thrive in arid areas as well as wetlands. The widespread use of aspen trees in afforestation endeavours in habitats with extremities, mainly semi-arid, arid and steppe areas, will be beneficial for the reproduction of new forests across Turkey. Although they are not as resilient against the early/late frosts as birch (*Betula* spp.) and Scots pine trees, aspen trees have shown extraordinary resilience against frost in areas with extreme winter conditions, such as at the sample site. Aspen, which as a pioneer tree plays a vital role in the rebuilding or restoring the ecological balance in forests that have over time become degraded because of excessive cutting of trees and erroneous silvicultural interventions, should be used in the reclamation of broadleaved and mixed forests in a planned manner. In areas where forest degradation has taken place due to fires, snows and storms, aspen trees, due to of their fast growth and strong root shoots, should be used to restore the forest structure that has been damaged. In addition, genetic resources that represent marginal and peripheral populations, both within and outside the natural distribution area, should be established and protected.

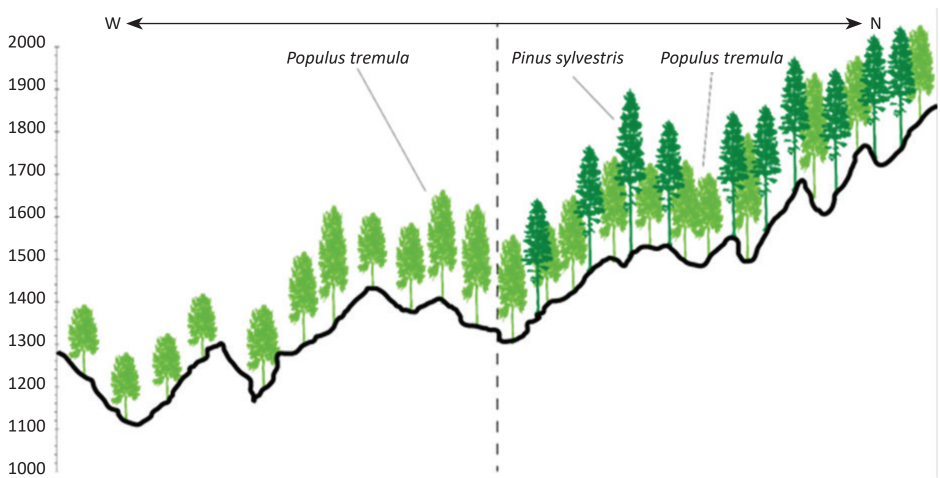

FIGURE 7. Cross-section of pure and mixed stands of aspen along the altitude levels (whole area).

REFERENCES

1. FAO 2018 The State of the World's Forests. Food and Agriculture Organization of the United Nations, Rome, Italy, 139 p
2. ÜRGENÇ S 1982 Forest Tree Breeding. University of İstanbul, Faculty of Forestry, No: 2836/293, İstanbul University Publisher, İstanbul, Turkey, 414 p
3. TUNÇTANER K 2007 Forest Genetic and Forest Tree Breeding. Turkish Forester Association, No: 4, Turkish Forester Association Publisher, Turkey, 364 p
4. YALTIRIK F 1993 Angiospermae. University of İstanbul, Faculty of Forestry, No: 3767/420, İstanbul University Publisher İstanbul, İstanbul, Turkey, pp 46-51
5. TUNÇTANER K 2008 Genetic Improvement and Selection of Poplars. Directorate of Research on Poplar and Fast Growing Forest Tree Species, No: 19, Directorate of Research on Poplar and Fast Growing Forest Tree Species Publisher, İzmit, Turkey, 268 p

6. SAATÇIOĞLU F 1969 Basic Principles of Silviculture. University of İstanbul, Faculty of Forestry, No: 1429/138, İstanbul University Publisher, İstanbul, Turkey, 323 p
7. ÖNER N, ASLAN S 2002 Technological Properties and Possible Uses of Trembling Poplar (*Populus tremula* L.) Wood. *Süleyman Demirel Üniversitesi Orman Fakültesi Dergisi* A (1): 135-146
8. KELEŞ H 2016 An Evaluation Natural Trembling Poplar (*Populus tremula* L.) Forests in Erciyes Mountain (Kayseri-Turkey). *Erciyes University Journal of Natural and Applied Sciences* 32 (3): 1-14
9. CAUDULLO G, DE RIGO D 2016 *Populus tremula* in Europe: distribution, habitat, usage and threats. *In*: San-Miguel-Ayanz J, de Rigo D, Caudullo G, Houston Durrant T, Mauri A (*eds*) European Atlas of Forest Tree Species. Publ. Off. EU, Luxembourg, pp e01f148
10. GDM 2017 Meteorological Data of Pasinler District (1967-2017). General Directorate of Meteorology Publisher, Ankara, Turkey, 12 p
11. BARIK K 2011 Effects of Barnyard Manure and Beet Pulp Addition on Some Soil Properties. Atatürk University. *Journal of Agricultural Faculty of Atatürk University* 42 (2): 133-138
12. BAYBURTLU Ş 2007 Contraction of Stem Volume Tables and Site Index Tables for Trembling Aspen. MSc Thesis, University of Karadeniz Technical, Faculty of Forestry, Trabzon, Turkey, 53 p
13. PEHLIVAN S 2010 Construction of Tree Volume Tables of Scots Pine (*Pinus sylvestris* L.). MSc Thesis, University of Karadeniz Technical, Faculty of Forestry, Trabzon, Turkey, 63 p
14. MYKING T, BØHLER F, AUSTRHEIM G, SOLBERG EJ 2011 Life History Strategies of Aspen (*Populus tremula* L.) and Browsing Effects: A Literature Review. *Forestry* 84 (1): 61-71. DOI: https://doi.org/10.1093/forestry/cpq044
15. SHOROHOVA E, KUULUVAINEN T, KANGUR A, JÖGISTE K 2009 Natural Stand Structures, Disturbance Regimes and Successional Dynamics in the Eurasian Boreal Forests: A Review with Special Reference to Russian Studies. *Ann For Sci* 66 (2): 201-220. DOI: https://doi.org/10.1051/forest/2008083
16. ROBALTE L, MATISONS R, ELFERTS D, BRÜMELIS G 2012 Natural Structures and Disturbances in an Old Growth Wet Norway Spruce Forest in The Nature Reserve Gruzdovas Mezi, Latvia. *Environmental and Experimental Biology* 10: 81-87
17. BØRSET O 1956 Silviculture of Aspen. *Scottish For* 14: 68-80
18. PETERSON EB, PETERSON NM 1992 Ecology, Management and Use of Aspen and Balsam Poplar in the Prairie Provinces. Forestry Canada Northwest Region Special Report 1, British Columbia, Canada, 252 p
19. SHEPPERD WD, ROGERS PC, BURTON D, BARTOS D 2006 Ecology, Biodiversity, Management, and Restoration of Aspen in The Sierra Nevada. United States Department of Agriculture (USDA) Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-178, Fort Collins, USA,124 p
20. ANONYMOUS 1994 Poplar Cultivation in Turkey, Directorate of Research on Poplar and Fast Growing Forest Tree Species Publisher, İzmit, Turkey, 268 p
21. BOKALO M, COMEAU PG, TITUS SJ 2007 Early Development of Tended Mixtures of Aspen and Spruce in Western Canadian Boreal Forests. *Forest Ecol Manag* 242 (2-3): 175-184. DOI: https://doi.org/10.1016/j.foreco.2007.01.038
22. TOPLU F, TUNÇTANER K, TULUKÇU M 1991 Investigation on Propagation with Cutting of Trembling Aspen. Directorate of Research on Poplar and Fast Growing Forest Tree Species Publisher, No: 154, İzmit, Turkey, 16 p
23. ÜÇLER AÖ 1994 Propagation with Tissue Culture Techniques of Trembling Aspen (*Populus tremula* L.) and Caucasian Lime (*Tilia rubra* DC.). PhD Thesis, University of Karadeniz Technical, Faculty of Forestry, Trabzon, Turkey, 113 p
24. BIRLER AS 2010 Propagation of Poplar in Turkey. Directorate of Research on Poplar and Fast Growing Forest Tree Species. Publisher, No: 22, İzmit, Turkey, 224 p

SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

PRELIMINARY COMMUNICATION

DOI: https://doi.org/10.15177/seefor.18-10

Characterization of *Eucalyptus maidenii* Timber for Structural Application: Physical and Mechanical Properties at Two Moisture Conditions

Marta Cristina de Jesus Albuquerque Nogueira[1], Victor Almeida De Araujo[2]*, Juliano Souza Vasconcelos[3], José Nilton da Cruz[4], Julio Cezar Souza Vasconcelos[5], Fabio Prataviera[5], André Luis Christoforo[6], Francisco Antonio Rocco Lahr[7]

(1) Federal University of Mato Grosso (UFMT), Department of Architecture, Av. Fernando Corrêa da Costa, BR-78060900 Cuiabá/MT, Brazil; **(2)** Research Group on Development of Lignocellulosic Products (LIGNO), Rua Geraldo Alckmin 519, BR-18409010 Itapeva/SP, Brazil; **(3)** São Paulo State University, Faculty of Agricultural Sciences (FCA-UNESP), Av. Universitária 3780, BR-18610034 Botucatu/SP, Brazil; **(4)** Federal University of Mato Grosso (UFMT), Department of Statistics, Av. Fernando Corrêa da Costa, BR-78060900 Cuiabá/MT, Brazil; **(5)** University of São Paulo (ESALQ-USP), Department of Exact Sciences, Av. Padua Dias 11, BR-13418900 Piracicaba/SP, Brazil; **(6)** Federal University of São Carlos (UFSCar), Department of Civil Engineering, Rod. Washington Luís, BR-13565905 São Carlos/SP, Brazil; **(7)** University of São Paulo (EESC-USP), Department of Structures Engineering, Av. Trabalhador Sãocarlense 400, BR-13566120 São Carlos/SP, Brazil;

