Effect of Tree Damage on Crown Defoliation and Diameter Increment of Silver Fir (Abies alba Mill.) during Timber Skidding in Gorski Kotar Region

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Abstract
Silver fir (Abies alba Mill.) is the most important commercial coniferous species in the Republic of Croatia. It is the main tree species of selection forests in Croatia that covers an area of 200,000 ha. However, silver fir is the most endangered forest tree species due to the effect of different unfavorable biotic and abiotic factors. The outcome of these factors is a serious tree decline. Due to such a serious decline of silver fir trees, salvage cuttings and skidding of forest wood assortments are very frequent. Timber skidding causes damage to trees and forest soil affecting adversely the diameter increment and tree value, and resulting in tree decline. This paper presents the analyses of damage caused to trees by timber skidding. The aim of this research was to determine the correlation between the surface of tree damage and crown defoliation, as well as the relation between tree damage and diameter increment. On a permanent experimental plot of 2 ha covered with commercial silver fir forests in Gorski Kotar region (northwest Dinarides), perennial data were collected about crown defoliation, diameter increment and damage to silver fir trees caused by machinery. Damaged trees had significantly higher crown defoliation than undamaged trees. Crown defoliation significantly correlated with the damage surface and number of tree damages. The correlation was positive and low (r = 0.31). Damaged trees of all diameter classes had smaller diameter increment than undamaged trees. Damage surface, as well as number of damages had no significant correlation with tree diameter increment. The average tree damage surface was 607 cm2, and the average number of damages per tree was 1.5. The highest number of damaged trees was recorded in 3a defoliation class (60 – 80 % defoliation) and in diameter class above 50 cm. The largest damage surface was recorded in 3b defoliation class (80 - 99 %) and diameter class above 50 cm. According to damage surface classes, the highest number of trees was recorded in the first damage class (< 100 cm2). The highest number of damaged trees was recorded with dominant trees according to Kraft, and the largest damage surface was recorded on codominant trees.

Keywords: damaged trees, forest machinery, crown defoliation, diameter increment, silver fir, *Abies alba* Mill.

1 Introduction

Silver fir is the most important commercial coniferous species in the Republic of Croatia. It is the main tree species of selection forests in Croatia that cover an area of 200,000 ha. With respect to tree crown defoliation and dieback intensity, silver fir is the first in the Republic of Croatia. The percentage of considerably defoliated silver fir trees is 72 % (Potočić and Seletković, 2011). The average dieback intensity in Gorski Kotar region in the period from 1995 to 2007 ranged between 4.1 and 9.2 %, and the annual increment ranged between 1.1 and 1.7 % of the growing stock (Ugarković et al. 2011). Dieback of silver fir trees is a complex issue, and it is the result of different effects of unfavorable biotic and abiotic factors. It is one of the most significant economic and ecological problems in the Croatian forestry (Tikvić et al. 2009). Economic problems are related to lower quality of wood material, disruption in sustainable planning and management as well as higher management costs and lower income. Serious tree dieback has an unfavorable impact on the dynamics of forest operations, and the need for a quick intervention aimed at lowering the losses results in decreased quality of planning, preparation and execution of works (Krpan 1989). Due to intensive tree dieback, salvage cuttings and timber skidding are frequent compared to standard 10-year rotation management. The factors affecting the execution of works are the terrain slope and numerous karst phenomena and this is why timber skidding prevails on a built network of secondary roads, the so-called strip roads.

In performing forest works, in spite of all protection measures, damage is caused to habitat and trees. Vehicles, primarily tractors and skidded wood, cause the biggest damage due to their continuous contact with the soil, and above all because of their moving around the stand.

According to Martinić (1991) the most significant factors affecting the damage caused to forests are: methods and means of skidding, man's attitude towards forest management and work conditions.

