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ORIGINAL PAPER

An environmental assessment of forest stands damages caused by excavators during road construction in Beech forests

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Abstract Construction of forest roads can cause short-term and long-term negative effects on forest ecosystems in different ways if they are not well planned and appropriately maintained. In this research, environmental damages caused by an excavator during road construction were examined in steep terrain covered by beech (*Fagus orientalis* L.) stands. The study was conducted along a 1.5 km road in western Blacksea Region of Turkey. All of the road construction operations were monitored during a construction period, and measurements of cross sections sizes and stand damages were measured during and after the construction activities. The road construction was evaluated according to the appropriate method and standards. The average widths of roadway, fill slope and construction zone were 4.82, 6.91, and 16.61 m, respectively. Along the 1,500 m road, forested area impacted was 24,915 m^2 while the number of trees cut was 1,495 and rate of the damaged trees below the fill slope was found to be 24.7 %. In the study, based on the appropriate method and standards, less forested area might have been impacted (23 %). As a result of regression analysis, it was found that the rate of damaged trees increased as the values of the proportion of rocks, the width of the road surface and the width of the cut-slope increased. To reduce the negative effects of forest road construction on the environment, new forest road construction by excavators should be performed using appropriate methods within mountainous terrains.

Keywords Construction zone · *Fagus orientalis* · Forest road construction · Steep terrain · Tree damage

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Introduction

Forest roads are essential for forest management activities including regeneration, harvesting, and timber logging as well as recreation and other social activities. New forest road construction has always been one of the main issues that arise in forestry management. In recent years, forest road construction activities have become controversial because of increasing public concerns over the short- and long-term effects of those activities on the environment. The ecological balance of forests and trees is adversely affected by road construction works (Tague and Band 2001; Tunay and Melemez 2004; Gumus et al. 2009). Roads are liable to have multiple impacts on animals, plants and ecosystems functioning (Trambulak and Frissell 2000; Avon et al. 2010). Forest ecosystems are more sensitive to environmental changes (Erdogan et al. 2011; Ciabanu et al. 2011); therefore, forest engineers should consider not only the total cost of road construction, but also its environmental impacts (Demir 2007; Akay et al. 2008; Ozturk et al. 2010). To reduce costs and the negative environmental effects, bulldozers have been replaced by excavators in forest road construction operations in steep terrains (Erdas 1986; Ozturk et al. 2010). In addition, excavators may improve the quality of forest roads in comparison to bulldozers (FAO 1998; Ozturk and Inan 2010). The excavator has advantages during excavation activity with better control, and during the placement of material efficiently on fill slopes (Stjernberg 1982; Winkler 1999; Fannin and Lorbach 2007).

The environmental impact of forest road constructions by different machines and in different terrain conditions has been studied in general by previous studies (Spaeth 1998; Winkler 1999; Tunay 2006; Gumus et al. 2009; Parsakhoo and Hosseini 2009; Ozturk et al. 2010), where researches have mainly focused on tree damages, and less attention has been given to standards and the appropriate methods by excavator. However, it is rather necessary that forest roads should be carefully constructed according to the standards, considering the importance of the forest road network in sustainable management of forest resources (Scandari and Hosseini 2011). Furthermore, environmental effects of forest road construction in beech stands at mountainous terrain have never been investigated in Turkey. Even though some species are inherently tolerant to damages, some species including beech and tulip trees are intolerant to construction and harvesting damages (Quesnel and Curran 2000). Consequently, there is a need to investigate the negative effects of non-standard forest road construction in beech forest stands in steep terrain.

The aim of this study is to analyze forest stand damages during forest road construction performed by an excavator. The study was carried out Zonguldak-Devrek Forest Enterprise in 2010. In the study, sample areas were selected to investigate the direct damage to the beech stands and trees damaged below the fill slope in steep terrain. An environmental assessment was made within forest road construction area, and sizes of cross section with the appropriate construction methods were evaluated with respect to forest stand damage.

