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DAMAGE OF THE REMAINING STANDS CAUSED BY VARIOUS TYPES OF LOGGING TECHNOLOGY

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Abstract

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Forest harvesting causes a lot of damage, which results in damage of the remaining stand. These damages have different character. Their origin, range, and type is affected by the type of machinery, harvesting technology and the machine operator. This paper was focused on the negative impact of three types of forest harvesting technologies to the remaining stand. We considered wheeled skidder technology, and CTL technology with wheeled and tracked chassis. The harvest in stands varied between 21 and 52%, with an average concentration of felling 13.7–95.4 m^3 per one skid trail. We observed that the damage rate in stands processed by CTL technology was between 7.3 and 8.03%. Skidder technologies caused damage between 17.8% and 44.6%. The average size of wound caused by CTL technologies was between 167 and 322 cm^2. Skidder caused damages with area between 395 and 506 cm^2. We also observed differences between damages caused by various types of chassis. CTL technology with tracked chassis caused more damages of timber and tree root system. We used multivariate regression and correlation analyses to evaluate the effect of stand density and intensity of harvest on the intensity of damage. The analyses did not confirm significant impact of these two characteristics on intensity of damage, with coefficients of correlation of 0.22 (stand density) and 0.53 (intensity of harvest).

Keywords: Cut-to-length technology, skidder technology, type of chassis, damage of remain stand

INTRODUCTION

Modern technologies for forest harvesting and timber transport have various weight, chassis, and engine power. It is very difficult to avoid negative impacts and damage of remaining stand in the process of forest harvesting (Meng, 1978). Felling and processing trees result in damaging the remaining trees. These damages depend on numerous factors, such as: felling, processing stems, and logging (Warkotsch *et al.*, 2004; Vasiliauskas, 2001). The most important are damages on tree species of great economic importance, which may range from 26 to 75% (Johnson and Cabarle, 1993), despite the fact that the skid trails have a small share of the total stand area (Gullison and Hardner, 1993). In terms of qualitative production, up to 80% of revenue comes from the lowest part of stem, therefore it is necessary to avoid damaging this part of stem (Schütz, 1985). Damages and bark scrapes on the lowest part of the stem (up to 1 m height) are classified as damage caused by skidding. Damages that exceed this height are classified as damage caused by felling (Güglhor and Melf, 1995). One of the principal problems of using mechanized harvesting technologies is to achieve high performance of the technology and to reduce mechanical damage to the remaining stand (Lukáč, 2005). Felling method, technology used and the characteristics of the machines (weight, power, type of tires) are considered very important factors, regarding the impact of technology on remaining stand. Machine movement on the skid trails causes very dangerous damages of root system of trees. Type of chassis and the type of machine are the most important factors determining the extent of damage (Kremer *et al.*, 2007; Korten, 2003; Uhl *et al.*, 2003, Brochert *et al.*, 2008). Several methods and classification systems were elaborated to evaluate damages on stems. The most frequent type of damage is bark scrape on stems, which are the gateway for wood – deteriorating fungi (Nill *et al.*, 2011). Damage assessment plays a very important role, mainly to determine whether the damage was caused by harvesting process, whether the extent of damage is acceptable and whether it is in compliance with criteria of sustainable management of forest (Whitman *et al.*, 1997).

Damage of remaining trees is the first indicator of negative impact of technology on forests. The extent, intensity, and type of damage is affected by numerous factors, such as: type of machine, distance between the skid trails, felling technology, terrain conditions, and other factors.

MATERIALS AND METHODS

Measurements were carried out in six forest stands which were located in the Slovak Republic (Tab. I). We focused on two types of technologies: CTL technology with two types of chassis (wheeled and tracked) and two types of skidders. Measurements were carried out from July 2012 until august 2012. Individual skills of machine operators are very important factors, affecting the impact of technology on the forest ecosystem (Tab. II).

We evaluated the damage to remaining stand on sample plots after the forest harvesting took place. Sample plots were rectangular, 20×20 or 20×40 m. Size of the plots depended on used technology and method of skidding. For CTL technologies and chokerless skidder technologies we used 20×20 m sample plots. For choker skidding, we used larger size of sample plots (20×40 m). We established the plots in the remaining stand so that they characterised the variability of natural conditions.

