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DETECTION OF DECAY IN INJURED TREES OF SILVER FIR USING THE METHOD OF TOMOGRAPHY

Utvrđivanje truleži kod povrijeđenih stabala jele metodom tomografije

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Abstract

Silver Fir in Bosnia and Herzegovina is the important coniferous species of trees in term of forestry and biodiversity. Numerous harmful factors have the impact to its health and vitality. One of them is different damages of standing trees by machinery. These injuries represent suitable entering openings for microorganisms which afterwards cause decay of the wood. Wood affected by this process has a decreased quality or it becomes completely unusable. Infection and development of decay are in correlation with the size of the injuries and its position on the tree. In recent times the methods of analysis of decay based on the flow of electric energy or sound through the wood were developed. One of these methods is the sound tomography which gives us the possibility to review the condition of the tree without the need to cut it or damage it significantly. It is performed by the device called tomograph. In this paper, by the method of tomography, the presence of signs of decay of wood on injured trees of Silver Fir was identified.

***Key words**: Silver Fir, Abies alba Mill., stem injuries, fungi, decay, tomography, ARBOTOM®*

INTRODUCTION - *Uvod*

Silver Fir in Bosnia and Herzegovina is the most present coniferous species of trees. Together with beech and spruce it builds valuable forest stands. Numerous abiotic and biotic factors have the impact to its health conditions (USĻUPLIĹ *ET AL.,* 2007; USĻUPLIĹ AND DAUTBAĠIĹ, 1998). The introduction of machinery in the process of exploitation of forests has as a consequence different damages of young and standing trees (FICKLIN *ET AL.*, 1997; DOLEĢAL, 1984). Injuries on trees are caused by contact between machinery and standing trees or by contact of the cable and hooked wood assortments which these machinery are moving and pulling. According to KRPAN *ET AL.* (1993) the most frequent injuries on the stem up to 1.5 m of height are

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peeled and smashed bark (over 70% of all injuries). Trees along the skidding road are the most exposed to injuries (JOURGHOLAMI AND MAJNOUNIAN, 2011; PORĠINSKY AND OĢURA, 2006).

The caused injuries represent suitable entering openings for inhabitation of microorganisms which afterwards destroy the wood and use it in such way for their feeding. As the decay are meant all physical and chemical changes by which is decomposed the celluloses, lignin and other wood materials. Wood affected by this process has a decreased quality or it becomes completely unusable. ZAHIROVIĹ (2012) has identified significant difference in the type of produced assortments between the trees with central decay and those which were not infected. The most frequent causes of decay are fungi and bacteria. The most important fungi that cause decay of the root and the stem of Silver Fir are species of the genus *Armillaria* spp. and *Heterobasidion* spp. (KARADĢIĹ, 2008). In Bosnia and Herzegovina *Armillaria* are present in all natural forests and artificially grown stands (USĻUPLIĹ *ET AL.,* 2007; TREĠTIĹ *ET AL.*, 2003).

Infection and development of decay are in correlation with the size of the injuries and its position on the tree. On 25% of damaged trees, three years after the injury is caused, basidiocarps are noticed (KRPAN *ET AL.*, 1993). Authors have also noticed that the basidiocarps appear more frequently on larger injuries. In injuries lower than 100 cm^2 the basidiocarps were not noticed. With the increase of the surface the basidiocarps were more frequently represented on it. Therefore on injuries with surface from 501 to 1000 cm^2 the basidiocarps were noticed in 28.9% cases, from 1001 to 2000 cm^2 in 26% and in damages of surface above 2001 cm^2 in 39.5% cases. The correlation of occurrence of fungi and the height of injury from the soil was also confirmed. The height of the injury from 50 to 100 cm from the soil represents the most favorable zone for infection and development of fungi-wood destroyer. The research was conducted on trees of oak and beech.