Materials and methods

An area that was exposed to forest road construction works within Zonguldak-Devrek Forest Enterprise was chosen as the study area. Devrek region is located in the southwestern part of Turkey at the Black Sea basin. Beech (*Fagus orientalis*), oak (*Quercus* spp.), and fir (*Abies* spp.) are common tree species in this region, while the study area is dominated by Beech (*F. orientalis* Lipsky). Most of the trees are in the size of 20–36 cm in diameter, and the stand density is classified as 3rd degree which means the stand coverage of 70–100 %. The average ground slope of the study area is 66 %, ranging from 58 to 78 %. Thus, the study area can be considered as very steep terrain (more than 51 %) according to the slope classifications suggested by IUFRO.

The selected forest road (code number 255) was planned in 2004 and constructed in 2010. Elevations of the road at starting and ending point are 585 and 855 m, respectively (Fig. 1). Average gradient of the road is 5 % ranging from 3 to 6 %. Total length of the road was planned to be 1,550 m with the average roadway width of 4 m while the width of ditch is 1 m. The study area consisted of common soil (38 %), hard soil (29 %), soft rocks (21 %), and hard rocks (12 %).

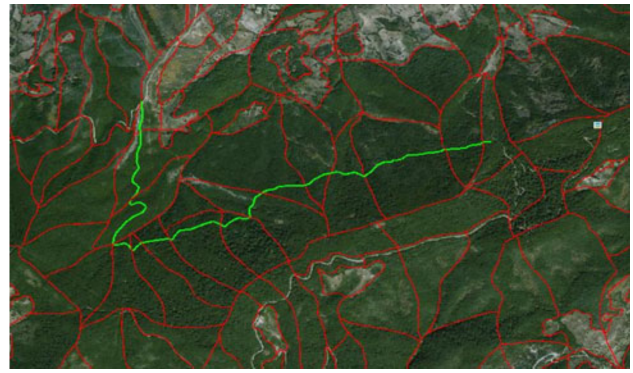

Fig. 1 The study area and forest road construction line

The forest road was built by a private contractor. For excavation and filling operations, a hydraulic excavator was used in the forest road building. Additionally, the excavator was equipped with a hydraulic hammer instead of the metallic bucket to break the rocks into pieces.

In the study area, all stages of the road construction works were monitored and necessary measurements were made during and after the road construction activities. The measurements include width of the cut slope (CS_w), width of the ditch (D_w), width of the roadway (R_w), width of the fill slope (FS_w), width of the construction zone (CZ_w), and effect distance of rolling rocks (E_d). The number of damaged trees (DT_n), the number of the trees (T_n), rate of damaged trees (DT_r), mean diameter of the trees (DT_m), slope of the ground (G_s), proportion of the soft rocks (SR_p), proportion of the hard rocks (HR_p), proportion of the soil (S_p), proportion of the hard soil (HS_p), slope of the ground under the construction zone (UG_s), and the road gradient (R_g) were also measured (Fig. 2, adapted from Aricak and Acar 2008).

Within the 1,500 m forest roads constructed, 30 test fields with a width of 10 m were chosen in every 50 m. The location of the test fields was determined using systematic sampling method. In addition, sample plots of 100 m^2 (10 m × 10 m) area were generated from the end of the fill slope using a rope, and then number of all trees and number of damaged trees within this plot were recorded. In a similar study, Gumus et al. (2009) found that the main injuries occurred in the first 10 m from the end of the fill slope. After measurements were completed within the study area, size of the construction zone, the size of the forested area impacted and the number of the trees cut were measured.