II: *Information about machine operators*

Machine	Operator	
	Age (y)	Practical experience (y)
John Deere 1070D [a]	42	10
John Deere 810D [b]	33	8
Neuson 132HVT [a]	29	3.5
Novotný LVS 5 [b]	41	4.5
HSM 805 HD [c]	52	7
Zetor 7245 [d]	-	-

a) harvester, b) forwarder, c) skidder with hydraulic crane, d) agricultural tractor adapted for forestry

The number of sample plots depended on the size of the stand (Ulrich *et al.*, 2002).

Generally the area of the sample plots should be at least 10% of the stand area. In stands with area larger than 5 ha, it should be at least 5% of stand size.

It is necessary to keep minimal spacing between the individual sample plots (Šmelko, 2007).

We established 49 research plots on total. Within these sample plots we evaluated the damage to the remaining stand. We assessed 1284 trees on all sample plots, from which 106 were damaged. We surveyed and recorded the following data about individual trees:

- tree species, number of damaged, and undamaged trees,
- distance of damaged tree from the edge of the skid trail in two metres strips,
- the location of damage on stems according to the classification scale (Tab. III),
- the size of the damage according to the classification scale (Tab. IV),
- damages smaller than 10 cm² were not analyzed further,
- intensity of damage according to the classification scale (Tab. V).

I: *Basic information about forest stands*

Stand	2052	2027	187C20	188	2051	588
Machine	John Deere 1070D + 810D	John Deere 1070D + 810D	Neuson 132 HVT + Novotný LVS 5	Neuson 132 HVT + Novotný LVS 5	Zetor 7245	HSM 805 HD
Chassis	wheeled	wheeled	tracked	tracked	wheeled	wheeled
Felling method	CTL	CTL	CTL	CTL	stem method	stem method
Type of treatment	thinning 50 +	thinning 50 +	thinning to 50	thinning to 50	thinning 50 +	shelterwood
Species and abundance (%)	OAK[a] 100	OAK 100	SP[b] 60 PI[c] 40	SP 90 PI 10	OAK 100	OAK 39 PI 23 HB[d] 17 BE 9 12 OB[e]
Age (y)	70	75	30	35	80	110
Area (ha)	8,58	7,9	5,89	12,52	16,70	4,12
Slope (%)	10	5	40	30	15	25
Dimensions of sample (m)	20×20	20×20	20×20	20×20	20×40	20×20
Number of sample plots	10	10	6	12	5	6

a)Oak – Quercus petraea, b) *Spruce – Picea abies,* c) Pine – *Pinus sylvestris,* d) Hornbeam – *Carpinus betulus,* e) *other broadleaved*

III: *Classification scale for location of damage on the stem (Meng, 1978)*

Number	Location of damage	Characteristics
1	Root	Root damage at a distance of 0.21 to 1.0 m from the stem
2	Buttress root	Damage of the butt part of a stem at a distance of 0.2 m from the stem and to the high 0.3 m on stem
3	Stem	Damage of stem between 0.3–1.0 m high
4	Stem	Damage of stem higher than 1 m

IV: *Classification scale for estimation the damage size (Meng, 1978)*

Stage of wound	Damage size (cm²)	Characteristic
0	< 10	meaningless
1	11–50	very small
2	51–100	little
3	101–200	medium size
4	201–300	great
5	> 300	very big
6	root rupture – break	destructive

V: *Classification scale for estimation of damage intensity (Butora, Schwager, 1986)*

Damage class	Damage characteristics
The top layer of bark is damaged	The outer layer of bark is damaged, cambium is undamaged, the tree reacts with low outflow of resin, low risk of fungal infection
Bark crushed (wrinkled)	Bark is wrinkled, but holds on a stem, fungal infection risk is low
Wood exposed but undamaged	Bark is peeled off, wood is exposed but undamaged, fungal infection risk is moderate
Wood exposed slightly damaged	Bark is peeled off, wood is exposed and slightly damaged, high risk of fungal infection
Wood exposed, heavily damaged	Bark is peeled off, wood is exposed and heavily damaged, risk of fungal infection is very high

