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The assessment of environmentally sensitive forest road construction in Calabrian pine forest areas of Turkey

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Abstract: *Forest road construction by bulldozers in Calabrian Pine (Pinus brutia Ten.) forests on mountainous terrain of Turkey causes considerable damage to the environment and the forest standing alongside the road. This situation obliges a study of environmentally sound road construction in Turkey. This study was carried out in 4 sample sites of Antalya Forest Directorate in steep (34-50% gradient) and very steep terrain (51-70% gradient) conditions with bulldozer and excavator machine and direct damages to forest during road construction was determined, including forest area losses and damages to downhill trees in mountainous areas. It was determined that in steep terrain when excavators were used, less forest area (22.16%) was destroyed compared to bulldozers and 26.54% less area in very steep terrain. The proportion of damage on trees where bulldozer worked was nearly twofold higher than excavator was used. The results of this research show that the environmentally sensitive techniques applied for the road construction projects are considerably superior to the traditional use of bulldozers on steep slopes. The environmentally sound forest road construction by use of excavator must be considered an appropriate and reliable solution for mountainous terrain where areas of sensitive forest ecosystems are to be opened up.*

Key words: *Forest road construction, Calabrian Pine, Bulldozer, Excavator, Environmental damage*.

Introduction

In Turkey, Calabrian Pine forests are generally located on areas which are mountainous and have hard conditions. It is obligatory in terms of modern forest management to plan rationally and construct forest roads which are involved in the process of growth, protection, production, transportation and marketing of forest products in these forests. Building and maintaining roads have become controversial, however, because of public concerns about their short and long term effects on the environment (Cole and Landres, 1996; Lugo and Gucinski, 2000).

Forest road construction is a hazardous operation in mountainous terrain which can inflict scars on the landscape and also cause substantial damage on the forest ecosystem. If we want to benefit from forests, building forest roads is inevitable despite their negative effects (Acar and Eker, 2001). The width of the surface of a road is much larger than the width of its ecological influence (Larsen and Parks, 1997; Olander *et al.*, 1998; Lugo and Gucinski, 2000). At a study in Artvin region in Turkey, during 2 km road construction by bulldozer in a terrain having a slope of 60%, it was discovered that 3.8 hectares of forest in total was lost (Erdas *et al.*, 1997). Kantarci (2002) calculated the width of the average forest destruction area as 50 meters in case that a wrong technique is applied during the forest road construction. In this study, sample areas were chosen and some research was done on these areas with the intention to determine the direct damage to the Calabrian Pine forests while constructing forest roads. Thus, losses in the forest areas caused by road construction and damage on the trees below the newly constructed forest roads in Calabrian Pine forests were investigated.

Materials and Method

Four areas in which forest road construction works are done and which have similar characteristics within the Taurus Mountains of Antalya region were chosen as the study area (Fig. 1). Antalya region is situated in the southern part of Turkey (31°26'-31°45'E, 37°25'-37°87'N) at the Mediterranean basin. Forest trees, especially Pinus spp in this region are very susceptible to fire. Also climate is suitable for forest fire. Forest road construction increases the risk of fire in this region.

The tree species in the study area was Calabrian Pine (*Pinus brutia Ten*). Most of the trees in all the study areas were included in the classification of 20-36cm diameter. Stand density in the areas was high. Two of the areas had slope values close to each other and they were included in the classification of steep terrain (34-50%) according to the slope classifications determined by International Union of Forest Research Organizations (IUFRO). The other two were included in the classification of very steep terrain (more than 51%) according to the slope classifications determined by IUFRO.

As the road construction machines, four work machines were used in the study areas in both slope groups; one bulldozer and one excavator in each slope group;

- Excavator I (EI): Road construction by excavator in steep terrain (34-50%)
- Bulldozer I (DI): Road construction by bulldozer in steep terrain (34-50%)
- Excavator II (EII): Road construction by excavator in very steep terrain (51-70%)
- Bulldozer II (DII): Road construction by bulldozer in very steep terrain (51-70%).

Fig. 1: The study area.

