Analysis of Tree Damage Caused by Excavated Materials at Forest Road Construction in Karst Region

Tolga Ozturk, Muhittin Inan, Abdullah E. Akay

Abstract – Nacrtak

Opening-up of forests enables the application of rational forestry, which means more productivity and suitability for sustainable use. Therefore, forest roads are one of the most important tools needed. This study investigates tree damage caused by excavated materials during forest road construction in a karst region. Bending, crushing and wounding were defined as tree damage because of excavated materials during forest road construction. Besides, forest road construction techniques, and productivity by using hydraulic excavator were investigated in forested lands in Antalya region in Turkey. The number of damaged trees regarding various gradient classes was also determined in the study area. The results indicated that during the forest road construction 12% and 27% of trees were wounded upon 20–45% and 46–90% ground slopes respectively. A maximum length of the fill slope for excavator was found to be 17 m on 80% slope gradient. The cost of excavator was calculated as 17.6 €/m. The productivity of the excavator was calculated as 105.8 m³/hr.

Key words: Hydraulic excavator, forest road, road construction, tree damage, excavated materials

1. Introduction – *Uvod*

According to the Turkish General Directorate of Forestry (GDF), the technical and economical management of forests requires 210,000 km of forest roads to be constructed. Up to now, approximately 150,000 km of forest roads have been constructed. GDF plans to construct 1000 km of new forest roads per year, so they will be on the agenda for a long time to come (Gumuş et. al. 2009). The forest roads are the base infrastructure foundations which provide access to forest lands for extraction, regeneration, protection, and recreation activities (Demir and Hasdemir 2005). However, designing low-volume forest roads is a complex engineering problem involving economic, environmental, and social requirements. Construction and maintenance costs are the largest components in the total cost of producing the timber for industrial uses (Akay 2006). Besides, road construction activities remove the forest vegetation and disturb soil structure, which may lead to a significant environmental damage in forest ecosystem (Grace 2002). For example, the sediment yield delivered from forest roads to streams results in dramatic impacts on water quality and aquatic life (Akay et al. 2008). Besides, planning forest road networks depends on social requirements since they provide access to forest villages, rural settlements, and recreational areas (Acar and Eker 2007). Therefore, forest roads construction activities must be carefully executed by considering economical, environmental, and social requirements (Akay and Sessions 2005).

In locating forest roads, construction methods and equipment selection directly affects the economical, functional, and ecological efficiency of the forest roads. Upon the terrains with gentle to moderate hillside slopes, bulldozers have been still commonly used in right-of-way, cut and fill slope, and subgrade activities. However, in steep and rocky terrain conditions, the efficiency of bulldozers diminishes and excessive environmental damage may occur, since it becomes troublesome to keep the excavated material along the day-light point of fill slopes. In order to reduce the environmental damage on forest ecosystems, especially on steep terrains, hydraulic excavators have replaced bulldozers in forest road construction activities (Stjernback 1982). Besides, the use of excavator improves the quality of forest roads, which extends life of the roads, improves the driver's comfort, and reduces the frequency of maintenance activities. In fact, using excavators can be the only option to perform feasible road construction activities on steep mountainous terrains (FAO 1998).

Excavator has the advantage of performing excavation activities with better control, and it places the material efficiently upon fill slope. In a study conducted by Erdas (1986), it was indicated that excavator should be used in construction activities on steep terrains to reduce environmental impacts. Bayoglu (1986) suggested that bulldozers should be used in the forested areas with less than 40% ground slope, while excavators should be preferred when the slope is greater than 40%. According to Spaeth (1998), a combination of bulldozers and excavators can be used in road construction activities on terrain with slopes greater than 50%.

Winkler (1999) evaluated the productivity of excavators by considering various types of road lengths and terrain conditions. The results indicated that the production rate of excavators was satisfactory in forest road construction. The performance of a skilled excavator operator can play an important role in reducing operation costs. Excavators perform road construction activities in stationary position with limited movements between work sites. Thus, excavators can not move further distances to collect material from outside of the work zone (Stjernback 1982).

The studies indicated that road construction activities using excavator have advantages in the long run due to reduced damage caused to forest ecosystems, biodiversity, and forest soil (Haanshus 1998; Winkler 1999). Heinrich (2001) indicated that excavators were commonly used in environmentally sensitive areas to reduce impact on forest vegetation, provide adequate drainage system, protect stream crossings, and improve the stabilization of cut-and-fill slopes. Excavators work with the narrow right-of-way method to reduce disturbance of the forest cover and decrease the risk of erosion in open areas. Besides, the ground pressure of excavators on forest soil is less than that of bulldozers (Stjernback 1982). Due to lower ground pressure, excavators can work in wet areas, while bulldozers would most likely stuck in mud.