* **Correspondence:** e-mail: engim.victor@yahoo.de

Citation: NOGUEIRA MCJA, DE ARAUJO VA, VASCONCELOS JS, DA CRUZ JN, VASCONCELOS JCS, PRATAVIERA F, CHRISTOFORO AL, LAHR FAR 2018 Characterization of *Eucalyptus maidenii* Timber for Structural Application: Physical and Mechanical Properties at Two Moisture Conditions. *South-east Eur for* 9 (2): 141-146. DOI: https://doi.org/10.15177/seefor.18-10

Received: 15 Mar 2018; **Revised:** 14 Jun 2018; 2 Jul 2018; **Accepted:** 6 Jul 2018; **Published online:** 7 Aug 2018

ABSTRACT

Background and Purpose: Eucalypt is an important raw material source of several industrial purposes. However, some eucalypt essences are still underutilized, possibly due to the lack of more embracing information about their properties. In this way, *Eucalyptus maidenii* species has presented a wide potential, and its lumber utilization is somewhat interesting. Nevertheless, a complete determination of its physical and mechanical properties, as carried out in this paper, certainly could encourage its popularization in construction.
Materials and Methods: *Eucalyptus maidenii* evaluation included two physical and fourteen mechanical parameters, regarding standard documents from Brazilian National Standards Organization (ABNT) and American Society of Testing Materials (ASTM). Thus, a simple comparison was established concerning the moisture content of wood samples, which were evaluated through two conditions: 30% as the initial level and a standard at 12%. All results were statistically evaluated by t-test. In sixteen parameters, 310 determinations were carried out.
Results: Half of mechanical properties presented significant changes in their resistances with the analysed moisture reduction. Modulus of rupture in static bending and in perpendicular compression, modulus of elasticity in perpendicular compression, strength in tangential cleavage, shear stress, and perpendicular and parallel hardnesses increased their resistances when the moisture content was reduced from 30% to 12%, that is, from green to dried standard stable point. Bulk density was also changed in the evaluated condition, decreasing to a smaller value. Volumetric mass density, modulus of rupture in parallel compression and in parallel and perpendicular tensiles, as well as modulus of elasticity in static bending and in parallel compression and tensile, and tangential toughness did not show any alteration in their values with this studied condition.
Conclusions: Lumber for civil construction needs to be suitable for efficient application, with air equilibrium, generally at 12% of moisture content as international normative documents require. As part of this, mechanical and physical properties/parameters were studied to characterize *Eucalyptus maidenii* wood regarding moisture content. The results obtained indicate the use of this essence from planted forests for structural purposes in construction.

Keywords: Maiden's Gum, wood density, strength modulus, cleavage, shear stress, hardness, toughness

INTRODUCTION

Eucalyptus maidenii F. Muell is commercially known as Maiden's Gum [1] or eucalypt maiden [2], as well as being widely recognized as "maidene eucalypt" in Latin American markets. This species occurs naturally in high-quality closed forests on sheltered slopes and gullies in good soils [1], among latitudes 34 and 39 S in altitudes from 230 to 915 meters, and its origin is along the Australian regions of southern New South Wales and northeastern Victoria [1, 3]. Maiden's Gum species is also found in Brazil [4, 5], Uruguay [6, 7], New Zealand [8-10], India [11], Portugal [5], Italy, Iberian Peninsula, Kenya, Malawi, Burundi [1], Tanzania [12], Uganda [13], Rwanda [14], etc. *Eucalyptus maidenii* is a tall to very tall forest tree usually 30 to 45 meters in height with a diameter of up to 2.5 meters, whose bark is smooth, whitish or cream, decorticating in strips to ground level, or sometimes with a short stocking of undecorticated rough bark [15]. Maiden's Gum trees could provide acid oils from their leaves [16] and their fruits [17] or medicines from their leaves [11], as well as extracts from their barks [18, 19]. Wood from Maiden's Gum has sapwood susceptible to *Lyctus* borer attack, and its light brown heartwood with pinkish to orange tints is hard, moderately strong and durable, coarse, uniform in texture, and with grain that is sometimes interlocked [1, 15]. *Eucalyptus maidenii* is usually applied for fuelwood [12], tannins [20], essential oils [20-22], pulp and paper [1, 8, 23], etc.

Maiden's Gum wood presents some good mechanical properties [24] and for that reason is recommended for heavy construction [1], products from sawmills, posts and poles [3]. Due to the *Eucalyptus maidenii* structural potentiality as sawn wood, the study aimed to explore physical and mechanical properties of this wood species at two different stable moisture contents, 30% and 12%, evaluating its reduction effect in a point close to the fiber saturation and other with respect to normative documents for structural applications.

MATERIALS AND METHODS

The wood species studied here was *Eucalyptus maidenii*, whose logs were collected in two Brazilian cities in São Paulo State to generate the wooden samples used in the tests (Table 1). A universal testing machine was used to perform the evaluation of properties.

To evaluate *Eucalyptus maidenii* as structural lumber, sixteen physical and mechanical properties were performed with small clear specimens, whose selection was based on defect absence. This testing followed the prescriptions of Brazilian ABNT NBR 7190:1997 [25] and American ASTM D-143-14:2014 [26] standards for the following properties: density (bulk and volumetric mass); perpendicular and parallel compressions, perpendicular and parallel tensiles, and static bending (in modulus of rupture and elasticity parameters); shear stress; cleavage (tangential); hardness (parallel and perpendicular); and toughness (tangential). Tangential orientation was selected due to strength in parallel direction to growth rings, and supported by an observation by Stolf *et al.* [27] claiming that there is no significant difference between radial and tangential toughnesses for dicotyledonous trees.

Similarly to Lahr *et al.* [28] and Nogueira *et al.* [29] studies, the samples used in these sixteen tests were prepared and conditioned for stabilization in both moistures at green (30%) and standard point (12%) in the Laboratory of Wood and Timber Structures (LaMEM) at the School of Engineering of São Carlos from the University of São Paulo (USP-EESC), São Carlos, Brazil. Furthermore, 310 determinations (or repetitions) were carried out in the aforementioned sixteen physical-mechanical parameters for the evaluation of *Eucalyptus maidenii*.

Ultimately, the obtained results by property were statistically verified with the analysis of t-test according to the significance level of 5% (P-value<0.05) to investigate the moisture content influence in the observed sixteen physical-mechanical properties of *Eucalyptus maidenii* wood. Through the hypothesis formulation, a P-value higher than the significance level implies accepting the null hypothesis, whose means of the two groups of moisture are equivalent, or rejecting it otherwise when the means are not equivalent.

RESULTS

Physical properties of density were verified and the obtained results are described in Table 2 with their respective statistical analyses.

Apart from the physical properties, 14 mechanical parameters were demonstrated with their statistical analyses (Tables 3, 4, and 5). Table 3 showed modulus of rupture results.

TABLE 1. Aspects of the *Eucalyptus maidenii* origin.

Log Amount	Beam Amount (unit)	Age (year)	Diameter (m)	Brazilian Region
1	2	28	0.260	Rio Claro (SP)
2	2	28	0.255	Manduri (SP)
3	2	28	0.240	Rio Claro (SP)
4	2	28	0.230	Rio Claro (SP)
5	2	28	0.255	Rio Claro (SP)

Table 4 indicated the obtained results and statistical analysis for modulus of elasticity of *Eucalyptus maidenii* wood.

Table 5 showed the obtained results for the last five strength properties, that is, shear stress, tangential cleavage, perpendicular and parallel hardnesses, and tangential toughness of the studied *Eucalyptus maidenii* wood species.

All listed tests were performed, revealing the successful obtaining of sixteen studied properties (Tables 2 to 5).

TABLE 2. *Eucalyptus maidenii* wood densities.

Characteristics	MC (%)	n	M_D	sd	P-value
Bulk Density ($g \cdot cm^{-3}$)	30	10	1.19	0.08	0.0003
	12	10	0.92	0.16	
Volumetric Mass Density ($g \cdot cm^{-3}$)	30	10	0.71	0.15	0.6277
	12	10	0.74	0.12	

TABLE 3. *Eucalyptus maidenii* wood modulus of rupture.

Characteristics	MC (%)	N	M_R	sd	P-value
Parallel Compression (MPa)	30	10	43.8	6.4	0.0978
	12	10	48.3	5.0	
Perpendicular Compression (MPa)	30	9	1.7	0.3	0.0032
	12	10	3.7	1.6	
Parallel Tensile (MPa)	30	9	93.6	24.8	0.4731
	12	8	83.7	29.9	
Perpendicular Tensile (MPa)	30	9	3.8	1.2	0.2537
	12	9	4.8	2.2	
Static Bending (MPa)	30	10	92	21.5	0.0000
	12	10	225	27.4	

TABLE 4. *Eucalyptus maidenii* wood modulus of elasticity

Characteristics	MC (%)	N	M_E	sd	P-value
Parallel Compression (MPa)	30	10	15564.0	5710.7	0.6302
	12	10	14431.0	4561.4	
Perpendicular Compression (MPa)	30	9	169.1	27.7	0.0029
	12	10	368.0	156.1	
Parallel Tensile (MPa)	30	9	16845.1	2787.1	0.2735
	12	8	18932.2	4411.7	
Static Bending (MPa)	30	10	13620.5	3994.8	0.1344
	12	10	16024.4	2692.2	

TABLE 5. Other strength properties of *Eucalyptus maidenii* wood.