The mean and the standard deviation values of the measurements obtained from cross sections were calculated. The completed road construction was evaluated according to the methods suggested by Winkler (1999) in which both width of the road surface and width of the fill slope could be approximately 4 m (Fig. 3). Then,

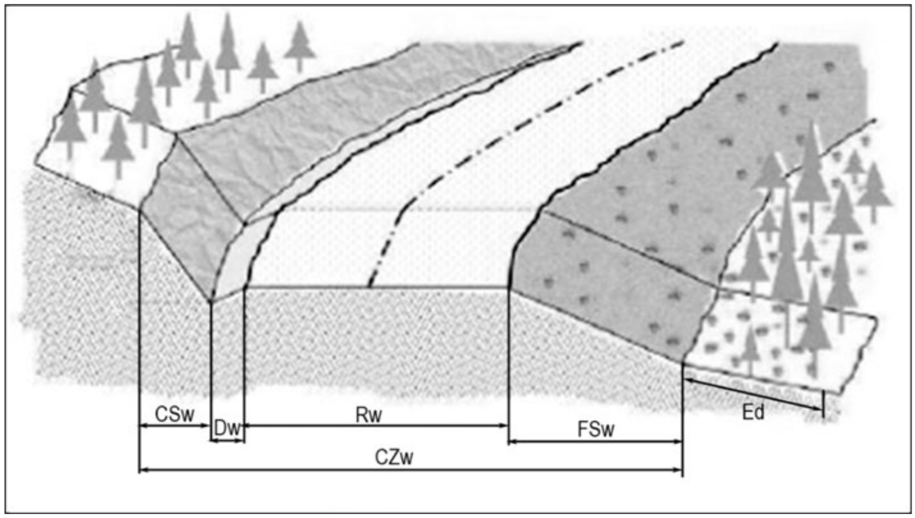

Fig. 2 Measurements in the road template on terrain

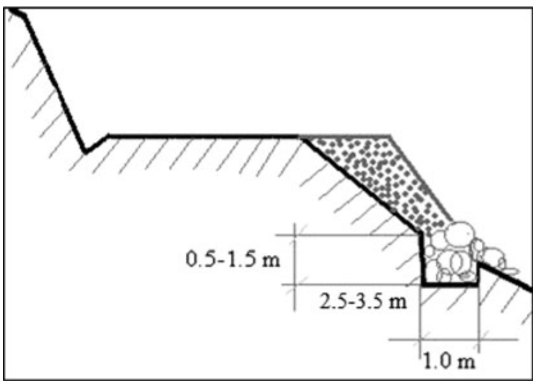

Fig. 3 Technique of forest road construction by excavator

evaluations of forest road and size of cross sections based on this appropriate method were compared with that of the method concentrated on forest stand damage. An environmental assessment was made for four different road conditions (Case I: actual case, Case II: width of road = 4 m, Case III: width of fill slope = 4 m, Case IV: width of road = 4 m and width of fill slope = 4 m) in the study area.

Correlation analysis was made to determine relationships between all the variables. Finally, regression analysis was made to find the most effective independent variables on the rate of the damaged trees (DT_r) which was considered as a dependent variable and the others were considered independent variables. Regression analysis was performed using the SPSS 16.0 statistic package program.

Results and discussion

Mean and standard deviation values at the test fields are given in Table 1. The table shows that the average widths of road, fill slope and construction zone were 4.82, 6.91,

Table 1 The values of decision variables measured on the cross sections

	Abbreviation	Mean	Std. deviation
Width of road surface (m)	R_w	4.82	1.08
Width of fill ditch (m)	D_w	0.94	0.21
Width of cut-slope (m)	CS_w	3.94	0.51
Width of fill slope (m)	FS_w	6.91	3.18
Width of construction zone (m)	C_w	16.61	3.43
Effect distance (m)	E_d	1.37	2.24
Slope of the ground (%)	G_s	66.20	4.83

and 16.61 m, respectively. It was observed that the width of the construction area was very large. The reason for this fact is due to the size of the road width and the width of fill slope. The results indicated that when these variables decreased, width of the construction area was decreased as well. Tunay (2006) stated that a road construction activity in steep terrain with more than 51 % ground slope resulted in 12.26 and 16.73 m wide road construction zones using excavator and bulldozer, respectively.

In case of road construction operations done by the appropriate method and standards, width of the construction zone is tend to be decreased. Width of the road surface and width of the fill slope could be constructed approximately 4 m (Winkler 1998; Winkler 1999). Thus, the width of forest road could be constructed in 4 m instead of 4.82 m based on the standards (Case II) and the width of fill slope could be constructed in 4 m instead of 6.91 m according to the appropriate method (Fig. 3) using excavator (Case III). The width of the construction zone could be constructed 12.88 m instead of 16.61 m in accordance with appropriate method and standards (Case IV). Calculations of width of the construction zone in case of different condition are given in Table 2.