In order to take advantage of using excavators in forest road construction, the performances of the excavator should be evaluated considering economical and environmental requirements. In this study, forest road construction techniques by using hydraulic excavator were investigated based on a sample road construction activity conducted in forested lands in Antalya region in Turkey.

2. Materials and Methods – *Materijali i metode*

2.1. Study Area – *Područje istraživanja*

The study area is selected from the office zone of Aykiricay Forest Enterprise in Finike Forest Management (Fig. 1).

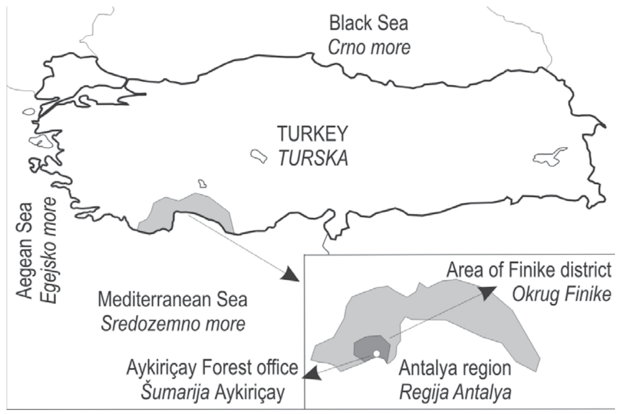


Fig. 1 The location of the study area in Antalya region

Slika 1. *Mjesto istraživanja*

In this enterprise, dominant commercial tree species include *Pinus brutia, Cedrus libani, Juniperus* sp. and *Quercus* sp. The elevation ranges from 700 m to 900 m with ground slopes of 20% to 100%. The study area consists of Type B forest roads with a density of 14 m/ha. Total length of the sample road examined in this study was about 1640 m with an average road width of 5 m. The study area is located on the Taurus Mountains, which is the largest and most important karst region in Turkey. According to Boydak (2003), this region has one of the most complex karst circulation system and rough terrain characteristics such as sharp peaks, deep valleys, and narrow gorges. Due to immediate penetration of rainfall and snow melt into the rock crack system, surface soil formation very slowly occurs along the cracks and stratification surfaces of the limestone (Boydak 2003).

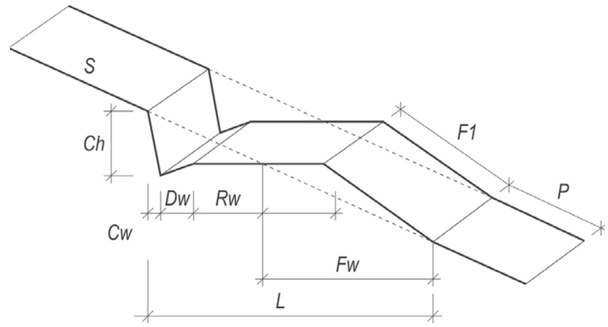
2.2. The Equipment Specifications *Karakteristike opreme*

Daewoo Solar 220 LC-V type hydraulic excavator and Soosan SB 81 TS type hydraulic hammer were used in forest road construction activity. The undercarriage of the excavator was equipped with full-length track guards and had a protective plate. The technical specifications of the excavator and hammer are shown in Table 1.

Table 1 Technical features of the Daewoo Solar 220-LC-V and hydraulic hammer (Anonymous 2007)

Tablica 1. *Tehničke značajke bagera* Daewoo Solar 220-LC-V *opremljenoga hidrauličnim čekićem*

Specifications – *Karakteristike*	Values – *Vrijednosti*
Weight – *Težina*	21500 kg
Capacity of bucket – *Obujam lopate*	0.93–1.17 m^3
Engine type – *Vrsta motora*	DB58TIS
Engine power – *Snaga motora*	148–1950 PS/rpm
Speed – *Brzina rada*	5 km/hr
Max. force – *Maksimalna snaga*	13100 kgf
Max. excavation depth – *Maks. dubina kopanja*	6630 mm
Max. unloading height – *Maks. visina utovara*	6810 mm
Boom turn speed – *Maks. brzina zaokreta*	10.9 d/min
Fuel tank – *Spremnik za gorivo*	370 liters
Hydraulic hammer – *Vrsta hidrauličnoga čekića*	Soosan SB81TS
Working weight – *Radna težina*	1721 kg
Working pressure – *Radni pritisak*	160–180 kg/cm^2
Number of stroke – *Broj udaraca čekića (frekvencija)*	400–490 bpm
Hammer diameter – *Promjer čekića*	140 mm
Excavator types – *Vrsta bagera*	18–34 ton