At the construction of roads, CAT D8 and D9H bulldozers with CAT 320 and SUMITOMO LS3400 hydraulic excavators were used. Also, in order to break the rocks into pieces, one tooth ripper at the back of the bulldozer was used. For excavators, equipped hydraulic hammer instead of the metallic bucket was used. Furthermore, when ripper power fell short to break the rocks into pieces, dynamite was used. This situation increases the risk of fire.

In the study areas, all the road construction works were monitored during a construction period and necessary measurements were taken during and after road construction activities. The measurements done width ways of the roads were: height of the cut slope (H cut), width of the cut slope (D cut), width of the ditch (D ditch), width of the roadway (D subgrade), length of the fill slope (L fill), gradient of the fill slope (P fill), width of the construction area (D construction), effect distance (the distance between the road and where the rolling rocks stop: L effect), slope of the terrain (P area) (Fig. 2). The measurements were done using hand-held clinometer, steel tape, four 10 - meter ropes, altimeter and compass.

In the forest roads constructed, in 1500m part in total, 30 test fields having a width of 10 m were chosen in every 50 m. The place of the test fields in which samples would be taken by systematic sampling was determined. Two cross-sections were taken at the beginning and at the end of each test field and 60 measurements were done. In addition, most of the damage to the trees below the roads was caused by work machines in the first ten meters. For that reason, from the end of the fill slope, an area of 10m x 10m (100m^2) was surrounded by a rope and the damaged trees within this area were counted.

With the help of measurements done along the road, the values of the size of the cut area in the test field, the size of the forest that was destroyed during the road construction and number of the trees that cut off were calculated.

The average and standard error values obtained from cross-sections have been calculated. Type of the machines and slope group were evaluated as two factors and variance analysis having two factors was made using statgraphics statistical package program. Necessary graphics were drawn using SPSS statistical package program. This analysis was made in order to determine whether the type of the machine and slope of the terrain had an effect on size of road cross-sections.

The number of damaged trees (T_{dn}) was considered a dependent variable and slope of the terrain below the road (S_p), gradient of the fill slope (P_f), cut area (C_a), slope of the terrain (P_a), length of the fill slope (L_f), effect distance (L_e), width of the roadway (D_r), proportion of the rocks (R_p), number of the trees (T_n), type of the machine (M_t) such as excavator=1, bulldozer=2, and the road gradient (G_r) were considered as independent variables and correlation analysis was carried out. Later, in order to find the most effective independent variables on the number of the damaged trees, regression analysis was made with the help of statgraph statistic package program.

Correlation and regression graphics were drawn using microsoft excel program. Nonparametric chi square test was applied on the number of damaged and undamaged trees that were checked in both of the 100m^2 areas. This test was applied in order to determine whether there is any difference between the damages on the trees during the work done using both types of machines.

Results and Discussion

Findings obtained from cross-sections: Average and standard error values belonging to the measurements done at the cross-sections which were at the test fields of all the research areas are given in Table 1.

From Table 1, it can be seen that when the bulldozers are used for road construction in both slope group, the values measured at the road cross-sections such as the height of the cut slope, width of the cut slope, length of the fill slope, width of the fill slope, the length of the area affected by road construction, width of the construction area and cut area increase. Types of the machine and slope group were considered as two factors and variance analysis having two

