

**Original Scientific paper**  
10.7251/AGREN2601083M  
UDC 630\*31:630\*4

## **RESIDUAL STAND DAMAGE IN SELECTION-CUT MOUNTAIN FORESTS: A COMPARISON OF OXEN AND SKIDDER LOGGING**

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### **ABSTRACT**

This study examines damage to residual trees and regeneration caused by oxen and skidder skidding in mixed silver fir and Norway spruce selection forests within the mountainous terrain of Han Pijesak, Republic of Srpska, Bosnia and Herzegovina. Fieldwork was conducted during summer on two spatially distinct sample plots, with nearly equivalent volumes of coniferous timber marked for felling. Skidding was carried out using an LKT 81 ILT skidder on one plot and oxen on the other. Damage was assessed based on wound size, position, frequency, and distribution across diameter classes, following established classification protocols. Results showed that skidder skidding caused significantly larger bark wounds and a greater proportion of damage in larger diameter classes compared to oxen. For both skidding methods, wounds occurred most frequently at the root collar and along the lower stem. Although oxen skidding resulted in a higher frequency of damage per metre of trail, the injuries were significantly smaller and more uniform in size. Damage distribution closely reflected the species composition and diameter structure of the stands. Fir trees sustained the largest wounds overall, particularly under mechanised skidding. The findings confirm that residual stand damage cannot be entirely avoided. Its severity is shaped by complex interactions among equipment type, stand characteristics, and operational practices. Key mitigation measures include clear marking of skid trails, protection of regeneration cores and high-value trees, limiting payload size, and strengthening supervision and contractor accountability.

**Keywords:** *LKT 81 ITL, animal logging, mixed forests, silver fir, norway spruce.*

## INTRODUCTION

In regions dominated by selection or uneven-aged forests (plenter forests), such as those in the Republic of Srpska and Bosnia and Herzegovina, planners and contractors face numerous challenges in both the planning and execution of logging operations. These challenges arise from the inherent conflict between operational pressures for efficiency and cost-effectiveness on one hand, and silvicultural and protection measures designed to preserve the potential for natural regeneration and long-term stand productivity on the other. Extreme terrain conditions – characterized by steep slopes and rugged topography – often force the construction of skid roads with excessively steep gradients and sharp curves. While this approach aims to shorten the average skidding distance and reduce costs, it directly contributes to increased damage in the residual stand, particularly to trees adjacent to the secondary forest road network (skid trails). Consequently, researchers such as Tavankar et al. (2013) and Knežević et al. (2018) emphasize that effective organization and careful operational planning, supported by clear field markings, preventive physical protection of trees, and precise layout of the secondary road network, can significantly reduce residual stand damage. Although animal skidding is a traditional, low-impact method promoting sustainability, its use in regional forestry has declined markedly in practice. The migration of rural populations to urban centers is a primary reason this traditional skidding system is gradually disappearing. From a silvicultural perspective, the choice of logging system has distinct consequences, primarily reflected in damage to residual trees, advanced regeneration, and forest soils. In stands where mechanized skidding is employed, damage to residual trees is often substantial. For instance, the use of skidders in the mountainous terrain of this region leads to various types of wounds in both pure and mixed beech stands, as well as in mixed fir-spruce stands, with reported damage intensities ranging from 12% to 18%. If bunching damage is assessed independently of skidding damage, its effect may be nearly twice as severe. Conversely, a combined system – using animals for bunching and skidders for subsequent logging along the trail, can markedly reduce damage levels. Knežević et al. (2023) observed that with such an integrated approach, damage intensity in mixed fir-spruce-pine stands was as low as 6.31%. Furthermore, directional felling plays a crucial role in damage reduction by preventing unnecessary log rotation that harms residual trees and saplings, as noted by Tavankar et al. (2013). Danilović et al. (2015) highlighted that the most damaging scenario occurs when logs are aligned parallel to or at an acute angle relative to the skid trail during skidding. However, the factors driving residual stand damage are not attributable to a single cause. As Ursić et al. (2022) point out, they result from a complex interaction of variables, including stand characteristics, the structure and dimensions of trees marked for felling, machinery specifications, and operator skill and technique. The objective of this study is to identify the key factors influencing damage to residual trees and regeneration during logging operations in the mountainous plenter forests of the Republic of Srpska, with particular focus on the logging system employed. Based on the findings, specific operational measures will be proposed to minimize stand damage.