Characteristics	MC (%)	n	M_{OP}	sd	P-value
Shear Stress (MPa)	30	10	11.7	1.9	0.0010
	12	10	17.2	3.7	
Tangential Cleavage (MPa)	30	10	0.64	0.21	0.0000
	12	10	1.16	0.22	
Perpendicular Hardness (kN)	30	10	7.34	1.62	0.0078
	12	10	10.03	2.29	
Parallel Hardness (kN)	30	10	7.48	3.31	0.0449
	12	10	10.08	1.69	
Tangential Toughness (N.m)	30	10	15.3	5.6	1.0000
	12	10	15.3	5.6	

DISCUSSION

Bulk density results indicated a decrease of 22.69% or 0.27 g·cm^{-3} in this property when the moisture contents of *Eucalyptus maidenii* samples were reduced from 30% to 12%. In contrast, the volumetric mass density slightly increased to 4.05% (0.03 g·cm^{-3}) with this same situation of moisture content reduction. With the support of t-test for these densities, we verified the bulk density and rejected the null hypothesis of mean equality, because of changes in moisture content from 30% to 12% showed significant difference in the obtained means (P-value<0.05). However, volumetric mass density did not present this null hypothesis rejection, which is explained by the independence of these means in relation to this reduction (Table 2). Comparing it with literature for *Eucalyptus maidenii* species from New Zealand, McKinley *et al.* [10] obtained nominal densities for 11-year-old wood between 600 and 760. This range is close, but lower, to the range showed in this study. This was expected, because their samples were younger than those 28-year-old woods studied here, that is, almost three times older and thus lightly denser.

Modulus of rupture results indicated increases of 9.32% or 4.5 MPa in the parallel compression, 54.05% (or 2 MPa) in perpendicular compression, 20.83% (1 MPa) in perpendicular tensile, and 59.11% (133 MPa) in static bending when the moisture contents of *Eucalyptus maidenii* samples were reduced from 30% to 12%. Even in this moisture content reduction, the parallel tensile presented a decrease of 10.58% (9.9 MPa). By the t-test analysis, we observed the perpendicular compression and static bending means and rejected the null hypothesis of equality means, whereas their means indicated significant difference when the moisture content was reduced from 30% to 12% (P-value<0.05). In contrast, parallel compression, and parallel and perpendicular tensiles did not reject the null hypothesis, i.e., their means did not present significant difference with the moisture decreasing (Table 3). In their study for 11-year-old *Eucalyptus maidenii* wood, McKinley *et al.* [10] reached two times lower modulus of rupture in static bending, likely due to this younger age and lower density.

Modulus of elasticity results indicated increases of 11.02% or 2087.1 MPa in parallel tensile and 54.05% (or 198.9 MPa) in perpendicular compression when the moisture contents of *Eucalyptus maidenii* samples were reduced from 30% to 12%. In such modulus, the moisture reduction caused decreases of 7.85% (1133 MPa) in parallel compression, and 15.00% (2403.9 MPa) in static bending. The t-test analysis applied in these modulus of elasticity showed only perpendicular compression which showed a significant difference in its means when the moisture content was reduced from 30% to 12%, due to the null hypothesis rejection (P-value<0.05). Successively, static bending, and parallel compression and tensile did not reject this null hypothesis, and due to these properties did not present significant differences in their means (Table 4). Thus, as compared to McKinley *et al.* [10], for 11-year-old *Eucalyptus maidenii* wood also at 12% of moisture content, the obtained results were one fifth higher than their modulus of elasticity in static bending, certainly, on account of the difference of age and density found in the two studies that focused on this particular species.

When the moisture content was reduced to 12% (dried and standard point), other strength property results indicated increases in tangential cleavage, shear stress, and parallel and perpendicular hardnesses in the amount of 44.83% (0.52 MPa), 31.98% (5.5 MPa), 25.79% (2.60 kN), and 26.82% (2.69 kN), respectively. Tangential toughness remained stable with the same value. The application of t-test in tangential cleavage, shear stress, and perpendicular and parallel hardnesses showed that these properties rejected the null hypothesis of mean equality, in other words, their moisture content revealed significant differences in their means when moisture content was reduced from 30% to 12% (P-value<0.05). Only modulus of tangential toughness did not present this significant difference in its means with this moisture reduction (Table 5).

In a study about the evaluation of *Eucalyptus urophylla* var. *maidenii* clones, Beltrame et al. [24] studied wood mechanical properties at 12% of moisture content. From values of rupture and elasticity modulus (both in static bending and parallel compression), and shear stress obtained by Beltrame *et al.* [24], it could be verified that this clone is mechanically similar to traditional *Eucalyptus maidenii* timber studied here. McKinley *et al.* [10] evaluated hardness of *Eucalyptus maidenii* 11-year-old wood, but did not evaluate shared specific direction, that is, parallel or perpendicular. In both cases, the obtained hardness was superior to that showed in their study, likely, due to their younger wood samples with lower densities.

Regarding those results that showed no effect with moisture content reduction, that is, volumetric mass density (Table 2), tensile strength parallel to fibers (Table 3), modulus of elasticity at parallel compression to fibers (Table 4), and tangential toughness (Table 5), these situations occurred possibly due to the grouped consideration of wood samples from five different farms (Table 1), that is, four forestry areas at Rio Claro city and another at Manduri city, both in São Paulo state, Brazil. This grouping was considered regarding of the exact age and eucalypt species from these five distinct plantations from the same Brazilian state region. However, such regard revealed three negative impacts and a neutral result (toughness), in contrast to other twelve positive effects verified with moisture reduction by this grouping.

There are cases, such as the one reported by Duarte [30], that the rupture can occur in fragile mode, resulting in a lower influence of moisture content in each studied mechanical property. In addition, eventual grain deviations are very common in eucalypts such as in maidenii [31]. Therefore, these two situations can be acceptable explanations to the observed negative effects, considering that specific property improvements were not captured by statistical analysis in view of these possible anatomical factors and rupture types from testing.

By adding value to forests by means of timber production used in prefabricated components employed in low-rise timber buildings, the reduction of wood utilization from native areas is required, for example, aiming at positive effects from forest management, which include the environment, the landscape, and the reduction of hydrogeological hazard [32]. At the same time, the popularization and correct utilization of wood, particularly those species available in planted forests, such as *Eucaliptus* spp, should be intensified [33].

Thereby, the study demonstrated that clear timber without perceptible defects of *Eucalyptus maidenii* species could be efficiently applied for lumber-based products and raw materials for construction, furniture and other structural uses, because its mechanical properties efficiently complied with the studied structural stress strengths at standardised moisture content. Popularization and correct use of wood from planted forests [32], such as *Eucalyptus maidenii*, according to Fragiacomo *et al.* [33], can contribute to the reduction of wood utilization from native areas, offering positive effects on the environment.

CONCLUSIONS

According to the results on clear pieces without perceptible defects, *Eucalyptus maidenii* wood species achieved required goals for its efficient utilization in structural applications, whereas woods from five forestry areas in São Paulo state were considered.

This forestry essence is raw material easily obtained from planted forests, and such eucalypt species demonstrated improvements in half of their mechanical strengths studied, when these properties were submitted to moisture reduction from 30% of fibre saturation point to 12% of air equilibrium prescribed by international normative documents for wood application in civil construction.

REFERENCES

1. FAO 1981 Eucalypts for planting. 2nd ed. Food and Agriculture Organization of the United Nations, Rome, Italy, 677 p. URL: http://www.fao.org/3/a-ac459e.pdf (15 March 2018)
2. MAIDEN JH 1922 The forest flora of New South Wales. 1st. ed. 7 (61-70). University of Sydney Library, Sydney, Australia
3. FERREIRA M 1979 Escolha de espécies de eucalipto. *IPEF* (47): 1-30. URL: http://www.almanaquedocampo.com.br/imagens/files/Eucal%C3%ADpto%20escolha%20de%20esp%C3%A9cies.pdf (15 March 2018)
4. SCHUMACHER MV, CALDEIRA MVW 2001 Biomass estimation and nutrient content of a *Eucalyptus globulus* (Labillardière) subspecie *maidenii* plantation (*in Portuguese with English summary*). *Ciencia Florestal* 11 (1): 45-53. DOI: https://doi.org/10.5902/19805098494
5. DOMINGUES RMA, SOUSA GDA, SILVA CM, FREIRE CSR, SILVESTRE AJD, PASCOAL NETO C 2011 High value triterpenic compounds from the outer barks of several Eucalyptus species cultivated in Brazil and in Portugal. *Ind Crops Prod* 33 (1): 158-164. DOI: https://doi.org/10.1016/j.indcrop.2010.10.006
6. PÉREZ CA, WINGFIELD MJ, ALTIER NA, SIMETO S, BLANCHETTE RA 2011 *Puccinia psidii* infecting cultivated *Eucalyptus* and native Myrtaceae in Uruguay. *Mycol Prog* 10 (3): 273-282. DOI: https://doi.org/10.1007/s11557-010-0698-x
7. SOTERO M, MONZA J 2007 Micropropagation of *Eucalyptus maidenii* elite trees. *Agrociencia* 11 (1): 81-89
8. KIBBLEWHITE RP, JOHNSON BI, SHELBOURNE CJA 2000 Kraft pulp qualities of *Eucalyptus nitens*, *E. globulus*, and *E. maidenii* at ages of 8 and 11 years. *N Z J For Sci* 30 (3): 447-457
9. STACKPOLE DJ, MCCONNOCHIE RM, DUNGEY HS, LOW CB, BURDON RD, KENNEDY SG 2013 Comparative performance of *Eucalyptus bicostata*, *E. globulus*, *E. maidenii* and *E. pseudoglobulus* on three northern New Zealand sites. *N Z J For Sci* 43 (6): 1-10. DOI: https://doi.org/10.1186/1179-5395-43-6
10. MCKINLEY RB, SHELBOURNE CJA, LOW CB, PENELLUM B, KIMBERLEY MO 2002 Wood properties of young *Eucalyptus nitens*, *E. globulus*, and *E. maidenii* in Northland, New Zealand. *N Z J For Sci* 32 (3): 334-356
11. PRABHU S, VIJAYAKUMAR S, YABESH JEM, RAVICHANDRAN K, SAKTHIVEL B 2014 Documentation and quantitative analysis of the local knowledge on medicinal plants in Kalrayan hills of Villupuram district, Tamil Nadu, India. *J Ethnopharmacol* 157: 7-20. DOI: https://doi.org/10.1016/j.jep.2014.09.014
12. ALLEN JC 1985 Wood energy and preservation of woodlands in semi-arid developing countries. *J Dev Econ* 19 (1-2): 59-84. DOI: https://doi.org/10.1016/0304-3878(85)90039-2
13. NYEKO P, MUTITU EK, DAY RK 2009 *Eucalyptus* infestation by *Leptocybe invasa* in Uganda. *Afr J Ecol* 47 (3): 299-307. DOI: https://doi.org/10.1111/j.1365-2028.2008.01004.x
14. NSABIMANA D, KLEMEDTSON L, KAPLIN BA, WALLIN G 2009 Soil CO_2 flux in six monospecific forest plantations in Southern Rwanda. *Soil Biol Biochem* 41 (2): 396-402. DOI: https://doi.org/10.1016/j.soilbio.2008.12.004
15. BOLAND DJ, BROOKER MIH, CHIPPENDALE GM. HALL N, HYLAND BPM, JOHNSTON RD, KLEINIG DA, MCDONALD MW, TURNER JD 2006 Forest trees of Australia. 5th ed. Csiro Publishing, Collingwood, Australia, 768 p
16. TIAN LW, ZHANG YJ, WANG YF, LAI CC, YANG CR 2009 Eucalmaidins A–E, (+)-oleuropeic acid derivatives from the fresh leaves of *Eucalyptus maideni*. *J Nat Prod* 72 (9): 1608-1611. DOI: https://doi.org/10.1021/np900290s
17. TIAN LW, ZHANG YJ, QU C, WANG YF, YANG CR 2010 Phloroglucinol glycosides from the fresh fruits of *Eucalyptus maideni*. *J Nat Prod* 73 (2): 160-163. DOI: https://doi.org/10.1021/np900530n
18. SANTOS SAO, VILLAVERDE JJ, FREIRE CSR, DOMINGUES RM, PASCOAL NETO C, SILVESTRE AJD 2012 Phenolic composition and antioxidant activity of *Eucalyptus grandis*, *E. urograndis* (*E. grandis×E. urophylla*) and *E. maidenii* bark extracts. *Ind Crops Prod* 39: 120-127. DOI: https://doi.org/10.1016/j.indcrop.2012.02.003
19. LUIS Â, NEIVA D, PEREIRA H, GOMINHO J, DOMINGUES F, DUARTE ÂP 2014 Stumps of *Eucalyptus globulus* as a source of antioxidant and antimicrobial polyphenols. *Molecules* 19 (10): 16428-16446. DOI: https://doi.org/10.3390/molecules191016428
20. BALACS T 1997 Cineole-rich *Eucalyptus*. *Int J Aromather* 8 (2): 15-21. DOI: https://doi.org/10.1016/S0962-4562(97)80020-3