Cw – Cut-slope width
Širina pokosa iskopa
Ch – Cut-slope height
Visina pokosa iskopa
Rw – Road width
Širina kolnika
Dw – Ditch width
Širina odvodnog jarka
F1 – Fill slope length
Duljina pokosa nasipa
Fw – Fill-slope width
Širina nasipa
L – Road construction zone width
Širina planuma
P – Length of the impact zone beyond the fill-slope length
Pojas utjecaja stroja na oštećivanje stabala iza pokosa nasipa
S – Length of the impact zone beyond cut-slope width
Pojas utjecaja stroja na oštećivanje stabala iza pokosa iskopa

Fig. 2 The decision variables measured from each cross section along the road

Slika 2. *Mjerenja na svakom profilu ceste*

2.3. Methods – *Metode*

Area and tree measurements were made to determine and investigate the damage caused by excavated material. Primarily, the cross sections were determined along road route. Some data were thus revealed during forest road construction with hydraulic excavator. These variables include cut-slope height (*Ch*), cut-slope width (*Cw*), ditch width (*Dw*), road width (*Rw*), fill-slope width (*Fw*), fill-slope length (*Fl*), road construction zone width (*L*), length of the impact zone beyond the fill-slope (*P*), and ground slope (*S*) (Fig. 2). The width of excavation and fill-slope length are important for this study. The amount of excavated materials and the slope gradient are also important, because the fill slope length increases with increasing slope gradients, and the damage consequently grows.

The surveying instruments such as clinometers, steel tape, measuring batten, altimeter, and compass were used in the field study. Along the 1640 m of the sample road section, decision variables were collected from 32 cross sections, which were 50 m apart. The number of damaged trees and undamaged tree were determined between two cross sections as gradient groups (Fig. 3). Observed were also the types of damage such as bending of tree, crushing of tree and wounding of stem. Distribution by damage type, relation to construction techniques and the effect of positional values of damaged trees were investigated by means of the data collected.

3. Results – *Rezultati*

In the first stage of road construction, 354 m^3 of logs were extracted by felling 345 trees along the road construction zone of the sample road. The trees fallen were mostly *Pinus brutia* and *Cedrus libani*. The logging residuals were placed on the fill-slope as a barrier that prevents the material from falling down the fill-slope. The results indicated that total exca-