In timber skidding, apart from soil compaction, damage is caused to trees, i.e. to saplings. In forest timber skidding, the level of forest damage increases with the increase of machine size and mass, degree of mechanization and skidding length (Martinić et al. 1999). Damage volume is closely related to means of work, work organization, suitability of work methods and quality of work techniques applied by forest operators (Martinić 2000). Peeled bark is the most frequent form of causing damage to trees in wood harvesting (Sabo 2003). Bark damage can disturb the above-ground growth of trees and make trees susceptible to mycosis infection. The possibility of dry rot fungal infection of trees is lower in case of bark contusion than in case of peeled bark (Limbeck-Lilienau 2003). With bark damage < 100 cm^2 the possibility of infection by fungal spores is lower because trees can quickly close such damages (Meng 1978). Bragg et al. (1994) outline that the surface of the critical peeled bark damage causes the tree dieback depending on tree species, tree age, genetic predisposition, place and position of damage, and size and form of damage with respect to the tree longitudinal axis. Smith et al. (1994) outline that the damage is only critical if its surface is equal to the square of the tree diameter at breast height. In forest timber skidding, the most serious damage is caused to trees along strip roads (Naghdi et al. 2011). In their research of tree damage caused by skidders, Krpan et al. (1993) outline that trees along skid trail are the most endangered and that the most frequent damages are bark contusions and peeled bark on stems up to 1.5 m from the soil surface. The authors also state that the development of mycosis has not been observed on damages < 100 cm^2 and hence they consider that trees can recover from damages of such size.

The objectives of this research were to determine the size of peeled bark damages on trees caused by timber skidding, intensity of tree damage and the effect of tree damages on crown defoliation and diameter increment of silver fir trees.

1.1 Scope of research

Wood harvesting operations can cause considerable damage to stands during felling, winching and skidding (Nikooy et al. 2010). Most researchers consider that the number of mechanically damaged trees is a good indicator of the total stand damage (Sirén 2001). The effects of tree damage are lower increment, value drop of technical wood and tree dieback. When bark is peeled on a tree, some physical changes and cell differentiation occur in the zone around the wound and the wound usually becomes closed (Shigo 1984). However, large wounds that cannot be closed by the tree are a real problem.

Dry rot usually enters the tree and spreads, and the effects of such injuries increase with time (Carvell 1984). According to Krpan (1983), the aim of construction of strip roads is to minimize stand damage caused by forest machinery, provide save skidder movement and lower skidding costs. Heavy forest machinery has an impact on the soil, saplings and trees along strip roads and it can affect the stand development. If strip roads cover around 30 % of the felling site area, forest machinery causes considerable damage to soil and stand (Murphy 2004). Compaction of forest soil, transfer of forest soil and removal of forest floor from strip roads are the main negative effects of forest machinery (Ampoorter et al. 2007, Naghdi et al. 2009). Compaction of forest soil and transfer of forest floor can limit the growth of tree roots along strip roads. There is also a lack of air, nutrients and water in the soil that trees need. These are the other negative effects of forest machinery (Hager, Sieghardt 1992, Davies et al. 1992). The results of these changes can have an impact on the tree height, diameter increment, crown condition and other quality and quantity characteristics of trees and saplings along strip road. Anderson et al. 1992 established that root biomass at the roadside landing and on strip road differed significantly from the control area even after 25 year.

Therefore, forest habitat can be degraded for a long time (Kozlowski 1999, Makineci et al. 2008). Injuries caused by collision of felled trees and crowns of standing trees during wood harvesting operations can affect the growth, diameter increment and crown vitality (Han and Kellogg 2000).

2 Material and work methods

For analyzing the relationship between the tree damage surface and crown defoliation and diameter increment of silver fir trees, an experimental plot of 2 ha was selected. It is a permanent experimental plot on which monitoring of tree crown condition and damage to silver fir trees has been performed since 1998. All silver fir trees with the diameter at breast height above 10 cm were numbered and their crown condition has been monitored for 10 years. Crown defoliation was estimated in July each year according to the methodology of ICP Forest Manual (PCC 1988). Diameter increment was determined by control method. Out of tree damages caused by skidding, we have taken into consideration peeled bark on the tree stem, butt end and root collar. Tree damages were classified into classes < 100 cm^2, 100 – 500 cm^2, 500 – 1000 cm^2 and > 1000 cm^2. The intensity of stem damage was determined as the percentage of damaged trees after timber harvesting compared to the total number of trees. The social position in the stand of each marked tree was determined according to Kraft and the crown height compared to tree height was determined by a heightmeter. Also, by each damaged tree, terrain slope was measured by a clinometer. Statistical data processing (descriptive statistics, Student t-test and Sperman correlation) was carried out in statistical program Statistica 7.1. (StatSoft, Inc. 2007).