21. GUNDIDZA M, CHINYANGANYA F, MAVI S 1993 Antimicrobial activity of the essential oil from *Eucalyptus maidenii*. *Planta Med* 59 (1): 705-706. DOI: https://doi.org/10.1055/s-2006-956515
22. ROH HS, LEE BH, PARK CG 2013 Acaricidal and repellent effects of myrtacean essential oils and their major constituents against *Tetranychus urticae* (Tetranychidae). *J Asia Pac Entomol* 16 (3): 245-249. DOI: https://doi.org/10.1016/j.aspen.2013.03.001
23. RENCORET J, GUTIÉRREZ A, DEL RIO JC 2007 Lipid and lignin composition of wood from different eucalypt species. *Holzforschung* 61 (2): 165-174. DOI: https://doi.org/10.1515/HF.2007.030
24. BELTRAME R, PERES ML, DELUCIS RA, FREITAS DL, GATTO DA, HASELEIN CR 2015 Longitudinal growth stress and mechanical properties of wood from *Eucalyptus* spp. clones (*in Portuguese with English summary*). *Matéria (Rio J)* 20 (4): 1061-1074. DOI: https://doi.org/10.1590/S1517-707620150004.0108
25. ABNT NBR 7190 1997 Design of wooden structures (*in Portuguese with English summary*). Brazilian National Standards Organization, Rio de Janeiro, Brazil
26. ASTM D143-14 2014 Standard test methods for small clear specimens of timber. American Society of Testing Materials, West Conshohocken, USA.
27. STOLF DO, BERTOLINI MS, ALMEIDA DH, SILVA DAL, PANZERA TH, CHRISTOFORO AL, LAHR FAR 2015 Influence of growth ring orientation of some wood species to obtain toughness. *REM: Rev Esc Minas* 68 (3): 265-271. DOI: https://doi.org/10.1590/0370-44672014680018
28. LAHR FAR, NOGUEIRA MCJA, DE ARAUJO VA, VASCONCELOS JS, CHRISTOFORO AL 2017 Physical-mechanical characterization of *Eucalyptus urophylla* wood. *Eng Agric* 37 (5): 900-906. DOI: https://doi.org/10.1590/1809-4430-Eng.Agric.v37n5p900-906/2017
29. NOGUEIRA MCJA, ALMEIDA DH, VASCONCELOS JS, ALMEIDA TH, ARAUJO VA, CHRISTOFORO AL, LAHR FAR 2018 Properties of *Eucalyptus umbra* wood for timber structures. *International Journal of Materials Engineering* 8 (1): 12-15. DOI: https://doi.org/10.5923/j.ijme.20180801.03
30. DUARTE BB 2017 Influência de componentes químicos em propriedades mecânicas da madeira (*in Portuguese with English summary*). PhD thesis, School of Engineering of São Carlos, University of São Paulo, São Carlos, Brazil, 127 p
31. NOGUEIRA MCJA 1991 Indicações para o emprego de 16 espécies de eucalipto na construção civil (*in Portuguese with English summary*). MSc dissertation, School of Engineering of São Carlos, University of São Paulo, São Carlos, Brazil, 150 p
32. DE ARAUJO VA, GARCIA JN, CORTEZ-BARBOSA J, GAVA M, SAVI AF, MORALES EAM, LAHR FAR, VASCONCELOS JS, CHRISTOFORO AL 2017 Importance of wood from planted forests for manufacturing industry (*in Portuguese with English summary*). *Pesq Flor Bras* 37 (90): 189-200. DOI: https://doi.org/10.4336/2017.pfb.37.90.824
33. FRAGIACOMO M, RIU R, SCOTTI R 2015 Can structural timber foster short procurement chains within Mediterranean forests? A research case in Sardinia. *South-east Eur For* 6 (1): 107-117. DOI: https://doi.org/10.15177/seefor.15-09

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

PRELIMINARY COMMUNICATION

DOI: https://doi.org/10.15177/seefor.18-11

Biomorphology of Spruce Trees as a Diagnostic Attribute for Non-Destructive Selection of Resonant Wood in a Forest

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

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

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

Citation: FEDYUKOV VI, SALDAEVA EY, CHERNOVA MS, CHERNOV VY 2018 Biomorphology of Spruce Trees as a Diagnostic Attribute for Non-Destructive Selection of Resonant Wood in a Forest. *South-east Eur for* 9 (2): 147-153. DOI: https://doi.org/10.15177/seefor.18-11
Received: 20 Feb 2018; **Revised:** 3 May 2018; 19 Jul 2018; **Accepted:** 27 Jul 2018; **Published online:** 11 Sep 2018

ABSTRACT

Background and Purpose: Nowadays selection of resonant raw material in forests is not practically carried out; there are no standards and samples for a tree with such timber, and, consequently, rational target use of this unique natural material is not achieved. Thereof a lot of valuable wood remains in forests or is harvested for utilizing as general-purpose forest products or firewood. The research is focused on the studies of interrelation of resonant properties of wood and its biomorphological attributes such as crown diameter and height, trunk habitus, branchless zone extension, etc.

Materials and Methods: Test material for the research of dendroacoustic parameters were cross-section radial cores 4.0 mm in diameter selected with an increment borer at breath height from 16 model trees after cutting them down. Simultaneously, diameters of trunks at relative heights (H) of 0.2H, 0.5H and 0.7H, as well as branchless zone extension and tree crown parameters (its extension, first alive knot fastening height, etc.) were defined. Then, the interrelation was revealed between the biometric data of a tree trunk and average sound velocity measured across the trunk with UK-14П ultrasonic device at different relative heights.

Results: The results submitted in this paper present practical value and assess the accuracy of standing spruce wood resonant properties' forecasting based on its 'wood study portrait' parameters.

Conclusions: Acoustic properties of wood depend on biomorphology of a tree as well. The parameters of stem tapering, trunk volume and especially branchless zone extension and crown elevation have, to any extent, the greatest practical value for standing resonant raw material express diagnostics.

Keywords: sonorous spruce, tree biomorphology, the macrostructure of wood, density, acoustic constant, dendroacoustic parameters identification

INTRODUCTION

Wood quality is initially predetermined by the biology of a certain tree, including the breed and other hereditary-genetic, i.e. 'intrinsic' biotic factors. In the process of growth and development, a tree cannot remain indifferent to the influence of all external, abiotic factors influencing wood quality as well. These can be soil-climatic conditions, changes of light and temperature modes in the action of the planting itself, consequences of human intervention into the forest's life by its thinning, all types of reclamation, etc. After all, wood quality is formed under the complex action of internal and external factors [1-3].

Individual-genetic (hereditary) factors undoubtedly prevail in wood quality formation in general, not to mention the features of physical and mechanical properties, macro- and micro- structure. Despite the substantial polymorphism of spruce trees, hereditary factors prove themselves as rather stable through external biomorphological attributes of a tree: type of branching and crown form, bark color and structure, trunk habitus, etc. [1, 4-8]. It is impossible to find reliable data on the use of these attributes by Stradivari and other masters of the Old Italian school in selection of wood for manufacturing unique musical instruments. However, it is wrong to exclude this, as later and modern ways of standing resonant wood quality by visual estimation apply the above-mentioned attributes.

