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The Effect of Forest Road Distance on Forest Fire Severity (Case Study: Fires in the Neka County Forestry)

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ABSTRACT The effect of forest roads on the extent and type of fire damage occurred in forests and rangelands of the Neka County in Mazandaran province was investigated. For this purpose, all fire spots, stand number, percentage and type of injury and damage to tree species, and average diameter at breast height (DBH) were noted with 100% inventory; area and geographic location of access roads were determined using GPS. The results showed that distance from the main access road had a significant correlation with the area of fire spots, but no significant correlation existed between the distance from the strip roads, skid ways, town of Neka and the area of fire spots. The factors influencing fire severity were analyzed using the stepwise regression model. Model also showed that just the distance from the main access road affected the area of fire spots. For every one meter increase in the distance from the main access roads, the area of fire spot was increased by 1.545 m^2. Further, the extent of fire can be controlled by reducing the distance from the main access roads.

Key words: *Road distance, Fire, Forest roads, Stepwise regression, Neka city*

1 INTRODUCTION

Conflagration of forests and rangelands in Iran is one of the most frequent events (Ariapour *et al.*, 2014). For instance, 54 cases of fire affecting about 90 hectares of forest and rangeland in the summer and fall of 2010 were reported from the Neka County Forestry (Amoozad et al., 2011).Fire reduces the number of trees per hectare and canopy class and increases the number of dried trees per hectare (Banj Shafiei *et al.*, 2007). Various sources of the forest fires have been specified (Chou, 1992; Turner and Romme, 1994; Vega Garcia *et al.*, 1995; Amoozad *et al.*, 2011). In order to control and suppress a fire rapidly, we should be initially aware of its occurrence as suppression of a fire in the early stage is easier than when it outbreaks.

Forest roads are often constructed for forest management, utilization and segmentation; also they are the most important factors for forest fire control and containment. The design

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and construction of forest roads was often based on wood production services, while the role of forest roads for fire protection and management was not given much importance (Hosseini *et al.*, 2007). Forest roads have been reported to increase the risk of unwanted fires, but they also provide access for fire control management and damage reduction (Gucinski *et al.*, 2001). Although several studies have associated human-caused fire ignitions with road corridors (Syphard *et al*., 2007, 2009; Narayanaraj and Wiberly, 2011, 2012), less consideration has been given to understanding the multiple influences of roads on the fire regime at a broader landscape-scale. Access to the impassable forest regions through road construction has many benefits such as ability to quickly detect fires close to the road and faster actions in the firefighting operation (Hosseini *et al.*, 2007; SPGS, 2010. Forests roads have been found to serve as fire breaks and provide access for fire suppression activities (Price and Bradstock, 2010; Narayanaraj and Wiberly, 2011). Forest roads create linear biomes, margins and topographic borders against the spread of fire (Reed *et al.*, 1996; Forman and Alexander, 1998; Watts *et al.*, 2007). Besides, lightning-caused ignitions were found to concentrate in areas with lower density of roads and population (Narayanaraj and Wiberly, 2011). In an investigation, most small fires that accounted for only a small proportion of the total burned area were found to occur in roaded areas, but the large fires that accounted for most of the burned areas occurred in wilderness with no roads (Narayanaraj and Wiberly, 2012).

Despite frequent fire occurrence in northern forests of Iran, no study has been conducted to assess the effects of forest roads on fire severity and extent of damage. The main objective of this work was to determine the role of forest roads on the intensity of fire effects. The effects of distance from main access road, strip roads, skid ways and town of Neka on the type of fire damage, fire extent and the damaged tree species were examined to determine their relationship with the fire consequences.

2 MATERIALS AND METHODS

2.1 The study area

Covering an area about 136,038 ha, forests and grasslands of the Neka county (36° 28´ 24´´ to 36° 37´ 21´´N and 53° 19´ 15´´ to 53° 35´ 23´´E) are located in south of Neka and Behshahr counties of Mazandaran province, Iran. About 54 cases of fire affecting about 90 hectares of forest and rangeland in the summer and fall of 2010 were reported from the area.