2.1 Research area

The research was carried out in mountainous Croatia, in the range of beech-fir and fir forests, in Gorski Kotar (northwest Dinarides), in the management unit "Brloško" within Fužine Forest Administration. According to Köppen classification, Gorski Kotar belongs to Cfsbx type of climate. This is a moderately worm rainy climate without dry periods. According to the data of the meteorological station Vrelo Ličanke, the average annual air temperature for the research area is 7.2^0 C, and the average precipitation volume is around 2000 mm (Seletković 2001). The relief of the research area is very irregular and loose. The experimental plot is situated at the altitude of 800 m above sea level, with different exposition, on dystric brown soil in the community of fir forest with hard fern. Terrain slope ranges between 5 and 20°. Silver fir prevails in the mixture with 77 %, and on the experimental plot there are 275 silver fir trees. The growing stock is 345 m^3/ha.

3 Results of research

According to the results presented in Table 1, the average crown defoliation of silver fir trees damaged by timber skidding was 69.2 %, and the average annual diameter increment 0.4 cm. The average tree damage surface was 606.7 cm^2 ranging from minimum 4 cm^2 to maximum 3780 cm^2. The damaged trees had an average diameter at breast height of 63.9 cm.

Table 1: Descriptive statistics of variables of damaged silver fir trees (*Abies alba* Mill.) for the period 1998 to 2008 in the research area of Gorski Kotar

Variable	Mean	Minimum	Maximum	Std. Dev.
Crown defoliation (%)	69.2	25.0	90.0	15.0457
Diameter increment (cm)	0.4	0.1	1.1	0.2641
Damaged area (cm^2)	606.7	4.0	3780.0	880.5319
Number of damages (N/tree)	1.5	1.0	5.0	0.9023
DBH (cm)	63.9	12.8	114.7	26.4617
Terrain slope (%)	24.1	0	50.0	15.3901

The total sum of the damage surface on damaged trees was 30941 cm^2 on the area of 2 ha and in a ten-year period. Out of a total of 275 silver fir trees on the experimental plot, 51 had stem, butt end and root collar damage. Damage intensity was 18.5 % related to the total number of trees of the same species. However, this damage intensity is only related to silver fir trees and to the period of ten years. In the period of ten years, instead of a regular felling in the stand, there were seven salvage cuttings so that the damage percentage per each wood harvesting cycle is 2.64 %. In the class of surface damage < 100 cm^2 there were 18 trees or 35 % of trees, in the class 100 – 500 cm^2 there were 14 trees or 27 %, in the class 500 – 1000 cm^2 7 trees or 14 % and in the class > 1000 cm^2 12 trees or 24 %.

Table 2: Descriptive statistics of the damage surface according to crown defoliation degrees of silver fir trees (*Abies alba* Mill.) for the period 1998 to 2008 in the research area of Gorski Kotar

Degrees of defoliation (%)	Means	N trees	Std. Dev. cm^2	Minimum	Maximum
25 – 40	43	2	9.899	36	50
> 40 – 60	486	7	526.475	75	1426
> 60 – 80	793	22	1163.058	4	3780
> 80 – 99	500	20	605.629	18	2164
All degrees	607	51	880.532	4	3780

The highest number of trees with damage was recorded in the crown defoliation degree 60-80 %. Also the largest average damage surface was recorded in the same degree of crown defoliation of trees. The smallest number of trees with damages caused by timber skidding was recorded in the degree of crown defoliation 25-40 %. Trees in that degree also had the smallest average damage surface amounting to 43 cm^2 (Tab. 2).