Other important factors are visual appearance and tree condition. Among modern masters there is a point of view that a spruce tree selected for the manufacturing of musical instruments should meet the following requirements: it should (a) be absolutely vertical; (b) have symmetric, narrow and spiry crown; (c) have a trunk with a cylindrical surface and branchless zone not less than 5-6 meters; and (d) not contain other visible defects and damages.

Thicker trunks are in demand: if the diameter at breath height is less than 35 cm, i.e. at the age of less than 100-120 years, the use of such a tree as a source of resonant material [9] is considered counterproductive [10]. It is not difficult to guess that such requirements for a 'resonant' tree are imposed, first of all, by technological and economic reasons, considering maximal output of industrial assortment and parameter limits of the assortment for manufacturing decks of a musical instrument. Grapini [11] specifies more detailed data for resonant spruce: (a) the crown is in the form of a column, almost symmetric, gradually decreases from the basis to the top at an angle of 30-40° and is formed by thin branches running mainly downwards; (b) the branches from the third part of the middle and the bottom of a crown are attached to the trunk at an angle of 30-40°; large branches are arranged in clusters, and besides there are branches outside the clusters as well; (c) the second order branches are rather rare, thin, long, hanging down, ash-gray-green; (d) the third order branches are also rare, thin, but light green; and (e) needles are evenly distributed along the branch, but are never heaped up at the top, as in some forms of spruce. A lot of individual masters also consider descending branches to be an attribute of a resonant spruce [7, 8, 11]. Special value is set on the fact that it 'is not warped'. It is determined by attentive inspection of the tree from the view point of branch clusters arrangement, bark cracks, etc., which requires considerable experience.

Furthermore, bark structure and color are morphological attributes of spruce that are often used by masters selecting the material for manufacturing musical instruments both on root and in round assortments. However, there is no general opinion about any specific attribute undoubtedly acceptable as a diagnostic one. This is probably related to strong variability of the attributes specified, which also correlate with biological and ecological features of individual trees [1]. Imperfection (or even absence) of a uniform method of express diagnostics of standing wood acoustic properties is caused by the elements of subjectivity in conclusions based on the results of observations by different authors, especially regarding different soil, climatic and geographical environment.

According to Redulescu [12], the bark of a resonant spruce-tree should be grey and should consist of rather small and smooth scales. Gavris [4] and Yablokov [13] also recommended the selection of plus spruce trees with smooth bark forms (lowland, as the authors confirm) as resonant. Bagayev and Alexandrov [1] believe that smooth-barked spruce-trees with narrow crown of both Norway and Siberian species have the best resonant properties.

Sankin [8] conducted a thorough study on the relations between variability of macrostructure, anatomical structure of wood, and physical, mechanical and acoustic properties depending on spruce tree bark appearance in the environment of the Vologda Region of Russia. Having studied the trees of two groups (with platy and scaly bark), he came to a conclusion that spruce with scaly bark is preferable since it possesses greater genetic plasticity. Meanwhile, the relationship of late wood percentage and annual ring width with wood density, dynamic modulus of elasticity and acoustical constant is equally strongly expressed in both groups.

Basing on such biomorphological preconditions, some scientists consider that there is a certain phylogenetic biotype of resonant spruce [11, 13]. To prove this hypothesis it is possible to recall a well-known fact: not each tree, even of the same breed and within a particular taxon, possesses necessary wood dendroacoustic parameters; in other words, 'musicality' of one tree does not guarantee that all trees of the same breed in the neighborhood have such wood.

Therefore, studies represent not only theoretical, but also concrete practical interest for the selection of qualitative material for manufacturing musical instruments.

MATERIALS AND METHODS

When searching for an objective biomorphological attribute, we decided upon the seed scales on trunk habitus and tree crown parameters.

Test material for the research of dendroacoustic parameters were cross-section radial cores 4.0 mm in diameter selected with an increment borer at breath height from 16 model trees of spruce (*Picea abies* (L.) Karst.) at the age of 120-140 years. They were selected in the north of Kirov region of Russia after having been cut. Simultaneously, diameters of trunks at relative heights (H) of 0.2H, 0.5H and 0.7H, as well as branchless zone extension and tree crown parameters (its extension, first alive knot fastening height, etc.) were defined. The method of standing resonant wood revealing against the cores has been introduced abroad [14] and in Russia [9] relatively recently.

As a rule, wood structure is different along the length of a radial core and, accordingly, wood physical and mechanical parameters in medullar parts and in sapwood are also different. This distinction is well noticeable even with a naked eye, first of all, when judging from wood macrostructure: narrow annual rings are in trunk peripheral zone and wide ones are close to juvenile central zone (Figure 1a).

Rather homogeneous wood between undercork and near-core zones is usually taken for deck manufacturing. In view of this, we studied this part of a trunk along the radius, conditionally denoted on cores as a 'working' zone (Figure 1b).

Basic physical and dendroacoustic properties of wood – humidity, density, macrostructure, and ultrasound velocity

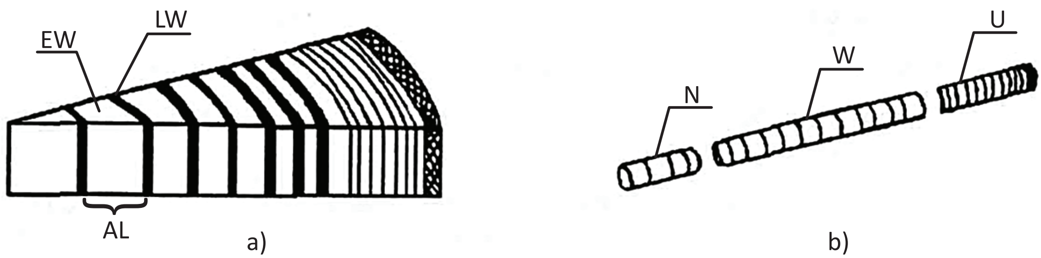

FIGURE 1. General view of wood macrostructure according to the trunk zone: **a)** elements of wood macrostructure (EW - early wood; LW - late wood; AL - annual ring); **b)** scheme of core division according to zones (N - near-core zone; W - working zone; U - undercork zone).

– were defined in laboratory environment. The research was carried out in the laboratory of resonant wood qualimetry of the Volga State University of Technology. To ensure the accuracy of performing ultrasound studies the samples of wood were kept at standard conditions, i.e. at 20°C and relative air humidity of 65%. The general order of complex research is presented in Figure 2.

The macrostructure of wood was studied with an electronic dendrometer, whose principle of action is based on the assessment of early (b_1) and late (b_2) wood zone width in annual rings according to their microhardness [15].

Sound velocity in wood (C) was assessed by a pulse ultrasonic method by fixing the time (τ) of elastic longitudinal wave propagation along the sample (l):

$$C = l/\tau \qquad (1)$$

It should be noted, that 60 kHz piezoelectric transducer optimal for wood study was used in the device.

Sound velocity in the material (C), and its density (ρ) given, it is possible to assess Young's dynamic modulus (E_{dyn}), on the basis of the following known ratio:

$$C = \sqrt{\frac{E_{dyn}}{\rho}}\text{, then } E_{dyn} = C^2 \cdot \rho \qquad (2)$$

It is known that today the acoustic constant of sound radiation (K) suggested by academician N.N. Andreyev is accepted as the basic criterion of 'musicality' of a given material in many countries:

$$K = \sqrt{\frac{E}{\rho^3}} \qquad (3)$$

Threshold value is $K \geq 12.0$ $m^4 \cdot kg^{-1} \cdot cm^{-1}$ for resonant wood in a longitudinal direction along fibers, and under cross-section radial measurements $K \geq 3.5$ $m^4 \cdot kg^{-1} \cdot cm^{-1}$ [16].

Small transformations and joint solution of equations 2 and 3 allow to define the size of acoustical constant K through C and ρ:

$$\begin{cases} K = \sqrt{\dfrac{E}{\rho^3}} \\ C = \sqrt{\dfrac{E}{\rho}} \end{cases} \Rightarrow \quad K = \frac{C}{\rho} \qquad (4)$$

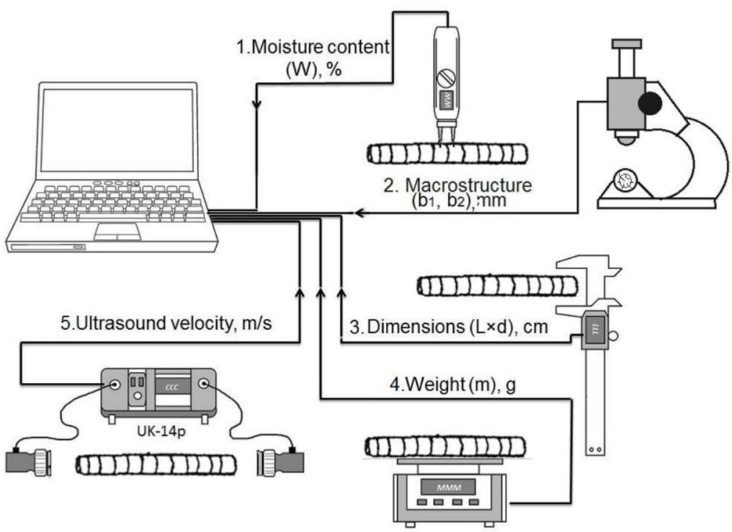

FIGURE 2. Principle diagram of experimental measurements.

Thus, the physical essence of resonant wood represents combination of incongruous properties, i.e. high parameters of rigidity, sound velocity and low density.

RESULTS AND DISCUSSION

Over the last years scientists around the world have become more active in studying acoustic and elastic properties of coniferous wood, both standing and in assortments [2, 17-19]. However, they do not touch upon the interrelation between acoustic properties of wood and biomorphology of a tree.