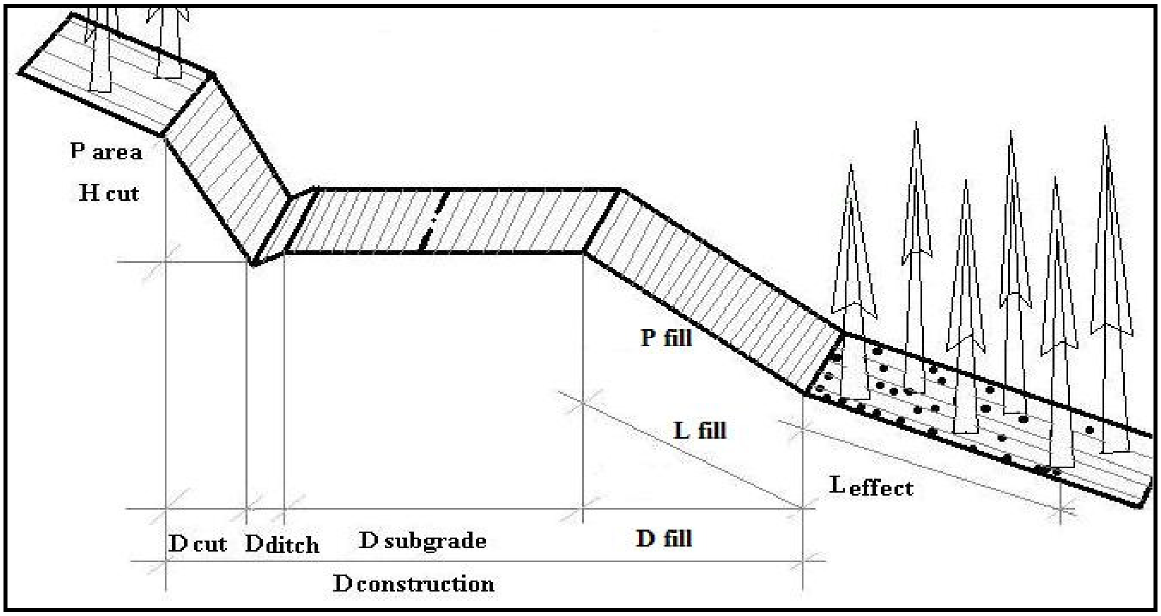

Fig. 2: Measurements in road template on the terrain.

Table – 1: Distribution of measured values at machine and slope groups[a]

	Excavator I	Bulldozer I	Excavator II	Bulldozer II
Height of the cut slope (m)	1.72 ± 0.07	3.83 ± 0.20	5.20 ± 0.17	5.08 ± 0.18
Width of cut slope (m)	0.53 ± 0.04	1.70 ± 0.08	1.77 ± 0.07	1.89 ± 0.09
Width of the ditch (m)	1.102 ± 0.005	1.097 ± 0.017	1.102 ± 0.002	1.381 ± 0.018
Width of the roadway (m)	4.36 ± 0.06	4.31 ± 0.07	4.30 ± 0.04	4.78 ± 0.06
Length of the fill slope (m)	3.97 ± 0.21	5.94 ± 0.30	6.31 ± 0.16	10.60 ± 0.46
Gradient of the fill slope (%)	54.7 ± 1.5	57.6 ± 1.2	72.0 ± 0.5	67.9 ± 0.6
Width of the fill slope (m)	3.41 ± 0.18	5.07 ± 0.24	5.09 ± 0.14	8.68 ± 0.36
Effect distance (m)	2.30 ± 0.16	3.37 ± 0.22	4.60 ± 0.16	9.97 ± 0.97
Width of the construction area (m)	9.40 ± 0.17	12.17 ± 0.31	12.26 ± 0.17	16.73 ± 0.36
Cut area (m^2)	0.935 ± 0.059	0.966 ± 0.699	4.169 ± 0.101	4.795 ± 0.184

[a] Mean ± standard error.

Table – 2: Results of variance analysis with two factors as machine type and slope group.

	F values[a]	
	Type of machine	Slope group
Height of the cut slope	71.43***	37.32***
Width of cut slope	62.52***	76.54***
Width of the ditch	74.95***	80.50***
Width of the roadway	11.68***	10.80**
Length of the fill slope	122.27***	98.36***
Gradient of the fill slope	0.29	163.56***
Width of the fill slope	111.02***	109.35***
Effect distance	30.15***	170.75***
Width of the construction area	177.19***	185.44***
Cut area	8.01**	923.82***

[a]*, **, *** significant at $p<0.05$, <0.01 and <0.001, respectively.

factors was made in order to determine whether the differences among the values had a statistical meaning and to determine the causes of the differences (Table 2).

In the result of the variance analysis, it was observed that both the slope group and the type of the machine have a significant effect on almost all cross-section measurement values. The graphics of the values belonging to the length of the fill slope, length of the affected area (effect distance), width of the construction area, the cut area which have considerable differences according to variance analysis are given in Fig. 3.

It was observed that the width of the construction area was smaller when excavators were used. For that reason, less forest area was destroyed and fewer trees were cut off in order to clear the road alignment.