Scope of research was in the section 2 of Neka forestry, including 6 series located in watershed No. 75 of north forests of Iran (Figure 1). This section leads from the north to the section 3 and 4, from the south to the section 1, 6 and 8, from the east to the section 4 of the Nekachoob Corporation Company and from the west to the agricultural land and scattered forest in low area (Engineers Consultant Development of Central Alborz, 2008).

2.2 Sampling method

Eleven severe fire spots with a total area of 4.7 ha were covered in this study. Their distances from road were determined by Geographical Positioning System. To complete field results, information and documents from the relevant organizations were used. Characteristics of the fire spots are presented in Table 1. In order to survey the number of damaged trees, injury type, DBH and total number of tree species in the fire spots, all data were collected in all eleven fire spots.

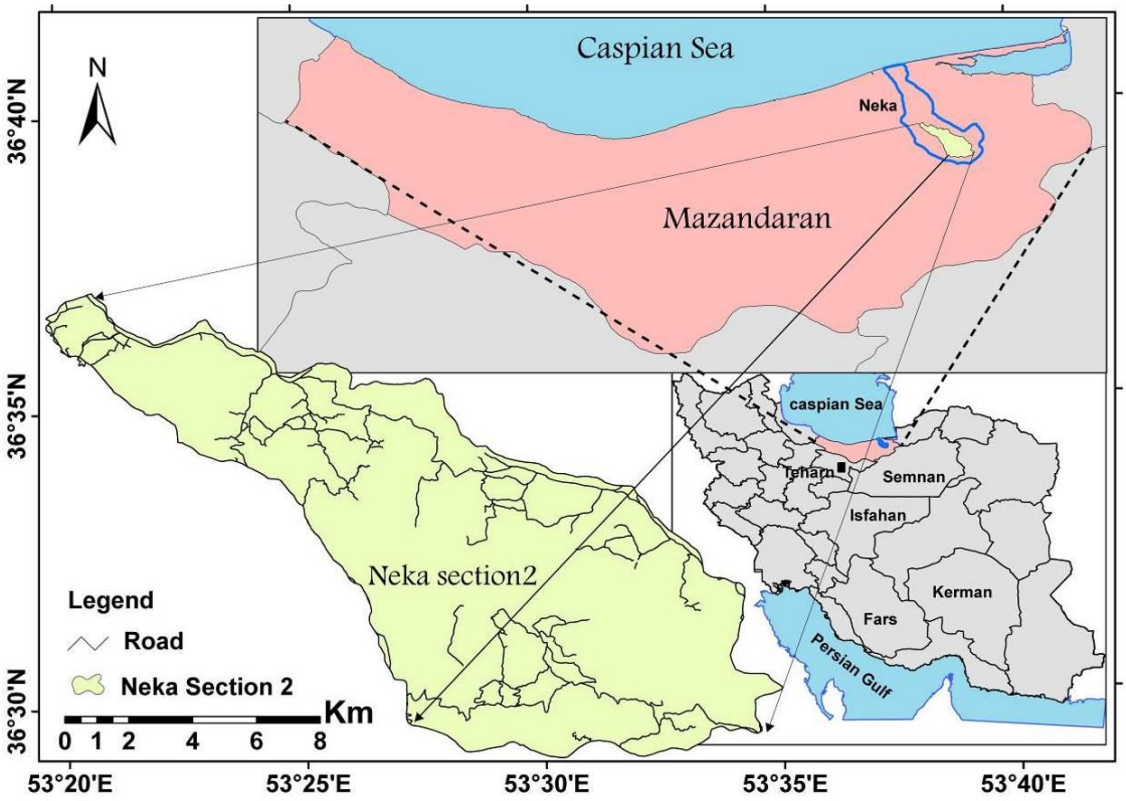

Figure 1 Map of the study area

Table 1 Fire spots characteristics in Study area

Row	Forest name	Spot No.	Spotarea (m^2)
1	Upper Zarandyn	27	2230
2	Qormaraz30	30	2462
3	Eukrka	31	2247
4	DarvishKhelak	35	858
5	Lower Zarandyn	39	1940
6	Porva41	41	1785
7	Qormaraz53	53	2375
8	Darvishan	2	4985
9	Molakhyl	16	3530
10	Doab	51	4985
11	Porva32	32	19897