We studied the influence of absolute and relative tree morphology parameters on average velocity of sound in a trunk. Tree height, crown diameters in latitudinal and longitudinal directions and their mean values, branchless zone extension, height of the first alive knot fastening, alive crown extension, and alive crown relative extension are submitted here as input data.

As shown in Table 1, average sound velocity across a trunk has rather low factors of linear correlation with tree morphology parameters; besides, their reliability does not exceed 70%. The factors of linear correlation (Table 1) characterize the interrelation between sound velocity in stem wood along fibers and the corresponding biomorphological parameters. This was obtained by using data correlation analysis.

Although the correlation coefficient is small, the parameter of correlation of sound velocity with branchless zone extension (r=0.334) and with first alive knot fastening height (r=0.282) stands out among the presented parameters. Such tendency corresponds to the rule which masters have used for a long time, providing the selection of resonant spruce with highly lifted crown.

In a certain degree, it is also proved by negative correlation of sound velocity with relative extension of a crown *(*r=-0.177).

However, in this case, the opinion of masters regarding the trees with narrow crowns as the best source of resonant raw material has not proved to be true; the correlation of sound velocity with crown diameter appeared positive.

Further calculations showed that rather low values of the given coefficients are somehow accounted for by nonlinear character of the relationships under consideration. Therefore, further analyses are graphically presented on the basis of quadratic equations. Apart from the tree morphological parameters listed, we shall also consider the influence of average stem taper and trunk volume on sound velocity in wood across fibers.

Here the parameters of branchless zone extension L_b and crown relative extension L_c/H stand out. Quadratic equations of their influence on sound velocity appeared significant among all other parameters of tree morphology and they are expressed accordingly (Figure 3 and 4).

$$C = 1{,}800.6 - 187.41L_b + 24.42L_b^2 \qquad (5)$$

$$C = 3{,}735.1 - 6{,}451.6L_c/H + 4{,}552(L_c/H)^2 \qquad (6)$$

The influence of alive knots fastening height (Figure 5) and tree height itself (Figure 6) on sound velocity are of special practical interest as well.

Stem taper (q, $cm \cdot m^{-1}$) as a parameter of its thickness reduction along the height is calculated against its diameter $D_{1.3}$ according to the formula:

$$q = D_{1.3} / H - 1.3 \qquad (7)$$

Figure 7 shows that influence of stem average taper on sound velocity across wood fibers is expressed by the equation:

$$C = 2{,}233.4 - 922.06\, q + 272.41\, q^2 \qquad (8)$$

Despite the insignificance of the regression equation against Fisher's variance ratio, the nature of approximation line allows to question the weak influence of average stem taper on cross-section sound velocity in wood.

However, the tendency remains that the less tapering trunks have relatively better wood from the viewpoint of acoustic parameters than the more tapering ones. Basically, this corresponds to standard resonant raw material selection rule in denser stands where full-bold trunks with smaller taper are formed.

Trunk volume (V, m^3) has the nature of influencing sound velocity rather close to the diameter; maximum velocity is observed at its certain interval, outside which, both increasingly and decreasingly, there is a reduction of the given acoustic parameter value (Equation 9, Figure 8).

$$C = 1{,}396.2 + 105.12V - 22.88\, V^2 \qquad (9)$$

TABLE 1. Linear correlation coefficients of sound velocity across the trunk with spruce morphology parameters.

Parameters	Symbolic representation	Linear correlation coefficients, r
Tree height	H	0.179
Crown diameter in latitudinal direction	D_c, N-S	0.118
Crown diameter in longitudinal direction	D_c E-W	0.228
Mean crown diameter	D_c, M	0.191
Branchless zone extension	L_b	0.334
First alive knot fastening height	H_b	0.282
Alive crown extension	L_c	- 0.005
Relative extension of a crown	L_c / H	- 0.177

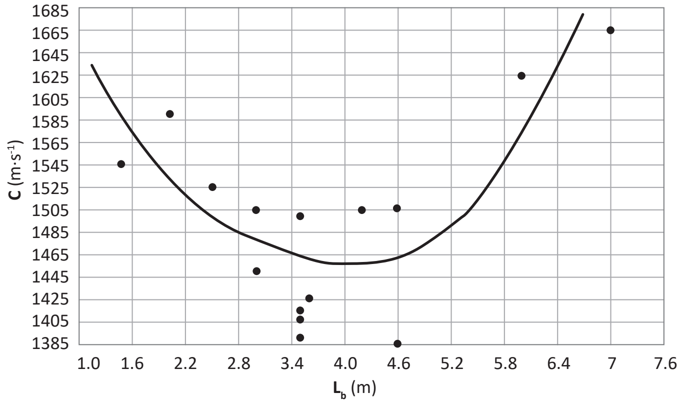

FIGURE 3. Influence of branchless zone extension on sound velocity.

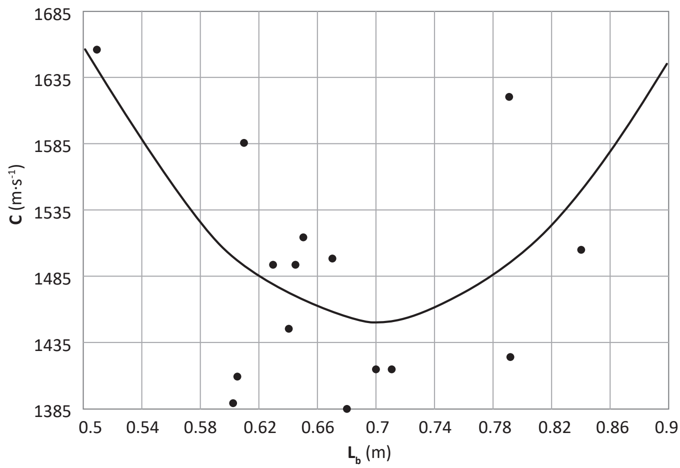

FIGURE 4. Influence of relative extension of the crown on sound velocity.

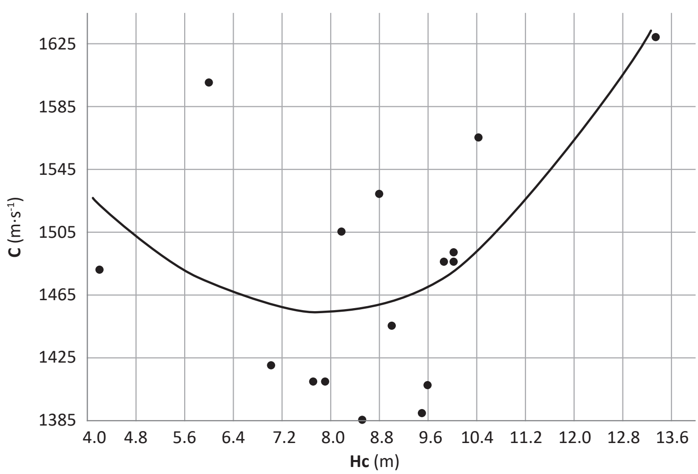

FIGURE 5. Influence of alive knots fastening height on sound velocity.

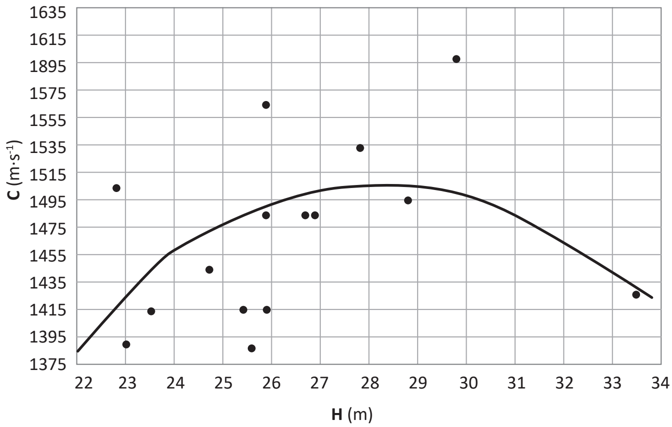

FIGURE 6. Influence of tree height on sound velocity.

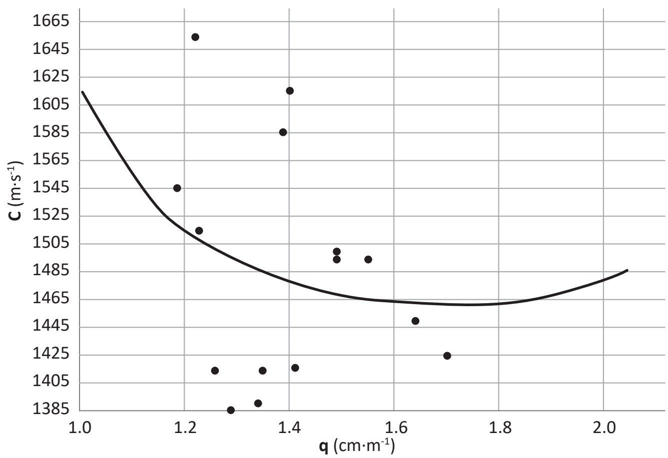

FIGURE 7. Influence of average stem taper on sound velocity.

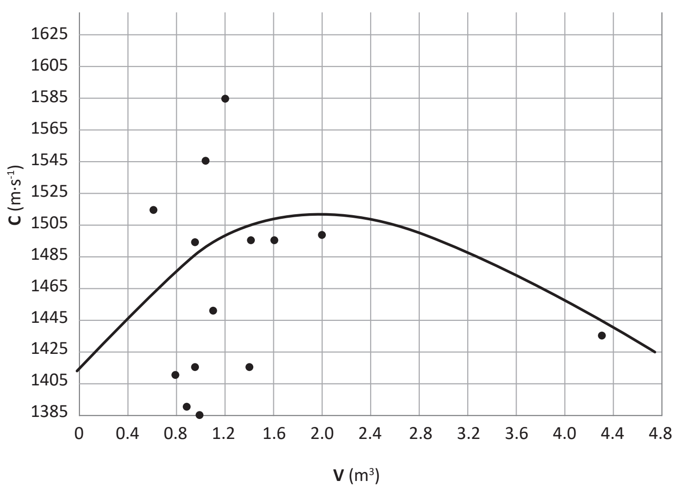

FIGURE 8. Influence of a stem volume on sound velocity.