One approach in identification of decay is analysis of visible changes on transversal diameter of felled trees (ZAHIROVIĹ, 2012). In recent times were developed also the methods of analysis of decay based on the flow of electric energy or sound through the wood. One of these methods is the tomography which gives us the possibility to review the condition of the tree without the need to cut it or damage it significantly. It is based on the principle of stress wave timing. Impulse velocities within the wood are highly correlated with the density of the material and can therefore be used to gather information on its quality. Dense wood transmits stress waves better than wood that is damage by decay or cracks. It is performed by the device called tomograph. Tomography is confirmed as good method for discovering of internal decomposition of the wood, location of the change, identification of its shape, size and the characteristics which impact the mechanical features of the wood (NICOLOTTI *ET AL.,* 2003). GĶLBERT AND SMĶLEY (2004) in their research have identified high correlation between the quantity of decay and advanced stage detected by tomogram and real quantity of decay in the transversal diameter. However, speaking about precise detection of early decay (change of the color of the wood without significant decomposition of wood components), the sound tomography has limited possibilities (LĶ*ET AL.*, 2009).

In this paper, by the method of tomography, the presence of signs of decay of wood on injured trees of Silver Fir was identified. The research has started from the following null hypothesis: There is no statistically significant difference between the average surfaces of decay of transversal section in wood of Silver Fir with different size of the injury.

MATERIAL AND METHODS - *Materijal i metode*

Researches were conducted in the compartment 86 of the forest management unit ĂIgmanñ, which belongs to forest management area ĂIgmanskoñ, and which is managed by Cantonal public enterprise ĂSarajevo ï ġumeñ d.o.o. Sarajevo. Field surveys were conducted in 2013. According to the records of the Enterprise, regular felling in the compartment 86 were conducted in 2006, when also trees of Silver Fir which were the subject of the research were injured. Compartment 86 has the surface of 55.5 ha. Average altitude above the sea level is 1275 m. Dominant aspects in the compartment are south-west and south. Main substrate is consisted of lime stones and dolomites of Mesozoic age on which were formed the following types of soil: rendzine, brown shallow soil on lime stones and diluvial soil. Compartment belongs to management class 1205 ï Forests of Silver Fir and spruce (Silver Fir) and white pine on lime stone and lime stone ï dolomite soils. For the said management class was predicted group-selective system of management.

The survey was conducted on injured trees of Silver Fir which were selected near tractor roads. In total 30 trees were selected along the section of 550 m tractor road. On these trees injuries of the stem up to 2 m of height from the soil were recorded and there was measured their width and length in centimeters. For the most significant damage were recorded changes in the wood in cross-sections of the stem in the zone of damage. The survey was conducted by tomograph ARBOTOM® Version 5 (Rinntech, Germany). Based on the collected information, the software package of the tomograph provides graphical presentation of results of measurements (tomogram) in which are visible differently colored zones of cross-section depending on the degree of decomposition of the wood. Shade of the color which points to decay is designated based on tomograms which were recorded on felled trees, by comparative analysis of visible changes on real transversal section and changes which are visible on tomogram. In this way was designated a unique scale of frequencies of the sound speed for Silver Fir which in the tomogram has in the most realistic way presented the real changes in the wood. Surfaces of colored zones of tomograms are measured using software WINGIS 2003.

Statistical analysis was performed using software SPSS 18.0 and Stat graphics 5.0. In the investigation of the impact of size of injury to the size of decay of wood were used regression analysis and the analysis of variance. Injuries were divided according to their size into four surface classes: up to 100 cm^2, 101 ï 500 cm^2, 500 ï 1500 cm^2 and over 1500 cm^2 in order to examine significance of average size of decay to transversal section between categories. Multiple tests were performed using Tukey HSD test (MONTGOMERY, 2005).

RESULTS - Rezultati istraživanja

The research has covered 30 trees on which were recorded 37 transversal sections in zones of injuries (22 trees with one injury, 6 trees with two and one tree with three injuries). On the trees were measured width and length of the injury based on which was calculated the surface of the injury (cm^2), and on tomograms was designated surface of decay of the wood (cm^2). Descriptive statistics of examined variables are presented in Table 1.