Table 2 Calculations of width of the construction zone in case of different condition

	R_w (m)	D_w (m)	CS_w (m)	FS_w (m)	C_w (m)
Case I (16.61)	4.82	0.94	3.94	6.91	16.61
Case II (16.61–0.82)	4.00	0.94	3.94	6.91	15.79
Case III (16.61–2.91)	4.82	0.94	3.94	4.00	13.70
Case IV (16.61–0.82–2.91)	4.00	0.94	3.94	4.00	12.88

Changes in destroyed forest area and the number of trees cut depending on the width of the construction zone are given in Table 3. It can be suggested that when construction is conducted using appropriate method and standards, less forest area may be impacted (23 %). One of the negative effects of roads is the loss of forest area due to their construction in the forest environment (Sorkhi et al. 2012). Along the 1,500 m road, at least 5,595 m^2 of forest area was impacted. The average number of trees is approximately 6, while the average diameter of the trees is 27 cm based on the measurement in the test areas on both sides of the road. It can be seen that the number of trees cut decreases from 1,495 to 1,159 in accordance with the appropriate method and standards (Case IV). In a similar study (Tunay 2006) conducted in very steep terrain for 1 km long road, impacted area was found to be 12,000 m^2 when excavator was used. In another study, along a 3,670 m road, the average construction zone width was 7.27 m; therefore, sample road section impacted was approximately 2.67 ha of forested area during the road construction by bulldozer (Ozturk et al. 2009). During the construction project of a forest road, the standard design must be carried out on the ground to achieve the desired road with minimal impact on environment (Sorkhi et al. 2012).

The stones and rocks that roll down the slopes may also damage the beech stand. The values about the damaged trees in the study area are given in Table 4. Along the constructed road, number of the damaged trees was 250 while the rate of the damaged trees was approximately 24.7 %. Ozturk et al. (2010) found that 27 % of total trees were damaged during road construction by excavator upon 46–90 % ground slopes. A similar study indicated that the 36 % of trees under the forest road construction by bulldozer were damaged (Ozturk et al. 2009). Parsakhoo and Hosseini (2009) determined that 87 % of total regenerations were destroyed by bulldozer during land working.

Table 3 Changes in destroyed forest area and number of trees cut depending on width of the construction zone

	Width cons.zone (C_w) (m)	Rate of decrease (%)	Destroyed forest area (m^2)	The number of trees cut off
Case I (16,61)	16.61	0	24,915	1,495
Case II (16.61–0.82)	15.79	5	23,685	1,421
Case III (16.61–2.91)	13.70	18	20,550	1,233
Case IV (16.61–0.82–2.91)	12.88	23	19,320	1,159

Table 4 The values about the damaged trees in the study area

	Average	Total 30 test area	Total 1,500 m road
Number of total trees	6.2	187	935
Number of undamaged trees	4.6	137	685
Number of damaged trees	1.6	50	250
Rate of damaged trees (%)	24.7		

Some statistically significant correlation coefficients between the variables are given in Table 5. As a result of the correlation analysis, it was determined that there was a significant relationship between the rate of the damaged trees and variables such as rate of hard rocks and width of road surface at 0.01 confidence level. It can be seen that as the rate of the hard rocks increases, the rate of damaged trees also increases. In addition, the number of damaged trees increases with increasing width of the road surface as well.