Since the materials can be put somewhere within sight under control by the operator, length of the fill slope is shorter when excavators are used. While working with bulldozers, the material is placed on the fill slope by being pushed.

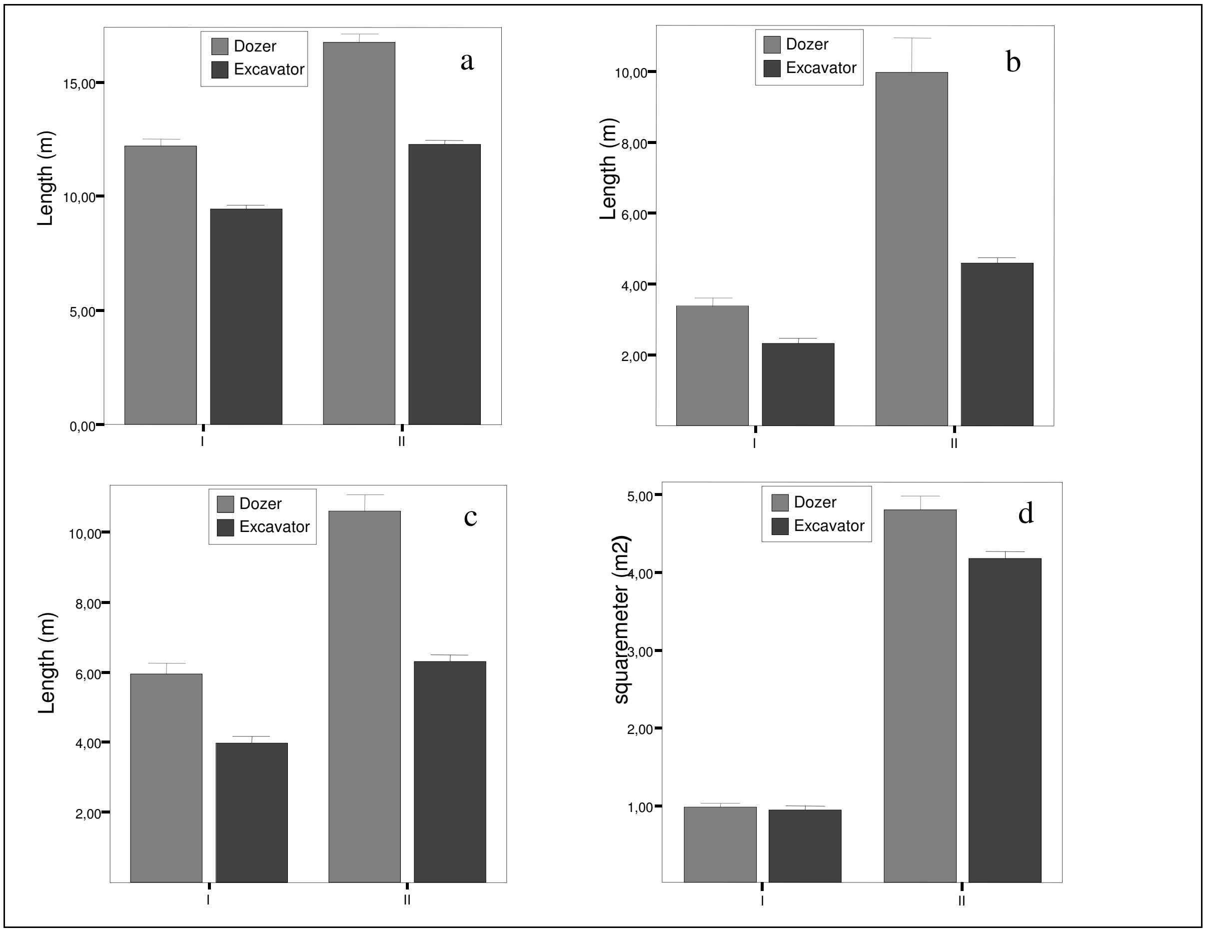

Fig. 3: Graphics of the values belonging to width of the construction area (a); effect distance (b); the length of the fill slope (c); and the cut area (d).