Table 1. Descriptive statistics of examined variables
Tabela 1. Deskriptivne statistike analiziranih obilježja

Characteristics	N	Minimum	Maximum	Mean
Surface of the injury (cm^2)	37	28	3330	790.51
Diameter in section zone (cm)	37	30	70	46.45
Surface of section zone (cm^2)	37	719	3854	1750.11
Surface of decay (cm^2)	37	0	1800	275.68
Percentage of surface of decay	37	0	62	14.22

For designation of the impact of size of injury to size of decay of analyzed trees regression analysis was conducted (Table 2 and 3; Figure 1).

Table 2. Regression analysis of impact of size of injury to size of decay
Tabela 2. Regresiona analiza uticaja veličine povrede na veličinu trulež drveta

Parameters	Coefficients	Std. Error	t	Significance
Constant	39.2955	56.0918	0.70056	0.4882
Coefficient of	0.2990	0.0477	6.27251	0.0000

Regression linear model which describes the relation between the surface of injury and surface of decay of analyzed trees can be presented by formula: $\hat{Y} = 39.2955 + 0.299X$, where Y is surface of decay (cm^2) and X is surface of injury (cm^2). Correlation coefficient and coefficient of determination of this linear model are $r = 0.72$ and $R^2 = 0.53$, respectively.

Conducted analyses point out existence of highly statistically significant regression of the surface of injury and surface of decay of the wood ($p < 0,05$).

Table 3. Analysis of the variance for regression between size of injury and size of decay
Tabela 3. Analiza varijanse regresije za površinu povrede i površinu truleži drveta

Data	Sum of Squares	df	Mean Square	F	Significance
Regression	2.51278E6	1	2.51278E6	39.34	0.0000
Residual	2.23533E6	35	63866.4		
Total (Corr.)	4.74811E6	36			

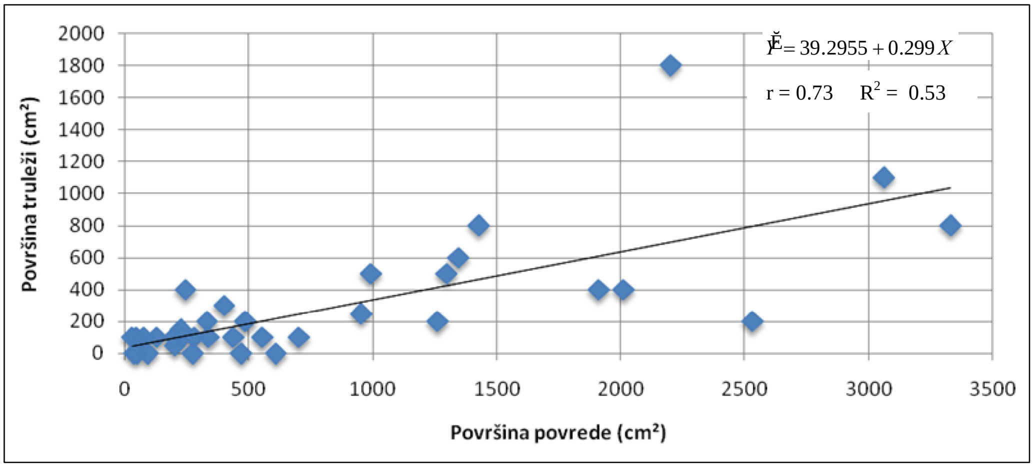

Figure 1. Model of linear regression of the surface of injury and surface of decay of the wood
Slika 1. Model linearne regresije površine povrede i površine truleži drveta

The statistical significance of average size of decay to transversal section between categories corresponding to the size of injury was checked by one-way ANOVA (Table 4).

Table 4. ANOVA for the size of injury and decay surface classes
Tabela 4. ANOVA za veličinu povrede u odnosu na površinske klase truleži

Variation	Sum of Squares	df	Mean Square	F	Significance
Between Groups	2214885.886	3	738295.295	9.618	0.000
Within Groups	2533222.222	33	76764.310		
Total	4748108.108	36			

According to the results of analysis there are highly statistically significant differences between average sizes of decay in transversal section in trees of Silver Fir for different surface classes of injury ($p < 0{,}001$). Significance of differences between average surfaces of decay for different surface classes of injury was designated by Tukey HSD test (Table 5).