For data analysis of the parameters, surface of damaged areas, distance from forest roads, and number of trees, DBH and number of hurt trees in any spot fires were calculated. An image of scattered fire spots and two-way main roads of the study area is shown in Figure 2.

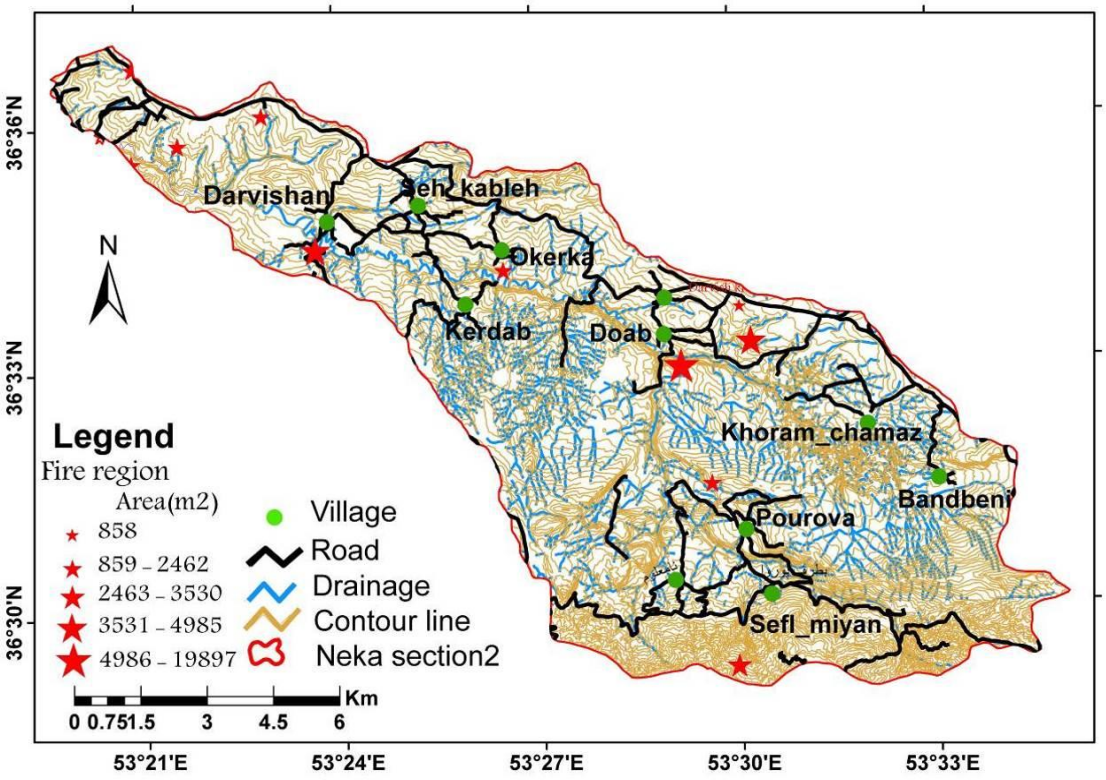

Figure 2 Distribution map of fire spots in the section 2 of Neka forest

2.3 Data analysis

The study covered the fire incidents recorded by Nekachoob Corporation from 2010/12/3 to 2011/1/3. The independent data such as the distances of fire spots from the 2 way main roads, strip roads, skid ways, and from Neka town were used in our analysis. Extent of the fires (in m^2) was taken as dependent data. Data was analyzed by descriptive statistics, repeated ANOVA, adjusted p-values, regression and Pearson's correlation coefficient with SAS software.