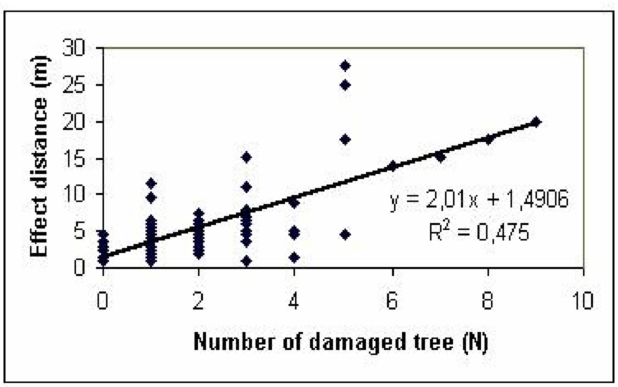

Fig. 4: Relationship between the number of damaged trees and the length of effect distance.

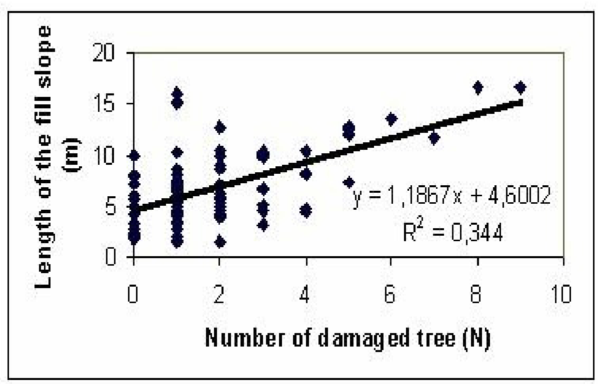

Fig. 5: Relationship between the number of damaged trees and the length of fill slope.

The height and width values of the cut slope can be kept low when excavators are used. Landslides which damage the road platform and the ditches beside the roads are also prevented. Duzgun *et al.* (1996) suggested that as the height and angle of the slopes increase, the sliding possibility of the slopes also increases.

The water which runs on the road platform when the ditches are blocked due to sliding of the materials damages the road platform, causes erosion and ruins the fill slopes below the road. When the construction sites were compared, it was observed that excavator could always dig ditches having a width of 1.1m and thus forest road standards could be met better.

Table – 3: Correlation coeffficients between dependent variable and independent variables.

	S_p	P_f	C_a	P_a	L_f	L_e	D_r	R_p	T_n	M_t	G_r	T_{dn}
S_p	1.00	0.75**	0.68**	0.79**	0.58**	0.60**	0.07	0.45**	-0.09	0.05	0.05	0.30**
P_f	0.75	1.00	0.47**	0.72**	0.55**	0.42**	-0.17	0.57**	-0.30**	-0.02	0.12	0.17
C_a	0.68**	0.47**	1.00	0.87**	0.38**	0.34**	0.48**	0.28**	-0.01	0.08	0.19*	0.19*
P_a	0.79**	0.72**	0.87**	1.00	0.51**	0.45**	0.12	0.46**	-0.12	-0.05	-0.02	0.20*
L_f	0.58**	0.55**	0.38**	0.51**	1.00	0.72**	0.06	0.11	0.09	0.47**	-0.33	0.59**
L_e	0.60**	0.42**	0.34**	0.45**	0.72**	1.00	-0.01	0.13	0.25**	0.34**	-0.32**	0.69**
D_r	0.07	-0.17	0.48**	0.12	0.06	-0.01	1.00	-0.21	0.29**	0.22*	-0.38**	0.09
R_p	0.45**	0.57**	0.28**	0.46**	0.11	0.13	-0.21*	1.00	-0.22	-0.40**	0.39**	-0.02
T_n	-0.09	-0.30**	-0.01	-0.12	0.09	0.25**	0.29**	-0.22	1.00	0.16	-0.22	0.64**
M_t	0.05	-0.02	0.08	-0.05	0.47**	0.34**	0.22*	-0.40**	0.16	1.00	-0.39**	0.44**
G_r	0.05	0.12	0.19*	-0.02	-0.33**	-0.32**	-0.38**	0.39**	-0.22*	-0.39**	1.00	0.28**
T_{dn}	0.30**	0.17	0.19*	0.20*	0.59**	0.69**	0.09	-0.02	0.64**	0.44**	0.28**	1.00

a*, ** significant at p<0.05, <0.01, respectively.