Table 5. Tukey HSD test for average surface of decay between classes of surface of injury
Tabela 5. Tukey HSD test prosječnih površina truleži u odnosu na klase površina povreda

Surface of injury (cm^2)	N	Average surface of decay (cm^2)	Significance of differences (cm^2) Surface of injury (cm^2)			
			< 100	101-500	501-	> 1501
< 100	7	50.00	-	0.893	0.184	
101-500	15	140.00	0.893	-	0.339	
501-1500	9	338.89	0.184	0.339	-	0.023*
> 1501	6	783.33			0.023*	-

(* statistically significant at $p < 0.05$; ** statistically significant at $p < 0.001$)

According to Tukey HSD test there is highly statistically significant difference in the size of the decay of the wood in the transversal section between the trees the surface of which is larger than 1500 cm^2 and those with injuries lower than 500 cm^2. Statistically significant differences in the size of the decay of the wood were identified between the trees with surface of injuries of 501-1500 cm^2 and those with surfaces of injuries larger than 1500 cm^2.

DISCUSSION - *Diskusija*

In the science of forestry and practice in Bosnia and Herzegovina since a long time was recognized harmful impact of mechanical injuries of trees (Matić, 1977). One of the criteria in assessment of silviculture-technical class of tree is the injury of the stem. According to this criteria, into the first silviculture-technical class are selected trees of Silver Fir with healthy or slightly injured stem (width of injury up to 5 cm). Trees with significantly damaged stem (width of damage over 10 cm) are selected into third silviculture-technical class. Such trees should be removed as soon as possible from the forest stands. According to research of Vasaitis *et al.* (2012) width of injury of *Picea abies* stem has positive correlation with decay of wood ($r = 0.925$; $p < 0.05$). These authors pointed out that wounds greater than 5 cm wide are prone to decay. Smith *et al.* (1994) suggest square diameter at breast height as threshold of significant surface of injury of stem. Krpan *et al.*, (1993) have noticed that basidiocarps were not present on injuries of *Quercus robur* lower than 100 cm^2 but those larger than 2000 cm^2 have had incidence of basidiocarps in 39.5% cases.

Late removal of damaged trees results in significant losses in quality and quantity of produced timber mass. However, more important than that is that such trees through the time loose vitality by which it become subject to attack of pests and causes of diseases. There are numerous stress factors which predispose Silver Fir for attack of pathogens (Usčuplić *et al.*, 2007; Wargo *et al.*, 1983). In such way it becomes cores of destabilization of forest stands from which harmful phenomena spread to surrounding healthy and vital trees.

Sanitary felling which are conducted in such situations and which have for a goal to re-establish the balance in disturbed forest stands, are expensive and it require additional sacrifice of production character (felling of trees in wider zone of the center/core of infection). Independent from that, the decay of wood in standing trees represents negative and harmful phenomena from economic point of view. Analyzing assortment of produced timber from healthy and trees infected by decay, ZAHIROVIĹ (2012) has identified statistically significant difference in the type of produced products. According to this author research fungi which cause decay, independently or in synergy with other harmful agents, have reduced the quality of produced timber mass on about 21% of analyzed trees. Because of damage caused by these fungi, the part of the produced timber mass was classified into less valuable timber assortments, most often the cellulose wood (12-13% of the volume of wood). In this way were caused direct losses in produced quantity of timber. In this case the volume of completely rotten wood was represented with 1.7% in the total volume of wood in cut trees with signs of decay. One part of this mass is compensated through cellulose wood. Other part represents total loss, because the high level of decomposition of wood is not tolerated even in the chemical processing. Because of that this loss in spite the low percentual representation is still important and it should not be underestimated. Similar results of the research are mentioned by VULETIĹ (2001) and DOLEÇAL (1984). KULUĠIĹ (1990) emphasizes that the value of the damages is often higher than costs of skidding and in some cases these costs are even higher than the value of obtained timber.