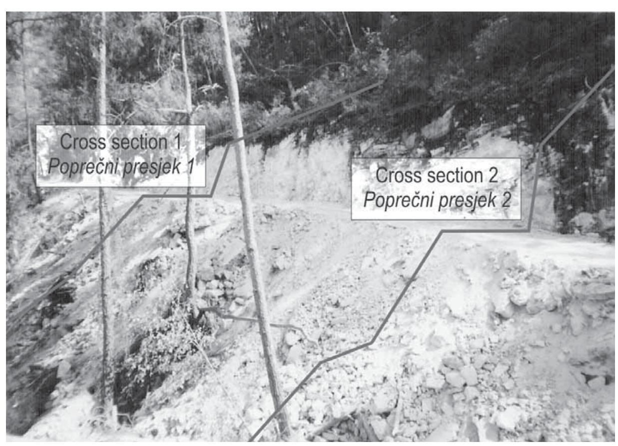


Fig. 3 Determination of cross sections along road route

Slika 3. *Utvrđivanje poprečnoga presjeka*

Table 2 The values of decision variables measured on the cross sections

Tablica 2. *Vrijednosti mjerenja na svakom profilu ceste*

Variables – *Varijable*	Symbol *Oznaka*	Average *Prosjek*	Standard Deviation *Standardna devijacija*	Max. values *Mak. vrijednost*	Min. values *Min. vrijednost*
Ground slope – *Nagib terena*, %	*S*	59.38	28.39	110.0	5.0
Cut-slope height – *Visina pokosa iskopa*, m	*Ch*	3.46	2.15	7.2	0.5
Cut-slope width – *Širina pokosa iskopa*, m	*Cw*	1.14	0.75	2.5	0.2
Ditch width – *Širina odvodnoga jarka*, m	*Dw*	0.78	0.08	1.0	0.7
Road width – *Širina kolnika*, m	*Rw*	4.10	0.09	4.3	4.0
Fill-slope width – *Širina nasipa*, m	*Fw*	4.94	2.70	10.8	1.2
Fill-slope length – *Duljina pokosa nasipa*, m	*Fl*	3.67	3.47	12.0	0.2
Impact zone length – *Pojas utjecaja stroja*, m	*P*	4.29	3.13	10.0	0.5
Construction zone width – *Širina planuma*, m	*L*	7.47	2.31	14.0	5.0

vated material along the roadway was 12 480 m^3, of which the percentages of soil, loose rock, and rock were 24.88%, 25.19%, and 49.93% respectively. In road construction activities, explosives were not used for crushing rocks. The average operation time of the hydraulic excavator was 8 hours per day. Since it is very hot in Antalya in the summer season, the excavator operated from 7:00 to 11:00 AM in the morning, and from 14:00 to 18:00 PM in the afternoon. The values of the specific variables measured on the cross sections were listed on Table 2.

The average construction zone width was 7.47 m; therefore, sample road section impacted approximately 1.23 ha of the forested area (7.47 m × 1640 m) during the road construction activity. The total road construction cost was found to be 28,922 €, with the unit cost of 17.6 €/m. The production rate of the excavator is generally computed as the length of constructed road per hour. In this study, the average production rate of the excavator was found to be 8.0 m/hr. The excavator excavated 36 m^3 of material per hour and cleared them away from the roadway. The productivity of the excavator was found as 105.8 m^3/hr. This high productivity indicated that hydraulic excavators combined with hydraulic hammers can perform excavation operations quickly and effectively in karst regions.

In road construction activity, optimum excavator operating techniques were tried to be implemented to minimize residual stand damage and overall environmental impacts. For example, after rocks were crushed by the hydraulic hammer, they were then carefully placed on the fill slope by using the bucket. Besides, the cut slope rate of 5:1 was maintained along the roadway to ensure slope-stability in terrains with steep hillside gradients. In fact, the cut slope rate of 5:1 is the most appropriate rate for karst areas, especially for steep terrains.

The percent of damage as wounding, crushing and bending of trees are 75%, 17% and 8% respectively (for 25–45% terrain slope) and 80%, 16% and 4% respectively (for 46–90% terrain slope). The number and rate of the damaged trees in the study areas are shown in Table 3.

In the 46–90% slope areas, the total number of damaged trees on forest roads construction by using excavator is 25. The damage rate of the excavator is 27%. On the terrain less than 45%, the number of total damage is 9. Wounding damage prevails in this area. The percentage of damage as bending, crushing and wounding is shown in Fig. 4.

Table 3 Number and rate of the damaged trees in the study areas

Tablica 3. *Broj i učestalost oštećenja stabala na istraživanom području*

Average terrain slope, % *Prosječni nagib terena, %*	Number of damaged trees *Broj oštećenih stabala*	Number of non damaged trees *Broj neoštećenih stabala*	Types of damages – *Vrsta oštećenja*			Number of total trees *Ukupni broj stabala*	Damage rate, % *Učestalost oštećenja, %*
			Bending *Savijena stabla*	Crushing *Otkinuta stabla*	Wounding *Stabla s ozlijeđenim deblom*		
20–45	12	90	1	2	9	102	12
46–90	25	68	1	4	20	93	27