3 RESULTS

As can be seen in Table 2, most of the variable models are significant in explaining the area of fire spots (P = 0.01), number and percentage of the damaged trees (P = 0.05). The maximum surface of fire spot was 19897 m^2 with a maximum distance of 4840 m from the main road. Small spots of burned forests with areas ranging 858 to 2230 m^2 were observed in places located less than a kilometer from the main road (eg. Darvish Khelak, Upper Zarandyn and Lower Zarandyn). About 42% of the damaged area was at a distance more than 3 km from the two-way main access road (Figure 3). Thus, it seems the extent of fire was reduced as distances between the fire spots and the two-way main access road decreased. The fire extent was not affected by the distance of other forest roads.

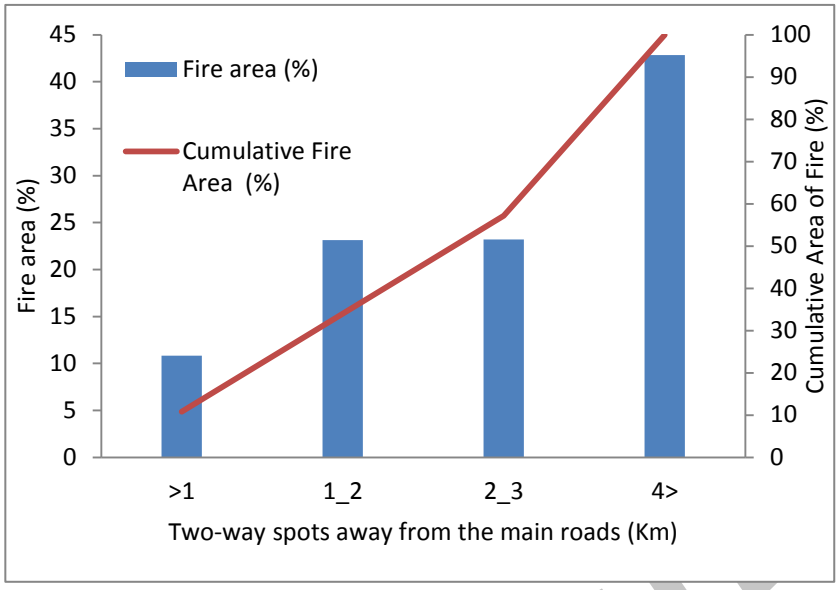

Figure 3 Distribution of the affected areas at different distances from the main access road

Table 2 Regression analysis between fire spots distance from forest roads and Neka city

Dependent variable	intercept	t	bias	RMSE	F	R^2	X4	X3	X2	X1
Forest Area	5.69	3.27**	-0.001	1.571	10.68**	54.3%	-	-	-	0.001
total trees of fire spots	0.627	3.65**	0.001	7.598	13.33**	59.7%	0.00049	-	-	-
total burned trees of fire spots	0.992	2.33*	0.00	0.281	5.42*	40.4%	0.00006	-	-	-

**Model at 99% probability level (p <0.01) was significant.
* Model at 99% probability level (p <0.05) was significant.
X1, X2, X3 and X4 are respectively distance from the main access tow-way road, distance from the strip roads, distance from the skid ways, and distance from town of Neka.

There was a significant correlation (p <0.01) between the total number of burned trees and the distance of fire spots from Neka city, and also between the fire spots distance form Neka city with the total number of trees and the average of damaged trees (p <0.05) (Table 3).