RESULTS AND DISCUSSION

We divided the results into three groups according to used technology:

1) Damages caused by wheeled CTL

This technology was used in forest stands n. 2027 and 2052. Harvester John Deere 1070D and forwarder John Deere 810D worked in these stands. The natural and production conditions were similar in both forest stands. Average felling intensity in these stands was 21% and we observed that 33 of 411 trees were damaged (8.03%). We recorded 22.5% of trees with multiple damages. The average size of damage was 322 cm^2, very large damage according to Tab. IV. The size of damages was affected by the time of felling (April to May). At this time oak is very sensitive to bark damaging. Most of damages (98%) were in the "wood exposed but undamaged" category (Tab. V). Only 2% were in category "wood exposed, slightly damaged".

Total area of damages in all sample plots was 12,875 cm^2 (16,094 cm^2.ha^{-1}). The largest share of total area of damages was located at the height of 0.3–1.0 m (Tab. VI). The most of the damages was also located in the lowest part of stem. The roots were damaged only occasionally, 2.7%.

We also examined the frequency of damages to the remaining trees depending on the distance

VI: *Location of damages on the stem (CTL, wheeled)*

Place on the stem	Root	Up to 0.3 m height	0.3–1.0 m height	Over 1.0 m height
Share of damaged area of stems (%)	2.7	27.6	62.2	7.5
Share of the number of damage (%)	7.8	37.4	37.8	17.1

VII: *Frequency of damage according to the distance from the skid trail (CTL, wheeled)*

Distance from the skid trail (m)	0–2	2–4	4–6	6–8	8–10
Share of damaged area of stems (%)	66.8	8.8	8.9	7.2	8.4
Share from the number of damage (%)	47.7	14.9	15.4	12.7	9.3
The average size of damage (cm²)	212	29	33	25	22

from the forwarding trail. Most of the damages were located near the skid trails (Tab. VII). The number of damages decreased with increasing distance from the skid trails.

2) Damage caused by CTL technologies by tracked chassis

This technology worked in forest stands n. 187C20 and 118. The natural conditions in both stands were similar. We observed 42 damaged trees from 573 assessed trees. The average size of damage was 167 cm^2, medium size (Tab. IV). The intensity of damage was 7.4% (felling intensity 24.5%). Multiple damages were recorded on 8% of the damaged trees. The total area of damage in all sample plots was 5900 cm^2 (8,194 cm^2.ha^{-1}).

We recorded 77.1% damages in category "wood exposed, but undamaged" and 5.3% of damages in category "wood exposed, slightly damaged". Track slippage caused 6.6% of damages located on the root system of trees near the skid trails (Tab. VIII).

Tracked CTL technology caused damages located in the lowest area (0–0.3 m) of stem (Tab. VIII). We found that the most of the area of damage (41%) was in distance 0–2 m from the skid trails (Tab. IX).

3) Damage caused by wheeled skidder technology

We recorded significant differences in size and location of damage caused by skidders compared to CTL technologies. Both tractors skidded whole stems (tree-length logging method). Damage caused by agricultural tractor adapted for forestry (Zetor 7245) in stand 2051 reached average damage size 506 cm^2. This represented "a very large" area (Tab. IV). Total size of damages in all sample plots was 21,750 cm^2 (54,375 cm^2.ha^{-1}). In this case we assessed 208 trees in total, 37of them were damaged (17.8%). Intensity of felling was 25.2%. Only 6 trees were damaged more than once. All damages lay in the category "wood exposed but undamaged" (Tab. V).

We observed similar character of damage in forest stand 588, processed by HSM 805 HD skidder. Technological process was based on the "machine to timber" principle (chokerless skidding of timber). The average size of damage was 395 cm^2 ("very large"). Total size of damages reached 15,805 cm^2 (65,854 cm^2.ha^{-1}). We assessed 56 trees in this stand, 25 of them were damaged (44.6%). Intensity of felling was 52.1%. Eight trees were injured more than once (14.3%). Most of the observed damages were in the category "wood exposed, but undamaged" (97.5%), 2.5% were in the category "wood exposed, slightly damaged". The highest intensity of damage, compared to the other stands, was caused due to higher intensity of felling and technology of skidding where skidder travelled directly into the forest stand.