Table 3: Descriptive statistics of damage surface on silver fir trees (*Abies alba* Mill.) according to some structural elements of the stand for the period 1998 to 2008 in the research area of Gorski Kotar

Structural elements		Means	N trees	Std. Dev. cm^2	Minimum	Maximum
Diameter classes (cm)	10 – 30	374	5	439.548	28	996
	30 – 50	548	13	958.209	40	3520
	> 50	665	33	910.823	4	3780
Social position of trees (Kraft)	Dominant	537	31	728.311	4	2990
	Codominant	1100	10	1433.422	40	3780
	Central	444	7	343.676	75	996
	Suppressed	64	3	44.677	28	114

Tree diameter class > 50 cm has the largest average damage surface of 665 cm^2. At the same time the highest number of damaged trees was recorded in the diameter class > 50 cm. With respect to the social position of trees, the highest number of damaged trees was recorded in the category of dominant trees, while the largest average damage surface was recorded with codominant trees.

Tree diameter class 10-30 cm and according to Kraft's classification the suppressed trees had the smallest average damage surfaces and the smallest number of damaged trees (Tab. 3).

According to the results presented in Table 4, positive and significant correlation was determined between the damage surface and number of tree damages and crown defoliation of silver fir trees. Negative and significant correlation was also determined between the damage surface and tree crown height from which it results that trees with crowns of bigger height have a smaller damage surface. According to strength, these correlations are weak or medium, and however they are statistically significant. No significant connection has been determined between the damage surface and diameter increment of damaged trees, nor correlation between damage surface and number of tree damages. Correlation between crown defoliation and diameter increment of damaged trees is negative and significant. Trees with higher crown defoliation also have a lower diameter increment (Table 4).

Table 4: Spearman correlation of variable coefficients of damaged silver fir trees (*Abies alba* Mill.) for the period 1998 to 2008 in the research area of Gorski Kotar

Variable	Damage surface	Crown defoliation	Diameter increment	DBH	Tree position	Crown height	Terrain slope
Crown defoliation	0.31*						
Diameter increment	- 0.03	- 0,25*					
DBH	0.11	0.04	0.65*				
Tree position	0.07	- 0.09	- 0.51*	- 0.74*			
Crown height	- 0.42*	- 0.19	- 0.03	- 0.06	- 0.09		
Terrain slope	- 0.19	- 0.13	- 0.24	- 0.45*	0.23	0.38*	
Nb of damages	0.35	0.31*	- 0.05	0.18	- 0.07	- 0.29*	- 0.23

* significant at the level $p < 0.05$

According to the results of the Student t-test, damaged trees have statistically significantly higher crown defoliation than undamaged trees. Diameter increment of damaged trees is lower than diameter increment of undamaged trees, and with trees of diameter class II (30-50 cm) it is statistically significantly lower (Tab. 5).

Table 5: Results of the Student t-test used to compare crown defoliation (%) and diameter increment (cm) by diameter classes of damaged and undamaged silver fir trees (*Abies alba* Mill.) for the period 1998 to 2008 in the research area of Gorski Kotar

Variable		Tree status		p – level
		Damaged trees	Undamaged trees	
Crown defoliation (%)		69.2 ± 15.045	62.1 ± 15.265	0.0039*
Class	I	0.16 ± 0.098	0.18 ± 0.139	0.799289
increment	II	0.23 ± 0.146	0.34 ± 0.177	0.040286*
(cm)	III	0.43 ± 0.236	0.51 ± 0.256	0.220272

* significant at the level $p < 0.05$, diameter classes I (10 - 30 cm), II (30 - 50 cm), III(> 50 cm)

4 Discussion

Different factors affect the damage caused to stands by forest operations, and the most important are the following: terrain and stand characteristics, types and features of machinery, technology and method of work and man's attitude towards work. According to Sabo (2003) the average damage surface in selection forests of silver fir ranges between 688 cm^2 and 1128 cm^2, with the maximum damage surfaces ranging from 3230 cm^2 to 5250 cm^2, and the minimum from 28 cm^2 to 72 cm^2. According to our results, the average damage surface was 607 cm^2, the largest damage surface was 3780 cm^2, and the minimum only 4 cm^2. Such a high percentage of damaged trees in wood harvesting (18.5 % trees in ten years) is the result of frequent "salvage cuttings" due to intensive tree dieback. A high percentage of crown damage and defoliation of silver fir trees results in frequent "salvage cuttings" and hence also in increased stem, butt end and root collar damage caused by felling, processing and skidding of wood assortments. The highest number of damaged trees and the largest damage surfaces were recorded in the tree diameter class > 50 cm and with dominant and codominant trees. These results are in accordance with the research by Sabo (2000).