## MATERIAL AND METHODS

Based on the dominant geological, pedological, and vegetation types within the area managed by the "Visočnik" Forest Management Unit (FMU) of the Public Forestry Enterprise "Šume Republike Srpske" in Han Pijesak (Republic of Srpska, Bosnia and Herzegovina), this study focuses on widespread mixed stands of Norway spruce and Silver fir. These plenter forests are located within the Javor Forest Unit (FU). Field research was conducted during summer conditions across two spatially distinct sample plots (SP1 and SP2; see Figure 1), which share similar stand and terrain characteristics.

**Sample Plot 1 (SP1)** covers 24.5 hectares, facing mainly north and northeast. It stretches across an elevation of 1,070 to 1,195 meters, with slopes averaging 7.52 degrees. The stand holds a growing stock of 570 m<sup>3</sup>/ha, made up mostly of silver fir (57.73%), along with Norway spruce (19.15%), European beech (20.30%), and other broadleaves (2.82%). The canopy is fairly closed at 73%, while ground vegetation is light and the understory regeneration is of moderate density. The primary soil type is dystric cambisol.

**Sample Plot 2 (SP2)** covers 25.85 hectares, oriented primarily toward the south and southwest. It stretches across an elevation of 1,122 and 1,161 meters, with slopes averaging 4.52 degrees. The stand holds a growing stock of 502 m<sup>3</sup>/ha, made up mostly of Norway spruce (67.94%), followed by Silver fir (28.17%), Scots pine (2.04%), European beech (1.73%), and minor proportions of other broadleaves. The canopy is moderately closed at 68%, ground vegetation is fairly developed, and advanced regeneration is present at a moderate density. Soils across the plot are predominantly shallow and derived from limestone parent material.

On both sample plots, forest management followed a combined group and single-tree selection system. During operational marking, nearly equivalent volumes of coniferous timber were designated for harvest: 1,976.97 m<sup>3</sup> on SP1 and 1,881.96 m<sup>3</sup> on SP2. Harvesting on both sites employed the assortment method (cut-to-length). Damage assessment was conducted along the most heavily used skid trails, covering 2,800 m of skidd trails and 817 m of oxen trails. The regional climate is montane, characterized by a mean annual temperature of 5.6°C and an average annual precipitation of 1,010 mm.

Damage classification followed the criteria established by Zahirović et al. (2016) for wound area, Danilović et al. (2015) for wound position, and Knežević et al. (2023) for the distribution of damaged trees by diameter classes. Accordingly, damage was defined as the presence of bark stripping on the root collar and stem, as well as crown breakage in smaller trees.

Based on size, i.e., the surface area of wounds on the bark of residual trees in the stand, all damage was classified into four groups: 1) < 100 cm<sup>2</sup>, 2) 100–500 cm<sup>2</sup>, 3) 500–1000 cm<sup>2</sup>, and 4) >1000 cm<sup>2</sup>. The number of all damaged trees – that is, their distribution – was presented by diameter classes: 1) 10.0–19.9 cm, 2) 20.0–29.9 cm, 3) 30.0–49.9 cm, 4) 50.0–79.9 cm, and 5) >80.0 cm.

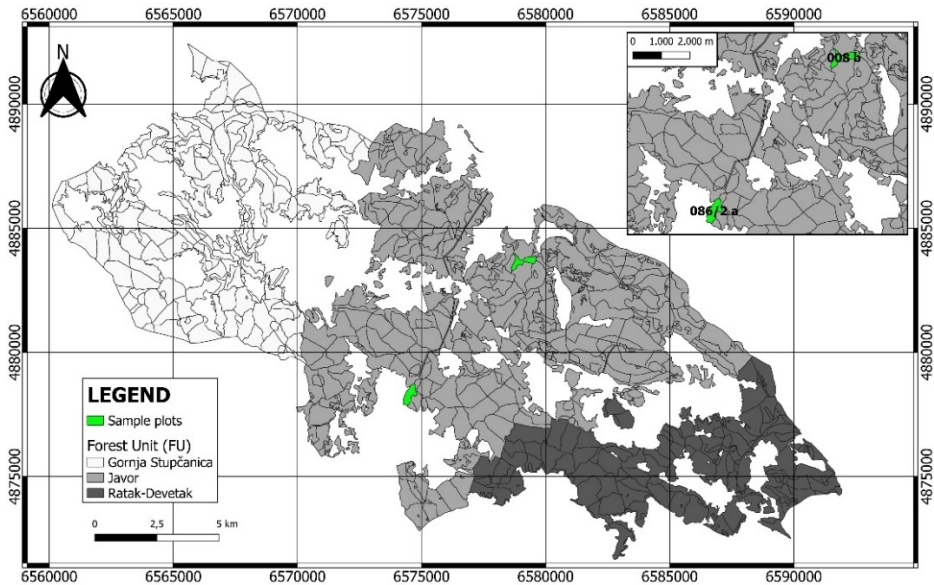


Figure 1. Research area with sample plots

Table 1. LKT 81 ITL characteristics

Type	Length (mm)	Width (mm)	Height (mm)	Weight (kg)	Engine	Power (kW)	No of cyl.	Winch type	Cable length (m)
LKT 81 ITL	6436	2550	3082	9800	CUMMINS F3.8	115	4	2 drums DANFOSS	75



Figure 1. Oxen (left) and skidder LKT-81 ILT (right) during logging operations (photo: Radulović, M.)