The extent and character of damage caused by skidders was similar to CTL technologies although with greater size of damages (Tab. X–XIII). Most damages were located in 0.3 to 1.0 m height on stem. In stand n. 2051–64.4% and in stand n. 588–68.9% of damages were located in this height interval. Most of damages in stand n. 2051 (58.1%) were placed in the lowest part of stem (up to 0.3 m) In stand n. 588 most of the damages (52.5%) were between 0.3 and 1.0 m height. We observed that in stand n. 2051 56% of damages occurred 2 m away from the skid trail,

VIII: *Location of damages on the stem (CTL, tracked)*

Place on a stem (m)	Root	To 0.3	0.3–1.0	Over 1.0
Proportion of damaged area of stems (%)	6.6	43	41.5	8.9
Proportion of the number of damage (%)	29.9	16.8	42.3	11

IX: *Frequency of damages according to distance from forwarding line (CTL, tracked)*

Distance from the skid trail (m)	2	2–4	4–6	6–8	8–10
Share of damaged area of stems (%)	41	19.9	3.9	32.2	3.0
Share of the number of damages (%)	72.1	14.7	2.5	9.5	1.2
The average size of damage (cm^2)	89	92	200	113	50

X: *Location of damages on the stem (agricultural tractor adapted for forestry)*

Place on a stem (m)	root	to 0.3	0.3–1.0	over 1.0
Proportion of damaged area of stems (%)	0	33.6	66.4	0
Proportion of the number of damage (%)	0	58.1	41.9	0

XI: *Frequency of damages according to distance from forwarding line (agricultural tractor adapted for forestry)*

Distance from the skid road (m)	2	2–4	4–6	6–8	8–10
Proportion of damaged area of stems (%)	70	3	11	1	3
Proportion of the number of damage (%)	56	7	7	5	9
The average size of a damage (cm^2)	631	233	767	150	150

XII: *Location of damages on the stem (HSM skidder)*

Place on a stem (m)	root	to 0.3	0.3–1.0	over 1.0
Proportion of damaged area of stems (%)	3.8	16.1	68.9	11
Proportion of the number of damage (%)	5	32.5	52.5	10

XIII: *Frequency of damages according to distance from forwarding line (skidder HSM)*

Distance from the skid road (m)	2	2–4	4–6	6–8	8–10
Proportion of damaged area of stems (%)	75	5	17	1	2
Proportion of the number of damage (%)	75	8	13	3	3
The average size of a damage (cm^2)	736	287	662	160	360

XIV: *Multiple regression and correlation analysis (impact of treatment intensity and stand density on intensity of damage)*

N = 20 2052 a 2027 CTL – wheeled	**The results of regression with the dependent variable: the intensity of damage R = 0.22; R² = 0.05 F(2.17) = .44 p < .65 standard deviation of estimate: 10.01**					
	b*	**St. deviaton of b***	**b**	**St. deviaton of b**	**t(17)**	**p-value.**
Absolute term			17.14	11.74	1.46	0.16
Intensity of felling	0.13	0.26	0.17	0.35	0.48	0.64
Density	–0.25	0.26	–0.47	0.50	–0.94	0.36
N = 18 187C20 a 188 CTL – tracked	**R = 0.54 R² = 0.29 F(2.15) = 3.09 p < .08 standard deviation of estimate: 7.00**					
	b*	**St. deviaton of b***	**b**	**St. deviaton of b**	**t(15)**	**p-value.**
Absolute term			–9.05	13.03	–0.69	0.50
Intensity of felling	**0.51**	**0.24**	**0.50**	**0.23**	**2.14**	**0.05**
Density	0.07	0.24	0.09	0.33	0.28	0.79
N = 5 2051 Tractor –Zetor 7245	**R = 0.48; R² = 0.23 F(2.2) = .30 p < .77 standard deviation of estimate: 11.77**					
	b*	**St. deviaton of b***	**b**	**St. deviaton of b**	**t(2)**	**p-value.**
Absolute term			16.79	72.65	0.23	0.84
Intensity of felling	0.36	0.64	1.41	2.50	0.57	0.63
Density	–0.41	0.64	–0.61	0.95	–0.64	0.59
N = 6 588 Tractor – HSM 805 HD	**R = 0.40; R² = 0.16 F(2.3) = .29 p < .77 standard deviation of estimate: 13.47**					
	b*	**St. deviaton of b***	**b**	**St. deviaton of b**	**t(3)**	**p-value.**
Absolute term			18.0	67.14	0.27	0.81
Intensity of felling	0.38	0.63	0.44	0.73	0.61	0.59
Density	0.04	0.63	0.23	4.07	0.06	0.96