According to the results of the correlation analysis, the increase of the damage surface and number of damages led to the increase of crown defoliation of silver fir trees. The results of research confirmed once again the assumption that trees with higher defoliation also have a lower diameter increment.

In the parts of the stand with higher tree density per surface unit, trees also have smaller crowns than trees that grow in a less dense forest. According to our results, the higher tree density per surface unit, the higher are the damages caused to trees by timber skidding. No correlation has been determined between the damage surface and number of damages on trees, from which it results that the surface of some injuries or damages caused by timber skidding are really large. According to the results of our research, no dependence was observed of damage surface on the tree diameter at breast height, which implies that the damaged trees are of all diameter classes. These results of research are in accordance with the results obtained by Poršinsky and Ožura (2006).

Bettinger and Kellog (1993) consider that trees with stem bark damages closer to the ground are more exposed to the development of mycosis. The same authors outline, as an accompanying phenomenon, the decrease of tree volume increment, i.e. the loss of value of the future logs. Krpan et al. (1993) also determined the decrease of increment with trees damaged by timber skidding. According to our results, damaged trees have a lower diameter increment than undamaged trees, and however, the diameter increment of damaged trees of diameter class 30-50 cm is statistically significantly lower. In the Republic of Croatia, the allowed tree damage in timber skidding has not been legally established yet. The law only provides subsequent felling of trees damaged by timber skidding. The regulations in USA allow 3 % to 5 % of trees remaining after felling, as an acceptable level of stand damage caused by forest operations, depending on authorities of individual inspectors (Han and Kellogg 2000). According to Sabo (2003) in fir forests of Gorski Kotar, the percentage share of damaged silver fir trees ranged between 1.7 % and 2.1 %. According to our results for a ten year period, the damage intensity was 18.5 %, which would be 2.64 % of damaged trees per each felling. According to Kulušić (1990), somewhere the estimated damage was higher than the costs of timber skidding, and somewhere even higher than the value of harvested wood. During timber skidding, damage is caused to the remaining trees that cannot be avoided. There are also damages that can be avoided by the use of suitable technologies and methods of work, selection of the right means of work, change of attitude of workers and management towards work, forests and damage to trees and stands. The choice of good work and planning methods can decrease the damage to trees (Naghdi et al. 2011).

As a protection measure for stands and trees, Spârchez et al. 2009 recommend placing logs along trees and along strip road, keeping the set travel direction, performing skidding operations in the period when the soil is dry and the stand covered with snow, introducing cable yarding wherever possible. Forest workers have to be well trained and experienced for carrying out forest operations. They also have to be aware of the value of the remaining trees and of the significance of minimizing the damage in irregular stands, if the intent is to provide sustainable management (Nikooy et al. 2010).

5 Conclusions

Wood harvesting operations cause direct and indirect damage in forest ecosystem. Mechanical damage to soil and trees can be considered as direct damage. However, wood harvesting operations also cause some indirect damage as e.g. trees with peeled bark in time get higher crown defoliation and lower increment. The highest number of trees with damage and the largest damage surface were recorded with trees of diameter class > 50 cm. With respect to the social position of trees, the highest number of damaged trees was recorded with dominant trees, and the largest damage surface was recorded on codominant trees. The research showed that damage surface as well as the number of damages caused by timber skidding affected considerably crown defoliation of silver fir trees. Crown defoliation of trees damaged during timber skidding is considerably higher than crown defoliation of undamaged trees. Generally, the increment of damaged trees is lower than the increment of undamaged trees, and the tree increment of diameter class 30-50 cm is statistically significantly lower.

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