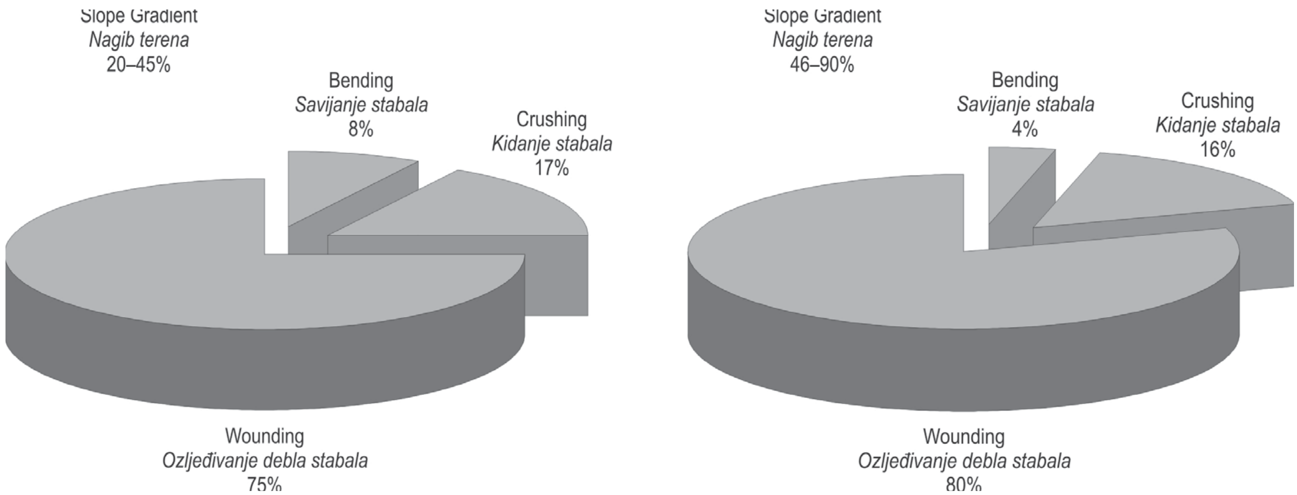


Fig. 4 The rate of damage on trees according to slope gradient

Slika 4. *Učestalost oštećenja na stablima s obzirom na nagib terena*

Bark beetles can occur upon damaged trees during road construction. The species of bark beetle in this region is *Orthotomicus tridentatus*. These beetles were caused big damage in this forest region. Thus, the direct economic loss was increased due to lesser timber quality. The damage on road construction is shown in Fig. 5.

4. Discussion – *Rasprava*

Previous studies indicated that forested areas under the road construction using bulldozers suffered much more damage than the ones in which hydraulic excavators were used. Besides, the visual quality of the forest roads constructed by using hydraulic excavators is much better that where bulldozers were used, considering technical and environmental aspects (Bayoglu 1989).

The average construction zone width was found as 7.47 m in this study. A study conducted in Antalya region (Tunay and Melemez 2004) reported that a road construction activity on a terrain with 36–50% ground slope resulted in 9.40 m and 12.18 m wide road construction zones by using excavator and bulldozer respectively. This suggested that the forested area using bulldozers was approximately 29.58% bigger than that using excavators. Tunay and Melemez (2004) also indicated that the bulldozer results in

Fig. 5 Damaged trees

Slika 5. *Oštećena stabla*

about 26.16% more affected forest area than does the excavator in road construction activity.

In this study, the total road construction cost was found to be 28,922 €, with the unit cost of 17.6 €/m. Besides, the average product rate of the excavator was found to be 8 m/hr. In a study conducted by Winkler (1999) in Himalaya (Bhutan), the unit cost of construction by excavator was 7.58 €/m with the production rate of 6.91 m/hr. Acar and Eker (2001) conducted a similar study in Eastern Black Sea Region of Turkey, where 4341 m of forest road was constructed by an excavator on a steep terrain with 70% ground slope. In that study, the unit cost of road construction, and average production rate were 4.74 €/m and 8.67 m/hr respectively. Another study conducted by Filipsson and Eriksson (2004) in Sweden indicated that the average productivity of using excavators in road construction was 12.7 metres per hour.

In this study, the unit cost of road construction (17.6 €/m) was higher than the unit costs reported by the previous studies. This was because the study area was located on a karst region with rough terrain characteristics and large amount of rocks (6232 m^3) to be excavated along the roadway. Besides, ground slope, soil characteristics, and operator factors might affect the cost of road construction. Cut slope rate for karst steep terrains in this study was determined as 5:1. Another study conducted by Kramer (2001) inicated that the cut slope rate of 5:1 is the most apropriate rate for especially steep terrains (Kramer, 2001).

5. Conclusions – *Zaključci*

In this study, the forest road construction techniques by using hydraulic excavator were evaluated by considering economical, technical and environmental requirements. The following suggestions are made in the light of the previous studies and the results derived from the sample road construction activity:

⇒ The use of excavator in forest road construction activities should be encouraged and even mandatory in mountainous regions with steep terrains.

⇒ In order to reduce road construction costs and environmental impacts, the excavators should replace bulldozers, especially in Antalya region where explosives are used on karst lands with great threat to forest ecosystems.