Table 3 Correlation coefficients between traits with fire spots distance from forest roads and Neka city

Forest road	Fire spot area(m2)	Average damaged trees diameter (cm)	Total trees of fire spots	Total burned trees of fire spots
Main road distance	0.80**	-0.21	-0.07	0.13
Strip roads distance	0.20	-0.48	-0.11	-0.37
Skid ways distance	0.21	-0.17	-0.25	-0.12
Neka city distance	0.26	0.68*	0.64*	0.99**

** Significant correlation levels p<0.01and * Significant correlation levels p<0.05

3.1 Using regression analysis to estimate the area of fire spots

Based on stepwise regression analysis, the best regression model was obtained for the case that included only the distance from the main access road among the independent variables. Normal probability plot and Kolmogorov–Smirnov test showed that the data of fire spots distance from main two-way access road, strip roads and Neka city were normal, but from skid ways were abnormal at 1% and became normal after taking the fourth root. Among the dependent variables, the date for the average tree diameter was normal, but data for the area (Y1), total trees (Y3) and total burned trees (Y4) of the fire spots, respectively at 1, 1 and 5%, were abnormal and became normal after taking the fourth root. The other data, such as the distances of other forest accessory roads from fire spots and Neka city, were not fed to the model. The obtained models, the determined coefficients, RMSE, bias percentage and t of model are presented in Table 2.

Results of biases and RMSE of model validation were acceptable. Results of distance determination of model prediction method at 95% confidence and evaluation of fire spots area based on the estimated distance from the main road, expressed that model efficiency was 95 percent. By increasing one meter distance from the main roads, the area of fire spot was increased by about 1.5 square meters.

3.2 Effect of distance from main access tow-way road on the tree species

The average number of trees per hectare in the fire spots was 173, of which the most affected ones were at a distance over 2 km from the main road, respectively belonged to the species of oak, *Quercus castaneifolia C*.A.M (43), Hornbeam, *Carpinus betulus L*. (38) and Zelkova, *Zelkova carpinifolia* (Pall.) Dippel (19) (Figure 4, right). At a distance of 10 to 20 km from Neka city, the maximum number of damaged trees (131) was recorded, of which hornbeam (*Carpinus betulus Lipsky*) was the most damaged of all trees, followed by maple (*Acer velutinum Boiss*.), the Persian ironwood (*Parrotia persica (DC.) C. A. Mey*.), and date plum (*Diospyros lotus L*.) (Figure 4, left). The maximum percentage of fire damage was observed on collar (88.6%), while the crown was the least affected (0.38%). Trunk damage constituted 12.8 and 8.8 percent of the total fire damage in oak and zelkova, respectively, while it was 17% for other species (eg. maple, Persian ironwood and date plum). Most collar damage occurred in spots located more than 4 km from the two-way main road, while the maximum trunk damage occurred in spots located 1-2 km from the main road (Figure 5). Maximum DBH (55 cm) of the damaged trees belonged to oak and beech, while the minimum DBH (22.5 cm) belonged to alder (*Alnus subcordata C.A.M*). Maximum DBH of the damaged oak and hornbeam trees was recorded in spots located 1-3 km from the main road. DBH was 52.5 cm within 1 km from the main road. The minimum DBH within 1-2 km from the main road was 21.25 to 22.5 cm (Figure 6), while it was 25 to 32 cm at a distance over 4 km from the main road.