Injuries on standing trees represent ideal place for penetration and negative impact of rot-causing fungi. Because of the importance of injuries of the stem for the vitality of the injured tree and the stability of forest stand in time, there is imposed the need of more precise designation of criteria by which the size of injury would be the criterion for making a decision for the removal of it from the stand. In this paper were researched possibilities to implement tomography as the method of designation and monitoring of advanced stage of decay of the wood with injured stem. GILBERT AND SMILEY (2004) in their research have identified high correlation between the quantity of decay of advanced stage detected by tomogram and real quantity of decay in transversal section. However, the implementation of tomograph in stand circumstances is connected with certain limitations. Devices used for surveying of trees are sensitive to rain and the accuracy of results of survey is not reliable in low temperatures. The weight of the device and its moving from tree to tree requires significant effort and time. However, the reliability of the results of measurements which are obtained in favorable weather conditions and the possibility of measuring on standing trees are giving to this method significant advantage compared to the analysis of decay on fallen trees.

According to the results of conducted research was obtained highly statistically significant regression between the surface of the injury and surface of the decay of the wood. One-way analysis of the variance was more precisely reviewed the impact of the size of the injury to the size of decay of the wood in the zone of the injury. According to Tukey HSD test was confirmed highly statistically significant difference in the size of decay of the wood in transversal section between trees with the size of injury larger than 1500 cm^2 and those with the size of injury lower than 500 cm^2. Statistically significant differences in the size of the decay of the wood were identified between trees with injuries of size 501-1500 cm^2 and those with injuries larger than 1500 cm^2. Similar results and conclusions are mentioned also by other researchers who have dealt with the problem of decay of wood. However, due to low number of analyzed trees the assessment of good quality for reliability of currently valid criterion for classification of trees into third silviculture-technical class (width of injury larger than 10 cm) based on the results of these researches is not possible (Zahirović, 2012; Krpan *et al.*, 1993; Schultz, 1973). However, it provides directions for better planning of the sample in further researches of the processes of decay of wood on injured trees and it confirms the negative aspect of this process.

CONCLUSIONS - *Zaključci*

Based on the results of this research highly statistically significant connection between the surface of the injury and the surface of decay in transversal section in the place of injury was identified. Highly statistically significant difference in the size of decay of wood in the transversal section between trees with size of injury larger than 1500 cm^2 and those with injuries lower than 500 cm^2 was confirmed. Statistically significant differences in the size of the decay of wood were identified between trees with sizes of injuries 501-1500 cm^2 and those with injuries larger than 1500 cm^2. In order to reduce economic damage caused by decay on most valuable parts of the tree, damaged trees have to be removed from the forest stands in due time. The best is to do this immediately after conducted felling.

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SAŽETAK

Obiļna jela u Bosni i Hercegovini je najrasprostranjenija ļetinarska vrsta drveta. Zajedno sa bukvom i smrļom gradi vrijedne ġumske sastojine. Na njeno zdravstveno stanje utiļu brojni faktori abiotske i biotske prirode. Jedan od tih uticaja jesu i oġteĺenja podmlatka i dubeĺih stabala koja nastaju pri iskoriġtavanja ġuma. Povrede na stablima nastaju kontaktom izmeĽu strojeva i dubeĺih stabala ili pak kontaktom sajle i zakaļenih drvnih sortimenata koje ovi strojevi primiļu i privlaļe. Nastale povrede predstavljaju pogodne ulazne otvore za naseljavanje mikroorganizama koji potom razaraju drvo i tako ga koriste za svoju ishranu. Drvo zahvaĺeno ovim procesom ima umanjen kvalitet ili postaje potpuno neupotrebljivo. Inficiranje i razvoj truleģi u korelaciji je sa veliļinom povrede i njenim poloģajem na stablu.