whereas in stand n. 588 more than 75% of damages occurred in this distance.

We used multivariate regression and correlation analysis to verify the relationship between stand density and felling intensity and damage to the remaining stand (Tab. XIV). The analysis proved a statistically significant relationship between intensity of felling and the extent of damage only in case of the stands processed by tracked CTL technology (187,188). The relationship between stand density and the extent of damage stand was not significant. The coefficients of correlation varied from 0.22 to 0.53, moderately strong relationship. The biggest coefficient of correlation (0.53) was achieved in stands n. 187 and 188, which suggests a strong influence of felling intensity to extent of damage. Slightly a weaker correlation coefficient was recorded in stands n. 2051 (0.48) and 588 (0.40). Stands 2052 and 2027 had the weakest relationship (0.22).

DISCUSSION AND CONCLUSION

Different types of technology have different effects on the remaining stand during forest harvesting. The most important factors are the type of technology (weight, characteristics of chassis), felling method, felling intensity, experience and skills of operators. The felling intensity was similar in all of the stands, except stand n. 588. We can see some differences in damage intensity between individual stands. These differences were caused by unequal skills of operators and the type of technology used. The experience of individual operators is a very important factor. This was visible in stands 187 and 188 where, despite the increased stand density only 7.3% of trees were damaged. In this case CTL technology showed its potential of decreasing the extent of damage to the remaining stand. Skidder technologies caused 17.8% to 44.6% damage intensity. The intensity is higher compared to CTL technologies. The average size of damages caused by skidders was also larger compared to CTL technologies. These differences were caused mainly by transporting different loads (short assortments/long stems).

Ferenčík (2009) presented research of processing softwood calamity in premature stands, by CTL technology, which damaged about 25% of remaining trees. Most of damages were located in heights lower than 3 m on the stem. Slugeň (2007) found damage in extent 17% caused by wheeled CTL technology.

Kindernay (2010) in his research recorded damage to the remaining stand caused by wheeled harvester at a level 8.6%. Messingerová (1997) observed damage of remaining stand caused by tractor technology in the range of 20 to 28%. Neruda (2005) reported 20% of damaged trees of remaining stand caused by skidder technology.

The chassis of forestry machinery was proven to be an important factor. CTL technology based on a tracked chassis caused more extensive damage to the root system of trees close to the forwarding lines. We observed that 6.6% of total area of damages was on the root system of trees in stands where tracked CTL technology worked. We did not confirm significant differences in the intensity and location of damages between tracked and wheeled CTL technologies. We observed significant differences in the character of damage. Kremer and Schard, (2007) studied the impact of different types of chassis on the root systems of trees. They investigated the influence of eight wheeled forwarder Dosser TRS 8.10 on the root system of trees. The research was conducted on the forwarding line with an average slope 35%. They observed 328 trees in total and found damages on 25% of them. Korten (2003) observed tracked harvester and recorded results similar to our observations. He found that the majority of root damages are found on trees closest to the forwarding line. Massive root damages with bark removed and wood damaged, were recorded on 80% of damaged trees. Comparison of differences between types of damage caused by wheeled and tracked CTL technologies was presented by Uhl *et al.* (2003). They found significant differences between these two types of the chassis only in the severity of damage. Wheeled chassis cause only bark removal, but tracked chassis cause massive damage to the root system on trees.

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