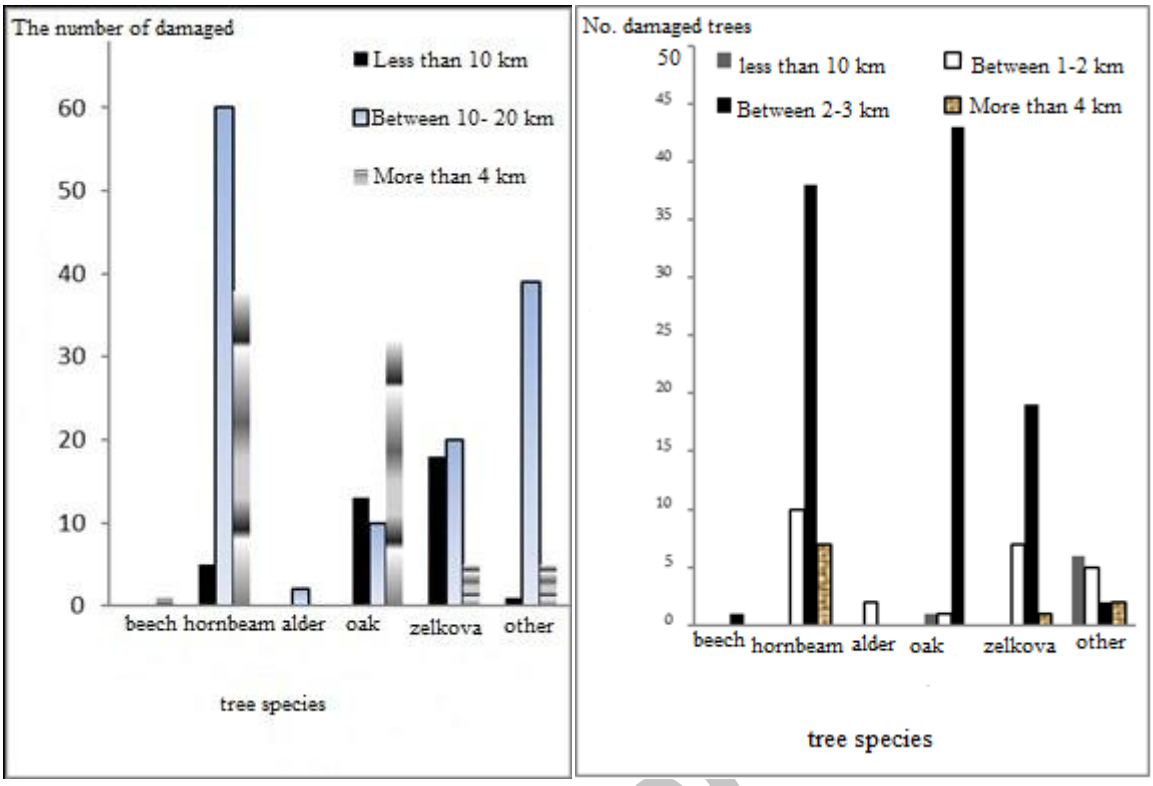

Figure 4 Number of damaged trees at different distances from the main road (Right); the number of damaged trees at various distances from Neka city (Left)

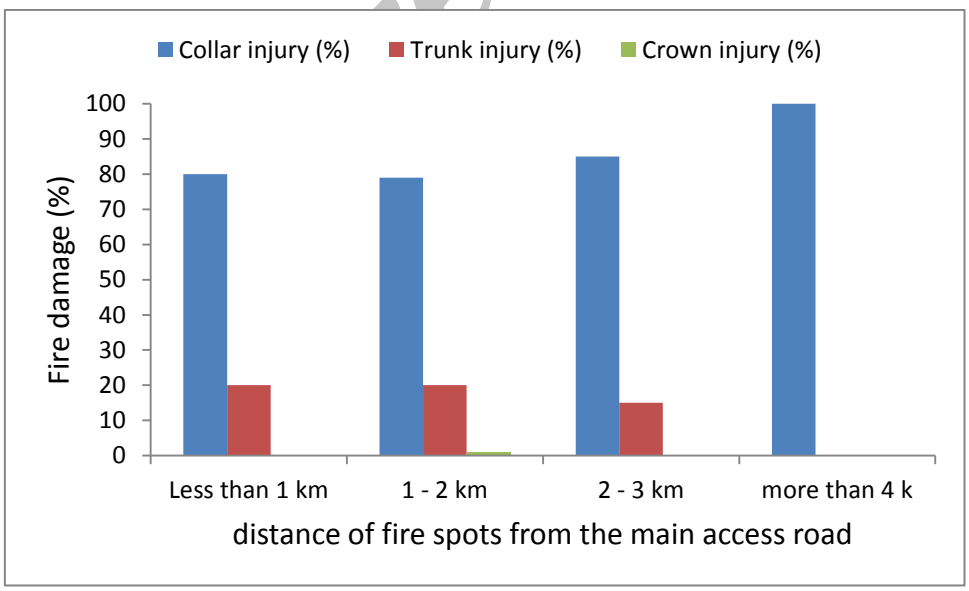

Figure 5 Type and percentage of fire damage based on distance of fire spots from the main road