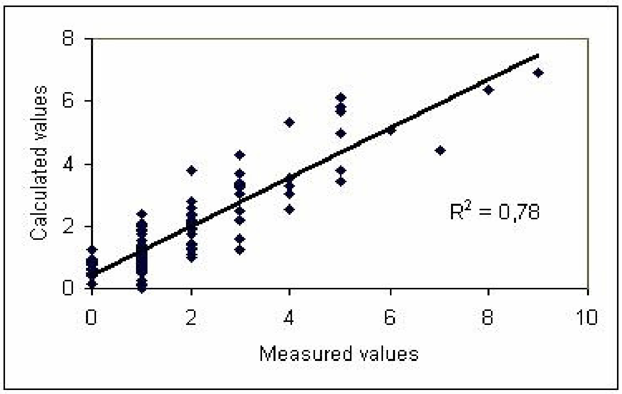

Fig. 6: A comparison between the calculated and measured values of number of damaged trees.

In a study by Tochiki and Kaibori (1990), it was stated that the major cause of damages on the slopes and sliding of materials along the forest roads in the northwest region of Hiroshima was the water that ran on the road after heavy rain. Similarly, in another study, it was observed that wrong forest road construction technique and unnecessary cuts and fills led to destruction of forests and landslides (Kantarci, 2002).

Correlation matrix between the dependent variable of the number of damaged trees (T_{dn}) and the other 11 independent variables is given in Table 3. As a result of the correlation analysis, it was determined that there was a significant relationship at 0.05 confidence level between the number of the damaged trees and independent variables such as the slope below the road, cut area, slope of the terrain, length of the fill slope, length of the effect distance, number of trees, type of machine and the road gradient. The graphics of the relations that are considered to be important in correlation matrix are given below. In the graphics, it can be seen that as the length of effect distance increases, the number of damaged trees also increases (Fig. 4). In the same way, as the length of the fill slope increases, the number of damaged trees increases (Fig. 5).

At the construction sites, the number of damaged trees was taken as dependent variable and the other 11 variables as independent and a regression analysis was conducted. The equation of the fitted model is

$$T_{dn} = -0.940312 + 0.346777 \times T_n + 0.0941625 \times L_f + 0.111444 \times L_e + 1.83205 \times R_p + 0.723703 \times M_t - 0.37136 \times D_r$$

Since the p-value is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level. The R-squared statistic indicates that the model as fitted explains 78.44 % of variability in the number of damaged trees. As a result of the multiple linear regression analysis, it was observed that the most important independent variables that had an effect on the number of damaged trees were the number of the trees, length of the fill slope, effect distance, proportion of the rocks, type of the machine and width of the roadway.

It was seen that the number of damaged trees increased as the values of the number of the trees in the construction sites, proportion of the rocks, length of the fill slope and effect distance increased and when the bulldozers were used instead of excavators. However, when the values of width of the roadway increased, the number of damaged trees decreased. The graphics of measured values and the calculated values belonging to the regression model are seen in Fig. 6.

Forest area destroyed during construction: In steep terrain, for 1 km long road, 1.2 hectare of forest is lost when a bulldozer is used and 0.9 hectare when an excavator is used. If in very steep terrain for 1 km long road, 1.6 hectare of forest is lost when bulldozer is used and 1.2 hectare when excavator is used. It is clear that the largest forest area was destroyed in very steep terrain where the bulldozer worked. However, in steep terrain where excavator worked, it was observed that the least amount of forest was destroyed. When excavator worked in very steep terrain, it destroyed nearly the same amount of forest as the bulldozer did in steep terrain.

For each 1km road construction, the fewest trees (21) were cut in steep terrain where the excavator worked and the most trees (34) were cut in very steep terrain where the bulldozer worked. It was understood that in steep terrain when excavators were used, less forest area was destroyed (22.16%) compared to bulldozers and 26.54% less area destroyed in very steep terrain. When excavators were used, less forest area was destroyed and a smaller part of the forest was occupied by the forest road. Furthermore, destruction of a wider forest area was prevented since the road was kept narrower.