Data were systematized, processed, and visualized using Microsoft Office Excel 2013. The relationship between breast-height diameter and wound dimensions was analyzed using Spearman's correlation coefficient and regression analysis. Correlation strength was interpreted using the Römer–Orphal scale (Sabo & Poršinsky, 2005), and the quality of determination was assessed with the Chaddock scale (Yakovleva & Titova, 2021).

Descriptive statistics summarized the basic characteristics of the measured wounds. A one-tailed t-test ( $\alpha = 0.05$ ) was used to determine whether bark wounds on residual trees differed significantly between skidding methods (oxen vs. skidder). All statistical analyses were performed in R Studio (R Core Team, 2021) using the base (R Core Team, 2021), readxl (Wickham et al., 2019), and stats (R Core Team, 2021) packages (Figure 8). The one-tailed test was justified by the prior assumption that the skidder produces larger wounds than oxen during logging operations.

## RESULTS AND DISCUSSION

Based on field measurements, the majority of trees damaged during logging operations whether by the LKT-81 ILT skidder or by oxen – fell within the third diameter class (30.0–49.9 cm) (Tables 2 and 3). Total stem damage was consistently higher under mechanized skidding, which was expected given the substantially larger payload capacity of the skidder compared to animal skidding. For context, heavy skidders like the ECOTRAC 120V (Horvat et al., 2007), Timberjack 450C (Mousavi, 2012), Timberjack 240b (Miletić et al., 2021), Timberjack 240a, and LKT 81T (Marčeta et al., 2024) routinely exceed 5 m<sup>3</sup> and can reach over 6 m<sup>3</sup> per transport cycle, whereas animal-drawn loads rarely surpass 0.6–0.8 m<sup>3</sup> (Rodríguez, 1986; Wang, 1997; Akay, 2005).

Results showed no significant differences in the relative distribution of wound positions between the two logging systems (Figure 1). However, the relative share of damaged trees across diameter classes did vary to some degree (Tables 2 and 3). Under ox logging, a higher proportion of damage occurred in thinner diameter classes. This pattern likely reflects the teamster's preference for navigating among smaller, easily avoided trees to minimize potential damage costs, avoiding the significantly higher financial risk associated with damaging trees from larger diameter classes. This higher percentage of crown damage at SP2 further supports the pattern, as crown damage is only feasible in younger trees, specifically those in the smaller diameter classes (Figure 2). The apparent absence of damage in the largest diameter class on the ox-logging plot, compared to the skidder plot, should be disregarded. Post-harvest stand tables reveal that the oxen-logging area contained no measurable stems in that diameter class.

Table 2. Distribution of damaged trees by diameter classes at SP1 (skidder)

Tree species	Diameter classes (cm)										Total	
	10.0-19.9		20.0-29.9		30.0-49.9		50.0-79.9		>80.0			
	n	%	n	%	n	%	n	%	n	%	n	%
<b>Silver fir</b>	5	10.0	10	20.0	17	34.0	17	34.0	1	2.0	50	76.9
<b>Norway spruce</b>	3	20.0	2	13.3	6	40.0	3	20.0	1	6.7	15	23.1
<b>Total</b>	8	12.3	12	18.5	23	35.4	20	30.8	2	3.1	65	100

Table 3. Distribution of damaged trees by diameter classes at SP2 (oxen)

Tree species	Diameter classes (cm)										Total	
	10.0-19.9		20.0-29.9		30.0-49.9		50.0-79.9		>80.0			
	n	%	n	%	n	%	n	%	n	%	n	%
<b>Silver fir</b>	4	16.7	7	29.2	7	29.2	6	25.0	-	-	24	60.0
<b>Norway spruce</b>	-	-	6	37.5	8	50.0	2	12.5	-	-	16	40.0
<b>Total</b>	4	10.0	13	32.5	15	37.5	8	20.0	-	-	40	100