⇒ Economical issues but also environmental requirements. Excavator operators should be well trained to improve the efficiency of construction activity, regarding economical and environmental aspects.

⇒ In the planning phase of the forest roads, the methods and equipment selection should be predetermined not only considering the

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Sažetak

Analiza oštećenja dubećih stabala pri izgradnji šumskih cesta u krškom području Turske

Prema Općoj upravi za šumarstvo Turske (OUŠ) gospodarenje šumama zahtijeva izgradnju dodatnih 210 000 km šumskih cesta. Do sada je izgrađeno otprilike 150 000 km šumskih cesta, a u budućnosti OUŠ planira izgradnju 1000 km šumskih cesta godišnje. Šumske su prometnice osnovni temelji infrastrukture koji omogućuju pridobivanje drva, obnovu i zaštitu šuma te rekreacijske djelatnosti na šumskom zemljištu. Međutim, projektiranje je šumskih cesta u šumama niskoga prihoda složen inženjerski postupak koji uključuje ekonomske, ekološke i društvene potrebe i zahtjeve. Ova studija istražuje oštećenja stabala pri gradnji šumskih cesta na krškom području. Savijanje i kidanje stabala te ozljeđivanje debla smatra se oštećenjem odnosno štetom nastalom prilikom izgradnje šumskih cesta. Osim toga, istraživan je i način gradnje te produktivnost hidrauličnih bagera za izgradnju šumskih cesta u šumariji Aykiricay, okrug Finike, regija Antalya u Turskoj. Glavne i ekonomski najisplativije vrste drveća na ovom su području Pinus brutia, Cedrus libani, Juniperus sp. i Quercus sp. Nadmorska je visina istraživanoga područja od 700 do 900 m, dok je nagib terena od 20 do 100 %.

Istraživano je područje otvoreno šumskim cestama tipa B s gustoćom prometnica od 14 m/ha. Ukupna je duljina istraživane trase ceste bila 1640 m, a širina je planuma bila 5 m te su svakih 50 m prikupljani podaci s 32 poprečna profila. Istraživano područje pripada planinskomu masivu Taurus koji je ujedno i najveće i najvažnije krško područje Turske. Na izgradnji je ceste radio hidraulični bager Daewoo Solar 220 LC-V s hidrauličnim čekićem Soosan SB 81 TS.

Pobrojana su oštećena i neoštećena stabla između svaka dva susjedna poprečna profila te su određivani tipovi oštećenja stabala kao što su savijanje i kidanje stabala te ozljeđivanje debla prilikom izgradnje šumske ceste. Količina je iskopa duž prometnice bila oko 12 480 m^3 materijala s 24,88 % udjela zemlje; 25,19 % udjela mješavine zemlje i kamenja te 49,93 % udjela stijene. Pri izgradnji prometnice nije korišten eksploziv, a prosječno je vrijeme rada hidrauličnoga bagera bilo 8 sati na dan, prosječna je širina pojasa izgradnje bila 7,47 m, što znači da je površina ceste u izgradnji zauzela oko 1,23 ha šumske površine. Ukupni su troškovi izgradnje iznosili 28 922 €, s jediničnom cijenom od 17,6 €/m. Bagerom je po satu rada prosječno iskopano i očišćeno 36 m^3 materijala s trase ceste, odnosno brzina je rada bagera iznosila 8 m/h. Produktivnost je bagera bila 105,8 m^3/h. Na terenu nagiba od 25 % do 45 % postotni je udio oštećenja na stablima iznosio: savijanje stabala 8 %, kidanje stabala 17 % i ozljeđivanje debla 75 %. Na terenu nagiba 46 – 90 % postotni je udio oštećenja na stablima iznosio: savijanje *stabala 4 %, kidanje stabala 16 % i ozljeđivanje debla 80 %. Na terenu nagiba 46 – 90 % ukupno je oštećeno 25 stabala, udio je oštećenja radom bagera 27 %, dok je na terenu nagiba do 45 % ukupno oštećeno 9 stabala s većinskim oštećenjen na deblu.*

Zbog nastalih oštećenja na stablima prilikom izgradnje šumskih prometnica stabla mogu napasti potkornjaci te bi se tako na istraživanom području mogla pojaviti vrsta Orthotomicus tridentatus. Ona u ovom području izaziva velike štete pa stoga pri izgradnji šumskih prometnica treba biti posebno oprezan.

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