When road construction is completed, the appearance of the fill slope along the road and piles of rocks and other materials that roll down the slope can lead to a bad view. The stones and rocks that roll down the slopes may also damage the plant cover. When the values of the proportion of damaged trees which were obtained by dividing the number of damaged trees by the total number of trees were studied, it was observed that the proportion of damage (0.38) in steep terrain where bulldozer worked was higher than the proportion of damage (0.19) in steep terrain where excavator was used. Similarly, the proportion of damage (0.55) in very steep terrain where bulldozer worked was higher than the proportion of damage (0.31) in very steep terrain where excavator worked.

During the forest road construction, stones and rocks rolling down the slopes damage a considerable part of the forest (Tunay and Melemez, 2004). In a study, it is stated that bark insects can easily cause epidemics on the trees which are damaged by stones and rocks, and fungi and other harmful organisms destroy 50 percent of first class timber trees (Sekendiz and Ozder, 1983).

In order to determine whether the type of machine used had an effect on the number of damaged trees chi square test was applied and an independence check was made. For the values in steep terrain and very steep terrain separate checks were made.

H_0 : type of the machine doesn't have an effect on the number of trees damaged during road construction in steep terrain.

Since $\chi^2 = 13.27 > \chi^2_{table} = 3.84$ null hypothesis is rejected in steep terrain.

H_0 : type of the machine doesn't have an effect on the number of trees damaged during road construction in very steep terrain.

Since $\chi^2 = 15.24 > \chi^2_{table} = 3.84$ null hypothesis is rejected in very steep terrain.

In both slope groups, the type of machine, bulldozer or excavator used for road construction does have an effect on the number of trees damaged. Working with excavator causes less damage on the trees below the newly constructed road since the operator can see where the material is unloaded and can control it.

It was observed that the values of the height of the cut slope, the width of the cut slope, the length of the fill slope, the width of the fill slope, the length of the effect distance, the width of the construction area and the size of the cut area in the cross-sections of the roads increased when bulldozer was used for road construction and when the slope was high. Road construction by excavators enabled the operator to unload material within sight, thus the width of the construction area, the length of the effect distance and the length of the fill slope can be kept shorter compared to the bulldozer.

Using the excavator, cut and fill slopes, ditches and roadway can be constructed in accordance with the standards. Thus, landslide and erosion risks in the cut and fill slopes are reduced and the ditches which allow the drainage of water can be used more efficiently. Also the use of hydraulic hammers attached to excavator is considered the ideal solution for rock disintegration in order to avoid rock blasting with dynamite which increase the risk of fire in Calabrian Pine forests.

As a result of the regression analysis it was understood that when the values showing the number of the trees, density of the rocks, the length of the fill slope and effect distance increased and when bulldozer was used instead of excavator the number of the damaged trees increased.

It was found that while working with excavator in steep terrain 22.16% less forest area was destroyed compared to bulldozer and in very steep terrain (26.54%). As it is seen, less forest area is destroyed with excavator and a smaller part of the forest is occupied with forest road compared to bulldozer. In addition, for each 1km long road in steep terrain where excavator worked only 21 trees were cut down while 25 trees were cut down when bulldozer were used. In very steep terrain, 25 trees were cut down while working with excavator and 34 trees were cut down while working with bulldozer. Destruction of the forest can be prevented since fewer trees are cut down and the roads can be kept narrower while working with excavators. With the use of excavator for forest road construction, the loss of forest area and plants can be reduced to the minimum possible level.

As a result of the Chi-square test, it was understood that using excavator or bulldozer for forest road construction has a significant effect on the number of damaged trees. It was observed that the trees below the roads constructed using bulldozers had more damage compared to the ones below the roads constructed using excavators. While working with excavators, since the operator can see where he unloads the materials and control them, the plants below the roads get less damaged. Furthermore, with the use of excavators, the harmful effects of damages by insects, fungi etc. that result from the scarred trunks of the trees can also be prevented.

In order to construct an environmentally friendly forest road, especially in Calabrian Pine Forests on steep and very steep terrain, firstly road planning should be done in accordance with the appropriate technique for mountainous forest area and excavators should be used as the type of machine.

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