The highest frequency of wounds on fir and spruce trees occurred at the root collar and along the stem, affecting 57 trees (87,69% of all damaged trees) during skidder logging and 30 trees (75,00%) during ox logging (Figure 2). The proportion of damaged trees closely mirrored the degree of species mixture found in the sample plots. Although this proportion reflects the estimated volumetric share of each species within the total stand volume, it also serves as an indicator, to some extent, of their relative abundance across the study area. While the frequency of damage per meter on the analyzed trails was significantly different (skidder: 0.02/m; oxen: 0.04/m), it should be noted that oxen logging typically occurs over shorter distances and does not always require prior soil preparation, such as trail construction. It is most likely that the higher frequency of oxen traffic along the same short routes, combined with the previously mentioned factors, contributed to this outcome.

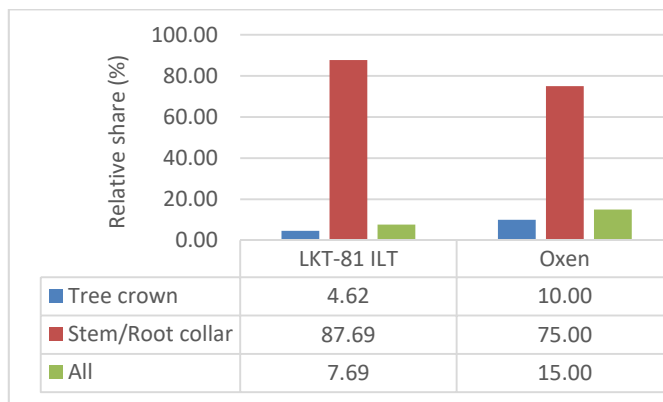


Figure 2. Distribution of trees according to the damage spots on both SP

Regardless of the points above, special attention should still be given to the size and type of damage, as these are the primary factors determining the future condition of affected trees. For both fir and spruce, the majority of damaged trees exhibited injuries in the 100–500 cm<sup>2</sup> range. Furthermore, skidder logging was associated with significantly more large injuries (>500 cm<sup>2</sup> and >1000 cm<sup>2</sup>) than oxen logging (Table 4). A one-tailed t-test confirmed that this difference was statistically significant ( $p < 0.001$ ; mean increase = 360.3 cm<sup>2</sup>) (Table 5). Notably, standard deviation values indicated that damage dimensions were significantly more uniform under oxen logging (Table 4), likely owing to the more consistent load sizes attainable during their transport cycles.

Table 4. Descriptive statistics of bark damage size (cm<sup>2</sup>)

Species	MIN		MEAN		MAX		SD	
	SP1 (S)	SP2 (O)	SP1 (S)	SP2 (S)	SP1 (S)	SP2 (O)	SP1 (S)	SP2 (O)
Silver fir	16	49	815.56	324.04	2580	900	520.85	250.46
Norway spruce	170	99	633.93	425.31	1300	1300	397.21	332.99
<b>Total</b>	16	49	733.65	375.35	2580	1300	498.16	285.22

Table 5. Difference analysis of bark damage dimensions on residual trees: comparison between oxen and skidder logging

Sample plots	n	mean	t	df	p-value	95 % CI	
						lower	upper
Skidder (SP1)	65	773.65	5.21	102.58	0.000	246.58	-
Oxen (SP2)	40	375.35	-	-	-	-	-

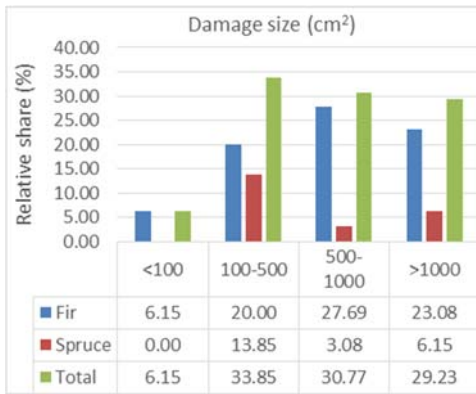


Figure 3. Bark injury size distribution of damaged trees SP1 (skidder)

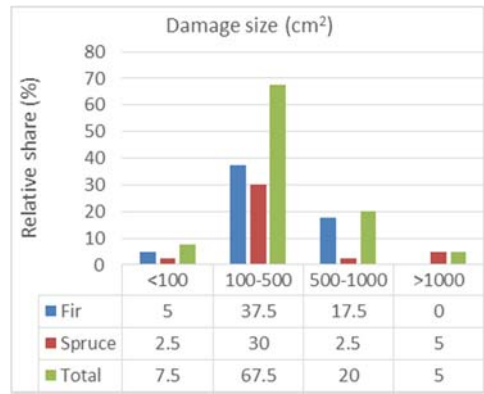


Figure 4. Bark injury size distribution of damaged trees SP1 (oxen)