Uobiļajeni naļin utvrĽivanja truleģi baziran je na sjeļi stabala i analizi vidljivih promjena na popreļnom presjeku. U novije vrijeme razvijeni su i metodi analize truleģi na bazi protoka elektriļne energije ili zvuka kroz drvo. Jedan od tih metoda je i zvuļna tomografija koja nam daje moguĺnost da sagledamo stanje drveta bez da stablo posijeļemo ili ga znaļajnije oġtetimo. Vrġi se ureĽajem koji se naziva tomograf. Ovaj ureĽaj prikazuje promjene u strukturi drveta na osnovu razlike u vremenu protoka zvuļnog sinala izmeĽu senzora postavljenih na mjestu mjerenja.

U ovom radu, metodom tomografije, utvrĽivano je prisustvo znakova truleģi drveta na povrijeĽenim stablima jele i analizirana je zavisnost ove pojave od veliļine povrede. Pri istraģivanju se poġlo od nul hipoteze da ne postoji statistiļki znaļajna razlika izmeĽu prosjeļnih povrġina truleģi na popreļnom presjeku kod stabala jele sa razliļitom veliļinom povrede uz nivo pouzdanosti $p < 0,05$.

Istraġivanja su provedena u odjeljenju 86 gospodarske jedinice ĂIgmanñ, koja pripada ġumsko gospodarskom podruļju ĂIgmanskoñ, a kojim gazduje Kantonalno javno preduzeĆe ĂSarajevo ï ġumeñ d.o.o. Sarajevo. Terenska snimanja su vrġena 2013. godine na 30 povrijeĽenih stabala jele koja su odabrana duġ traktorskih vlaka. Na ovim stablima evidentirane su povrede debla do 2 m visine od tla i izmjerena njihova ġirina i duġina u centimetrima. Za 37 najznaļajnijih oġteĆenja snimljene su promjene u drvetu na popreļnim presjecima debla u zoni oġteĆenja pomoĆu tomografa ARBOTOM® Version 5. Analiza povrġina na tomogramu je provedena pomoĆu programa WinGIS-a 2003 (tabela 1). U istraġivanju uticaja veliļine povrede na veliļinu truleġi drveta primjenjene su regresiono-korelaciona anliza i jednostruka analiza varijanse. Jaļina uticaja veliļine povrede na veliļinu truleġi testirana je primjenom Tukey HSD testa uz nivo pouzdanosti 0,05.

Prema rezultatima provedenih istraġivanja utvrĽena je visoko statistiļki znaļajna povezanost povrġine povrede i povrġine truleġi drveta (p < 0,001). Jednostrukom analizom varijanse preciznije je sagledan uticaj veliļine povrede na veliļinu truleġi drveta u zoni povrede (tabela 4). Tukey HSD testom potvrĽena je visoko statistiļki znaļajna razlika u veliļini truleġi drveta na popreļnom presjeku izmeĽu stabala ļija je povrġina povrede veĆa od 1500 cm^2 i onih ļije su povrede manje od 500 cm^2. Statistiļki znaļajne razlike u veliļini truleġi drveta utvrĽene su izmeĽu stabala ļije su povrġine povreda bile 501-1500 cm^2 i onih ļije su povrġine povreda veĆe od 1500 cm^2 (tabela 5).

U cilju smanjenja ekonomske ġtete koju prouzrokuje truleġ na najvrijednijim djelovima stabla, oġteĆenjivanju dubeĆih stabala prilikom sjeļe, primicanja i izvoza drveta iz ġume mora se pruġiti adekvatna paġnja. OġteĆena stabla moraju se pravovremeno ukloniti iz ġumskih sastojina. Najbolje je to uraditi neposredno nakon provedenih sjeļa. Ukoliko se ova mjera ne provede na ovaj naļin, neminovne su sanitarne sjeļe s ciljem sprijeļavanja ulanļavanja ġtetnih agenasa na povrijeĽenim stablima i iskoriġtenja drvne mase prije pojave naprednog stadija truleġi.