There was a significant relationship between the effect distance and variables such as slope of the ground and width of fill slope. It was determined that about 90 % of damaged trees were in the first 10 m from the beginning of the fill slope. To construct 1 km new road in a forest area,

Table 5 Some statistically significant correlation coefficients between the variables

	Rate of hard rocks (HR_p)	Width of road-way (R_w)	Width of fill slope (FS_w)	Effect distance (E_d)
Rate of damaged trees (DT_r)	0.706^{**}	0.468^{**}		
Slope of the ground (G_s)			0.500^{**}	0.439^{*}
Proportion of the soil (SS_p)	-0.723^{**}		-0.393^{*}	
Width of the fill slope (FS_w)				0.743^{**}

* Significant at $P < 0.05$

** Significant at $P < 0.01$

0.6–1.0 ha of forest area is opened directly and 400–3,500 trees are cut depending on stand age (GDF 2008). Gumus et al. (2009) observed 295 damaged trees throughout the 3,100 m of forest road construction area with average ground slope of 77 %.

In the construction sites, the rate of damaged trees (DT_r) was taken as dependent variable, while the remaining variables as independent to conduct a regression analysis. The equation of the fitted model is

$$DT_r\,(Y) = -56.237 + 0.665 \times HR_p + 5.988 \times R_w + 11.121\,CS_w,$$

where DT_r is the rate of damaged trees, HR_p is proportion of the hard rocks, R_w is width of the roadway and CS_w is width of the cut slope.

Since the P value is less than 0.01, there is a statistically significant relationship between the variables at 99 % confidence level. The R^2 statistic indicates that the fitted model explains 69.70 % of variability in the rate of damaged trees. The graphics of observed and expected values belonging to the regression model are seen in Fig. 4.

As a result of the linear regression analysis, it was observed that the most important independent variables that had an effect on the rate of damaged trees were the proportion of the hard rocks, the width of the road surface and the width of the cut-slope. It was seen that the rate of damaged trees increased as the values of the proportion of the rocks, width of the road surface and width of the cut-slope increased. The rockfall resulting from road construction can cause damages to forest trees (Gumus et al. 2009). In a study conducted by Aricak et al. (2010), the fill slope area and the area affected by the rolling filling material of a forest road was tried to be modeled. They found that the construction site calculated with developed model was 7.80 % larger than the real construction site.

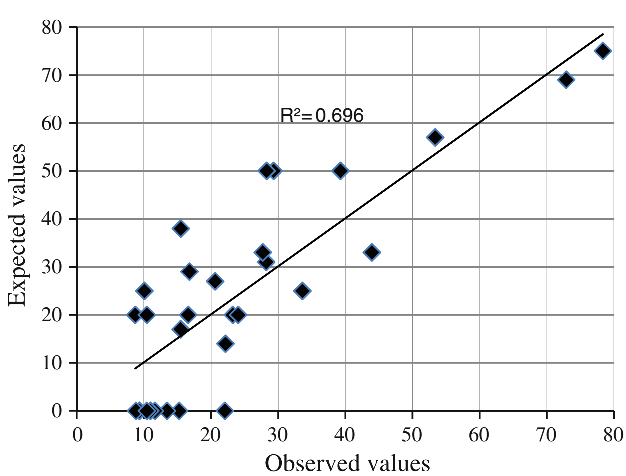

Fig. 4 A comparison between the observed and expected values

To minimize the environmental impacts of forest roads, forest road managers must design the road network efficiently and environmentally as well (Hayati et al. 2012). In addition, it is necessary qualified workers, to work best machines such as excavators and using methods to construct forest road for minimizing environmental damages (Acar 2005; Koser 2008; Parsakhoo et al. 2008; Parsakhoo and Hosseini 2009).

Conclusion

This paper has presented an environmental assessment of forest road construction aspect of forest stands damage. The direct environmental damage to the beech stands including forested area impacted and trees damaged below the fill slope in steep terrain was determined. As a result of this study, it was found that the rate of damaged trees increased as the values of the proportion of rocks, the width of the road surface and the width of the cut-slope increased. For the negative effects of forest road construction should be reduced, when planning forest road networks, instead of high rate rocky and steep terrain, more appropriate alternatives should be chosen as much as possible. If excess material cannot be used, excess material should be moved with a dump truck. New forest roads should be constructed in accordance with the appropriate methods by excavator within mountainous terrain. Operators of excavator and private contractors should be informed about forest road standards and appropriate methods. In addition, the construction operations should be regularly controlled.

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