It is necessary to note a sufficiently high degree of data dispersion, which is presented in the diagrams (Figsures 3-8). It also characterizes insignificant correlation between sound velocity and biomorphological parameters. The graphs were built using computer modelling. The given type of a regression model was chosen as the one most adequately describing all the dependences under study.

CONCLUSIONS

Acoustic properties of wood depend on biomorphology of a tree as well. The parameters of stem tapering, trunk volume and especially branchless zone extension and crown elevation have, to any extent, the greatest practical value for standing resonant raw material express diagnostics.

REFERENCES

1. BAGAYEV SN, ALEXANDROV VO 1976 Selection of resonant spruce against phenotype. Inf. sheet 125-76, Kostroma CSTI, Kostroma, Issue 38, 3 p
2. BLSKOVA G, BRDAROV N 2003 Sounding wood acoustic characteristics studies. *In*: Collection of scientific reports 50th anniversary of the Forest Engineering Institute: Woodworking and furniture production section, Sofia, Bulgaria, pp 49-53
3. LINDSTROM H, NAKADA R, RALSTON J 2003 Cell wall structureand wood properties determined by acoustics - a selective review. *Holz als Roh- und Werkstoff* 61 (5): 321-335. DOI: https://doi.org/10.1007/s00107-003-0398-1
4. GAVRIS VP 1938 Diversity of forms of coniferous breeds and practical use of valuable forms of the pine and the spruce. *Forest Industry* 1 (7): 78-88
5. KUZNETSOV II 1930 Resonant wood and its decks. *Forestry and Forest Industry* 2-3: 39-43
6. NESTEROV NS 1892 On resonant wood material for string instruments. *Russian Forestry* 2: 57-62
7. PRAVDIN LF 1975 Norway and Siberian Spruce in the USSR. Nauka, 187 p
8. SANKIN NA 1972 Variability of resonant properties of Norway Spruce wood against the background of variation of anatomic and morphological attributes inside the population. *Transactions/MFEI* 43: 57-65
9. FEDYUKOV VI, MAKARYEVA TA 1992 The diametrical rod as object for nondestructive method resilient-viscous characteristics definition of standing and sawn resonant wood. *In*: Proceedings of 5th conference "Forest product", Nancy, France, 23-28 August 1992, pp 344-345
10. FEDYUKOV VI, SALDAYEVA EY, CHERNOVA MS, CHERNOV VY 2018 Cone Morphology as a diagnostic attribute of resonant properties of standing spruce wood. *Drvna Ind* 68 (4): 333-340. DOI: https://doi.org/10.5552/drind.2017.1731
11. GRAPINI V 1967 Molidulde rezonantr. *Revista Prdurilor* 82 (7): 334-344
12. REDULESCU A 1969 Jn legrturr cu molidus de rezonantr. *Revista Prdurilor* 84 (3): 218-221
13. YABLOKOV AS 1962 Woody species selection. Sel'khozizdat, 367 p
14. BUCUR V 2006 Acoustics of Wood. Springer Verlag Berlin Heidelberg, Germany, 393 p. DOI: https://doi.org/10.1007/3-540-30594-7
15. Pat. № 2130611 RF. 1999 Method for and device for diagnosing wood resonant properties. FEDYUKOV VI, Veselov LN, VESELOV VL. – RU 97109185; appl. 28.05.97; publ. 20.05.99; Bul.of invent.– No. 4.
16. UGOLEV BN 2001 Wood science with basic concepts of timber merchandizing. MGUL, 340 p.
17. 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
18. MANDY C, ROZENBERG P, BASTION JC 1995 Non-Distinctive assessment of modulus of elasticity in genetic field tests in France. *In*: 20 IUERO World Congress, Tampere, 7-11 August 1995, IAWA Journal, 16 (1): 13
19. NAKAMURA N 1997 Development of measuring Young'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

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

GUIDELINES FOR AUTHORS

Introduction
SEEFOR is an open-access, peer-reviewed, international journal of forest science. Before preparing the manuscript, please read the Journal's Aims and Scope to have an overview and to assess if the contents of your manuscript is written according to the Journal's scope. More information please find in the journal's sections Publication Procedure, Publication Policy, Open Access & Copyright and Publication Ethics and Publication Malpractice Statement.
To facilitate the publishing process, please follow these guidelines to prepare your manuscript. You may also like to use the Manuscript Template and Reference Preparation Guide that will facilitate the formatting and manuscript preparation.
Manuscripts not prepared in accordance with these guidelines will be returned to authors.

Types of Papers
The journal publishes *original scientific papers*, *preliminary communications*, *review papers* and *professional papers* written in the English language. During the submission process authors are required to propose the category of the submitted manuscript.
Original scientific papers report unpublished results of original research. The papers have to contain all the necessary information to enable repeatability of the described research.
Preliminary communications contain unpublished preliminary, but significant, results of ongoing research which require immediate publication. The papers do not have to contain enough details to test reported results, as is the case with original scientific papers.
Review papers provide original, critical and up-to-date review of a particular field or topic in forest science based on relevant, updated and complete references.
Professional papers do not have to be based on original research, but they should contribute to the application of well-known research results and to their adaptation for practical use.

Submitting the Manuscript
Manuscripts should be submitted electronically by following the Manuscript Submission hyperlink. The entire submission and editorial process is carried out by using the *Open Journal System* and the appropriate on-line forms. Electronic submissions substantially reduce editorial processing, as well as shorten the reviewing and the overall publication time. Also, it allows authors to follow the editorial process and check the status of their manuscripts.

Conditions
During the submission process authors are required to agree with the journal's conditions stated in the Submission Checklist and Copyright Notice.
The submission of a manuscript implies: that the research described has not been published before; that it is not under consideration for publication elsewhere; that is prepared according to the Guidelines for Authors; that its publication has been approved by all co-authors. It is the author's responsibility to obtain a permission to reproduce illustrations, tables, etc. from other publications. One of the criteria considered in reviewing manuscripts is the proper treatment of animals. In particular, the use of painful or otherwise noxious stimuli should be carefully and thoroughly justified. Papers that do not meet these criteria will not be accepted for publication.
Unless otherwise noted, the Publishers retain the copyright on all papers published in the Journal, (whether in print or electronic form) under the Creative Commons Attribution 4.0 International License, but allow anyone to download, reuse, reprint, distribute or copy them, as long as the original author and title are properly cited. For more detailed information please read Open Access & Copyright.

Manuscript Preparation
Language and Style
Only papers written in proper English (UK language standard) are considered. The authors have to follow a concise scientific style of writing. The authors need to ensure that the manuscript does not contain grammatical, stylistic or other linguistic errors. Thus, the authors that are not native speakers of English are kindly asked to use an independent copy-editing service.

Manuscript Layout
Manuscripts have to be submitted as a single MS Word file (.doc, .docx) with all tables and figures placed at the end of the main text (after the References section).
Authors have to follow the rules for manuscript preparation:
- A4 paper format, font Times New Roman 12 pt, single column pages, 2.5 cm margins (top, bottom, left, and right sides), double line spacing, only the first line of the paragraph indented by 1 cm;
- Italics should be used only for scientific names of plant and animal species;
- Avoid footnotes;
- Introduce an abbreviation only when the same term occurs three or more times;
- SI Units should be used;
- All pages should be numbered (bottom right side of the page);
- All line numbers should be numbered continuously;
- There are no limitations on the length of manuscripts, provided that the text is concise and comprehensive.

Contents of the Manuscript

The structure of the manuscript has to follow the intended category of the paper. An original scientific paper should have the following sections: *Title and Running title*, *Abstract*, *Keywords*, *Introduction*, *Materials and Methods*, *Results*, *Discussion*, *Conclusions* and *References*. The inclusion of *Acknowledgments* is recommended. Exceptionally, *Results and Discussion* or *Discussion and Conclusions* may be combined in a single section. Other paper categories are not required to have all the above mentioned sections. For example, Review papers may have a different structure, e.g. Material and Methods, and the Results sections may be omitted.

IMPORTANT: Because of the double-blind review process, it is important that you do not identify yourself or the co-authors anywhere in the manuscript. Note that during the manuscript submission, you will be requested to submit the complete information of all authors, including e-mail addresses, in the OJS page. This information will not be revealed to the reviewers but it will be available to the editors.

A Manuscript should be structured in the following order:

Title

The title must be concise but informative. Avoid abbreviations and colloquialisms.

Running title

A concise condensed title of no more than 70 letters and spaces should be provided. It should reflect the most important elements of the manuscript.

Abbreviations (if any)

If abbreviations are used in the text, they should either be defined in the text where they are first used, or a list of abbreviations may be provided after the Running title. Introduce an abbreviation only when the same term occurs three or more times.

Abstract

An Abstract of no more than 350 words has to be divided into four separate sections: *Background and Purpose*, *Materials and Methods*, *Results* and *Conclusions.* It should be a factual condensation of the entire work including a statement of its purpose, a clear description of the main findings and, finally, a concise presentation of conclusions. An abstract should not contain cited references and the use of abbreviations must be minimized.

Keywords

The abstract is followed by 4-7 keywords, preferably different than the title words.

Introduction

Keep the Introduction brief, stating clearly the purpose of the research and its relation to other papers on the same subject. Do not give an extensive review of literature.

Materials and Methods

Provide enough information in the Material and Methods section to enable other researchers to repeat the study. This section may be divided into subsections, but it is optional.

Results

Report results clearly and concisely. Do not present the same results in tables and illustrations. Exceptionally, Results and Discussion may be combined in a single section. This section may be divided into subsections, but it is optional.