In comparison, the damage dimensions recorded in this study are considerably larger than those in similar research. For instance, Knežević et al. (2018, 2023) reported overall average bark damage areas of 222.54 cm<sup>2</sup> and 197.08 cm<sup>2</sup>, respectively. In contrast, the site-specific averages in this study were substantially higher: 733.65 cm<sup>2</sup> (skidder) and 375.35 cm<sup>2</sup> (oxen) (Table 4). Given that a weak logarithmic relationship has been established between tree diameter and damage size (Figure 4. and 5), it can be cautiously concluded that the stand's diameter distribution also partly determines the extent of damage on injured trees. Compared to Knežević et al. (2018, 2023), the growing stock recorded in our plots is over one-third larger. If this corresponds to a higher proportion of trees in larger diameter classes, then the previous conclusion carries greater weight.

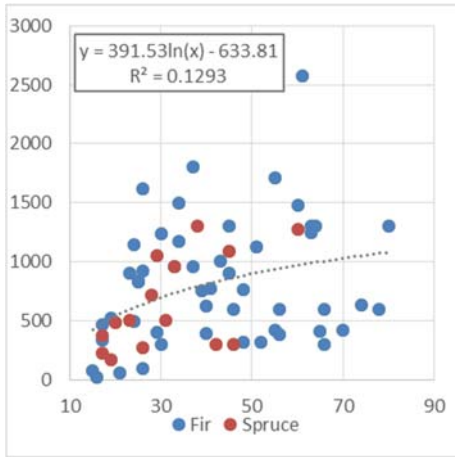


Figure 4. Influence of Stem Diameter on Bark Damage Dimensions at SP1 (Skidder)

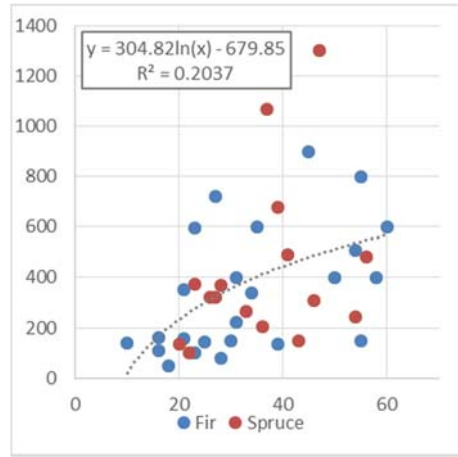


Figure 5. Influence of Stem Diameter on Bark Damage Dimensions at SP1 (Oxen)

On average, the most severe bark damage was observed on fir trees, particularly when a skidder was used for logging operations (Table 4). The single largest bark injury, measuring 2580 cm<sup>2</sup>, was also recorded on a fir tree at SP1 (skidder). Conversely, when oxen were used, average damage was greater on spruce trees. In this case, the single largest bark injury was also found on a spruce, measuring 1300 cm<sup>2</sup> (Table 4). This finding aligns with expectations, given the significant abundance of Norway spruce in this sample plot. Nevertheless, a one-tailed t-test (Table 6) revealed no statistically significant difference in damage size between remaining fir and spruce trees ( $p < 0.05$ ), despite a mean difference of 135.73 cm<sup>2</sup>. Increasing the sample size would likely yield statistical significance.

Table 6. Analysis of differences in damage size between remaining fir and spruce trees.

Species	n	mean	t	df	p-value	95 % CI	
						lower	upper
Silver fir	74	661.99	1.52	74.69	0.066	-12.56	-
Norway spruce	31	526.26	-	-	-	-	-

## CONCLUSIONS

The findings revealed that the choice of logging equipment is only one factor influencing stand damage, with human and operational management practices playing an equally critical role. Despite detailed operational prescriptions in the logging plan, greater emphasis must be placed on proactive mitigation and residual stand protection. Key recommendations include implementing modern operational technologies to streamline workflows, enhancing supervision of forest engineers, and rigorously enforcing contractual penalties for non-compliant contractors. Particular attention should be given to clearly marking designated skid trails, protecting regeneration cores by establishing no-extraction or restricted zones, safeguarding high-value trees using so-called tree protectors, and limiting skidder payload volume – specifically, the number of logs transported per cycle. Comparing the obtained results with those from similar studies confirmed that damage to residual trees in the stand cannot be completely eliminated, and that its frequency and severity are also directly influenced by stand characteristics.

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