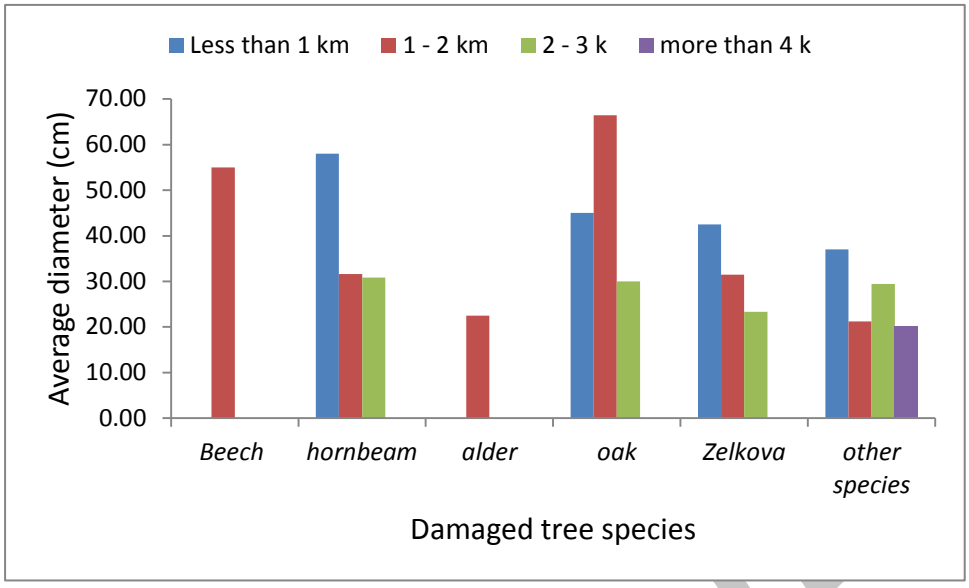

Figure 6 The average DBH of the affected species at varying distances from the main road

4 DISCUSSION AND CONCLUSION

As predicted, the distance from the main access road significantly affected the area of fire spots. More than 48% of the damaged areas were located at a distance of more than 3 km from the main road. The maximum fire affected areas (2 ha.) were found in spots located 4 km from the main road, while the minimum affected areas (0.5 ha.) were located within 1 km from the main road (Figure 3). Greater number of small fire spots due to human presence within 3 km from the main road and larger areas of the damaged regions within a distance of more than 3 km from the main road show the speed of fire control and difference in the fire duration. Narayanaraj and Wiberly (2012) also show less occurrence of fire around and near the main road by passing people due to traffic load, while fires are more often seen at the marginal roads where camping, hunting and fishing activities are oriented. These finding are in correspondence with other relevant studies (Maingi and Henry, 2007; Syphard *et al.*, 2007 and 2008; Yang *et al.*, 2007and 2008). The distance from the forest road, as the only predictor variable fed to the model, showed a linear relationship with increased size of the fire spots (Table 1), which is in contrast with the non- nonlinear relationship reported between road density and the occurrence of fires in Switzerland (Zumbrunnen *et al.* 2011). The difference lies in the size of fire spots that was not taken by the latter. In this study, 10.8% of the Neka section 2 jungle area was hurt by the fire in the distance less than a kilometer from the main road, while 23.1%, 23.2% and 42.8% of the damage occurred at spots located at a distance of 1-2 km, 3-2 km, and over 4 km from the main road, respectively.