Discussion

Interpret the results in the Discussion, state their meaning and draw conclusions. Do not simply repeat the results. This section may be divided into subsections, but it is optional.

Conclusions

List your conclusions in a short, clear and simple manner. State only those conclusions that stem directly from the results shown in the paper.

Acknowledgments

Acknowledgments of people, grants, funds, etc. that contributed to the research should be placed in a separate section before the Reference section.

References

All references cited in the text, including those in tables and figures, have to be listed in the References section according to the order of their appearance in the manuscript. If some reference appears in the text more than once, do not repeat it in the references list. Reference numbers should be placed in square brackets [ ], and placed before the punctuation; for example [1] or [2-4].

For more information please see Reference Preparation Guide.

Examples of in-text citations:

- … text text text [1].
- … text text text [1, 2].
- … text text text [3-6].
- … text text text [1] … text text text [2-5].
- … According to James et al. [5] the influence of…
- …James [5] stated that…

Reference list

The list of references should only include works that are cited in the text and that have been published or accepted for publication. Personal communications, Forest management plans and unpublished works should only be mentioned in the text, preferably in parentheses (Dr. John Do, University of Zagreb, pers. comm. in 2011). Avoid citing non-scientific literatures (e.g. legislations, regulations, web pages, etc.) as much as possible.

Cite in sequence all authors names and initials (last name first, then the first letters of the first name and, if available, the first letters of the middle name), the year of publication, the title of paper, the abbreviated name of journal, the volume and issue number of the journal, and first and last pages. There should be no punctuation other than a comma to separate the authors. Abbreviate journal titles according to the ISO4 Abbreviation (http://www.issn.org/en/services/online-services/access-to-the-ltwa/) and Journal Title Abbreviations from Web of Science (http://images.webofknowledge.com/WOK46/help/WOS/A_abrvjt.html).

Do not use footnotes or endnotes as a substitute for the reference list.

a) Journal paper:

1. PERNEK M, LACKOVIĆ N, MATOŠEVIĆ D 2013 Biology and natural enemies of spotted ash looper, *Abraxas pantaria* (Lepidoptera, Geometridae) in Krka National Park. *Period Biol* 115 (3): 371-377

- if the paper has more than eight authors, stop the listing after the eighth author and write et al.

2. VULETIĆ D, AVDIBEGOVIĆ M, STOJANOVSKA M, NEVENIĆ R, HASKA H, POSAVEC S, KRAJTER S, PERI L, et al. 2013 Contribution to the understanding of typology and importance of forest-related conflicts in South East Europe region. *Period Biol* 115 (3): 385-390

- papers written in the language other than English (e.g. German, Russian, Croatian, Serbian, etc.) should be translated into English.

3. MARJANOVIĆ H, OSTROGOVIĆ MZ, ALBERTI G, BALENOVIĆ I, PALADINIĆ E, INDIR K, PERESSOTTI A, VULETIĆ D 2011 Carbon Dynamics in younger Stands of Pedunculate Oak during two Vegetation Periods (*in Croatian with English summary*). *Sumar list* 134 (11-12): 59-73

- papers in journals with DOI number:

4. VULETIĆ D, POTOČIĆ N, KRAJTER S, SELETKOVIĆ I, FÜRST C, MAKESCHIN F, GALIĆ Z, LORZ C, at al. 2009 How Socio-Economic Conditions Influence Forest Policy Development in Central and South-East Europe. *Environ Manage* 46 (6): 931-940. DOI: http://dx.doi.org/10.1007/s00267-010-9566-3

- Early View papers (published online, waiting to be published in print version):

5. MATOŠEVIĆ D 2013 Box Tree Moth (*Cydalima perspectalis*, Lepidoptera; Crambidae), New Invasive Insect Pest in Croatia. *South-East Eur For* 4 (2): (early view). URL: http://www.seefor.eu/36-vol4-no2-matosevic.html (20 December 2013)

- or (if doi number is available):

6. ANČIĆ M, PERNAR R, BAJIĆ M, SELETKOVIĆ A, KOLIĆ J 2013 Detecting mistletoe infestation on Silver fir using hyperspectral images. *iForest* (early view). DOI: http://dx.doi.org/10.3832/ifor1035-006

b) Paper in Proceedings:

7. BALENOVIĆ I, SELETKOVIĆ A, PERNAR R, MARJANOVIĆ H, VULETIĆ D, BENKO M 2012 Comparison of Classical Terrestrial and Photogrammetric Method in Creating Management Division. *In*: Pentek T, Poršinsky T, Šporčić M (*eds*) Forest Engineering - Concern, Knowledge and Accountability in Today's Environment, Proceedings of 45th International Symposium on Forestry Mechanization, Dubrovnik, Croatia, 8-12 October 2012. Forestry Faculty of University Zagreb, Zagreb, Croatia, pp 1-13

c) Book:

8. VAN LAAR A, AKÇA A 2007 Forest Mensuration. Springer, Berlin, Germany, 383 p

d) Chapter in a book:

9. CURTIS PS 2008 Estimating Aboveground Carbon in Live and Standing Dead Trees. *In*: Hoover CM (*ed*) Field Measurements for Forest Carbon Monitoring. Springer, New York, NY, USA, pp 39-44

e) Thesis:

10. OSTROGOVIĆ MZ 2013 Carbon stocks and carbon balance of an even-aged Pedunculate Oak (*Quercus robur* L.) forest in Kupa river basin (*in Croatian with English summary*). PhD thesis, University of Zagreb, Faculty of Forestry, Zagreb, Croatia, 130 p

f) Non-scientific literature:
- Paper in online magazine:
  11. LEMMENS M 2011 Digital Photogrammetric Workstations, Status and Features. *GIM International* 25 (12). URL: http://www.gim-international.com/issues/articles/id1797-Digital_Photogrammetric_Workstations.html (20 November 2012)
- Professional and other web pages:
  12. CROATIAN FORESTS LTD 2013 Forests in Croatia. URL: http://portal.hrsume.hr/index.php/en/forests/general/forests-in-croatia (14 December 2013)
- Manuals, Reports and other documents from web pages:
  13. DOBBERTIN M, NEUMANN M 2010 Tree Growth. Manual Part V. *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, 29 p. URL: http://www.icp-forests.org/Manual.htm (12 December 2013)
  14. FAO 2012 State of the World's Forests 2012. Food and Agriculture Organization of the United Nations, Rome, Italy, 47 p. URL: http://www.fao.org/docrep/016/i3010e/i3010e.pdf (12 December 2013)
- Legislations, Regulations:
  15. THE MINISTRY OF AGRICULTURE, FORESTRY AND WATER MANAGEMENT 2006 Regulation on forest management (*in Croatian*). *Official Gazette* 111/06, Zagreb, Croatia. URL: http://narodne-novine.nn.hr/clanci/sluzbeni/128205.html (10 December 2013)

Tables
Tables have to be numbered using the Arabic numerals continuously through the paper (e.g. Table 1, Table 2), and together with their captions placed after the Reference section.
Table caption should be written above the table and should clearly describe the contents of the table. A detailed legend may follow the table (placed below the table), but should be concise. For indicating numerical values please use points (e.g. 2.53). Avoid using colours in the tables. Only the table heading may be shaded (grey color). For each table use a separate sheet. You may also like to use the Table Template within Manuscript template that will facilitate the table preparation.
If tables are taken from other authors or publications, the sources should be clearly stated as a reference. It is the authors' responsibility to obtain a permission from the copyright holder to use tables that have previously been published elsewhere.

Figures
Figures (photographs, graphs, schematic drawings, etc.) have to be numbered using the Arabic numerals continuously through the paper (e.g. Figure 1, Figure 2), and together with their captions placed after the Tables section.
Figure caption should be written above the table and should clearly describe the contents of the figure. A detailed legend may follow the figure, but should be concise. A legend may be placed inside or bellow the figure.
Both color and black-and-white figures are acceptable. However, consider carefully if the color is necessary. Color figures will be published online, while the black-and-white version of the figure will be published in the print version of the accepted paper.
Diagrams and graphs should appear on a white background. Always use the same identifier (symbol, column fill, line style and color) for a variable that appears in more than one figure of a manuscript.
If the quality of the submitted figure is low, upon accepting the manuscript, authors may be asked to send the figure of a higher quality.
If figures are taken from other authors or publications, the sources should be clearly stated as a reference. It is the authors' responsibility to obtain a permission from the copyright holder to use figures that have previously been published elsewhere.

Supplementary Files
The authors may upload Supplementary Files, in the form of data sets, research instruments, or source texts that will enrich the item, as well as contribute to more open and robust forms of research.
Supplementary Files may be uploaded in any file format within Step Four of the online submission process. The preferred file formats are:
- Additional documentation: .pdf, .doc, .docx
- Data sets (additional tables): .pdf, .xls, .xlsx
- Additional figures: .pdf, .tif, .jpg, .png, .bmp;
- Video: .mpeg, .avi.

During the submission process, name the supplementary files as follows: Suppl. file 1, Suppl. file 2, etc.
If supplementary material is provided, please list the following information in a separate section at the end of the manuscript text: File name, File format (including the name and a URL of an appropriate viewer if the format is unusual), Title and Description of Data. Supplementary materials should be referenced explicitly by the file name within the manuscript, (e.g. "See Supplementary Material 1: Video1").
Supplementary materials will not be displayed in the final paper, but a link will be provided to the files as supplied by the author.

Help
If you have any questions about the manuscript preparation and submission process, please contact Dr. Ivan Balenović at ivanb@sumins.hr.

SEEFOR Editorial Office
Croatian Forest Research Institute
Cvjetno naselje 41
HR-10450 Jastrebarsko, Croatia
Tel: +385 1 62 73 000; +385 1 63 11 584
Fax: +385 1 62 73 035; +385 1 63 11 588
e-mail: seefor@sumins.hr
URL: http://www.seefor.eu

Contents

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891