Oak and Hornbeam trees at a distance of 2-3 km from the main road were hurt most (Figure 5). Dikinson and Johnson (2001) also showed the effects of fire on trees varies, depending on species that differ in their trunk and leaves anatomical characteristics. Smit and Asner (2012) checked the mechanisms of the road as a fire break in African savannas and showed in 91.7% of the plots, the trees canopy of roadside areas were taller than areas farther away from the road. Forest roads as a fire break limited the spread of fire in forest and provided accesses for

extinguishing fire. Probably due to faster access of fire forces.

The number of damaged trees in spots located 10 km to Neka town was lower than those located 10-20 km, which could be attributed to faster access to fire extinguishing forces (Figure 4, left). Proximity to urban centers and increased human presence increases the number of fires. Given that the crown damage constituted less than 0.39 percent of the total fire damage (Figure 5), it could be concluded that fires in this area was often caused by human rather than natural lightning. Gonzalez and Rios (2009) reported that forest fires in Chile was often of surface fire and caused by humans, and most of them were in relevant areas of big cities and tourist areas around the road network between city. In general, the effect of forest roads on limiting the fire size was more evident than as it might be the cause of increased forest fires. Lack of relation between the narrow strip roads and skid ways and extent and severity of fires and presence of shrubs and plants along the road edge was probably because of the width of those ways. One of the most valuable results of research in the field of firefighting is quick methods to locate a fire and control it in the early moments (SPGS, 2010), the most essential factor for which is adequate access roads. Curt and Delcros (2010) also concluded that the main vegetation communities along the roads had various characteristics to prevent the fire extension. There is a significant relationship for regression equations using data of the tow-way main road distance in confidence level of 95 percent, normality of residuals, the coefficient of determination corrected and root mean square error show a good ability to estimate the fire spots area. Obviously using a larger number of data can achieve better results.

The above results suggest that in the regions with high risk of forest fire, species with low fire risk should be planted and fire breaks such as forest roads should be considered.

All serviceability of roads such as firefighting (fire safety roads) should be considered for design and construction of roads. Taking into account the interest of forest beneficiaries, particularly the domestic ones within and around the forests, and also the not so suitable circumstances of forests in Iran, the construction of access roads, fire breaks and other preventive measures matchable with the forest expanse and the scales of activities should be considered, otherwise the large scale forest fire, like the one in 2010, is not far from recurring.

5 ACKNOWLEDGMENT

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تأثیر فاصله جاده‌های جنگلی بر شدت آتش‌سوزی جنگل
(مطالعه موردی: آتش‌سوزی‌های حوزه جنگلداری شهرستان نکا)

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چکیدهاثرات جاده‌های جنگلی بر وسعت و نوع صدمات آتش‌سوزی‌های رخ داده در بخش ۲ حوزه جنگلی شهرستان نکا (استان مازندران) بررسی شد. در هر لکه آتش‌سوزی، تعداد پایه، درصد و نوع صدمه(یقه‌ای، تنه‌ای و تاجی) و میانگین قطر برابر سینه گونه‌های درختی با آماربرداری صد در صد برداشت شد و موقعیت جغرافیایی جاده‌ها با استفاده از GPS تعیین شد. نتایج نشان داد که فاصله از جاده همبستگی معنی‌داری با مساحت لکه‌های آتش‌سوزی دارد، اما بین فاصله از مسیرهای چوبکشی، راه‌های تراکتور رو و شهر نکا با مساحت لکه‌های آتش‌سوزی همبستگی معنی‌داری مشاهده نشد. اثر فاصله جاده‌های جنگلی بر شدت آتش‌سوزی با استفاده از مدل رگرسیونی گام به‌گام تجزیه و تحلیل شد. به ازای هر یک متر افزایش فاصله از جاده، مساحت لکه‌های آتش‌سوزی به مقدار ۱/۵۴۵ متر مربع افزایش پیدا کرد. بنابراین این مطالعه نشان داد که مقدار آتش‌سوزی با کاهش فاصله از جاده تحت کنترل قرار می‌گیرد.

کلمات کلیدی:آتش‌سوزی، جاده‌های جنگلی، رگرسیون گام به گام، فاصله از جاده، نکا