Effects of roads on understory plant communities in a froadleaved forest in Hyrcanian zone

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ABSTRACT: This study was conducted to assess the effect of forest road as a corridor on local biodiversity. For this purpose, 10 segments in a 10 year-old road were selected in Neka-Zalemrood forest in Hyrcanian zone. At each of the segments, we established two 100-m transects perpendicular to the road centre line, within which we sampled three macroplots of an area 400 m^2. In each macroplot, nine quadrant microplots 2 × 2 m in size were set up for regenerated tree species and herbaceous plant survey. Chemical and physical parameters of soil were measured in laboratory. Results indicated that thirty-six herbaceous species and 13 regenerated tree species were recorded within the area of 100 m from the road verge. At the different distances from the road verge and both down and up-slope, the ground cover of *Carex sylvatica* and *Rubus caesius* L. as well as regeneration density of *Carpinus betulus* L. were higher compared to other species. Menhenick, Margalef, Shannon and Simpson indices were higher at the distance of 0–20 m than at the distances of 40–60 m and 80–100 m. Camargo and Smith-Wilson indices decreased when increasing distance to the road. These results are expected to provide critical information for decision makers and land managers for managing plant species and maintaining the integrity of biological communities.

Keywords: road effect; regenerated tree species; herbaceous species; soil parameters; Hyrcanian forest

Forest roads alter disturbance regimes in adjacent plant communities, both directly by creating gaps and by changing the plant composition (Sousa 1984; Parendes, Jones 2000; Mirzaei et al. 2008) and indirectly by altering environmental conditions such as light, soil moisture and bulk density (Ferris et al. 2000; Watkins et al. 2003; Hansen, Clevenger 2005). Zhou et al. (2010) showed that wide and narrow roads had different edge effects. For the wide roads, plant diversity and soil moisture tended to increase, whereas herbaceous biomass tended to decrease, from the road edge to the forest interior. Zeng et al. (2010) argued that the dispersal function of road corridor was not a monopoly for alien species, but also for native species. Forest managers should take into account the impacts of roads on biodiversity, since the expected intensification of silviculture in response to global changes is set to accentuate the effect of forest roads (Auerbach et al. 1997; Pauchard, Alaback 2006; Avon et al. 2010).

It was proved that soil disturbance due to the road construction significantly increased the mineral N content in the first months and/or years after occurrence. This causes the establishment of legumes and other herbaceous communities. Mycorrhizal fungi enhance plant species diversity by increasing the establishment and abundance of different species (Van der Heijden et al. 1998; O'Connor et al. 2002; Parsakhoo et al. 2009). The patterns of plant species diversity in herbaceous vegetation subjected to various human activities were studied in most of the landscape elements in a rural area of central Japan (Ullman et al. 1995; Kitazawa, Ohsawa 2002; Truscott et al. 2005). Accumulated number of species increased in a stepwise pattern along DCA axis 1, in which the dominant plant life-forms were replaced from annuals to perennials and perennials/tree-saplings depending on different management regimes. The unique species which were confined to a certain management regime were identified in each site. Among four types of management regimes, mowing sites had the most abundant unique, rare species specially adapted to regular cutting. It is suggested that maintaining such traditional mown sites is important to conserve the unique biodiversity of the studied area (Van Schagen et al. 1992; Kitazawa, Ohsawa 2002; Lozano et al. 2005; Wang et al. 2011).

Karim and Mallik (2008) found that the floristic zonation along roadsides is a function of roadside microtopography, substrate type and environmental gradients created by the road building process. Several native plants, such as *Empetrum nigrum*, *Juniperus communis*, *Vaccinium angustifolium*, *Trifolium repens*, and *Anaphalis margaritaceae* are naturally abundant in side slopes and possess autecological attributes such as low stature, widespread above- and below-ground parts, and drought tolerance. The presence of these desirable properties and their perennial habit make them excellent candidates for roadside revegetation in Karim and Mallik (2008) study area. In Puerto Rico, Olander et al. (1998) found that pools of exchangeable nutrients, except total nitrogen, were higher in recent road fills than in mature forest soils. Research indicated that even after 35 years, regenerating road fills had different soil nutrient dynamics and pool sizes in comparison with those in soils of mature, undisturbed forests (Olander et al. 1998).

Species richness is defined as the observed number of species in a mixed stand. In contrast, species diversity considers the number and frequency of the species present (Pretzsch 2009; Shabani et al. 2009). Species evenness is defined as the number of individuals in each species. Forest road has far-reaching effects on plant species diversity across varying scales, and the estimation of its effect distance and effect zone is a key issue to integrate the road effect and ecological processes in forest area (Li et al. 2010). In the present study, we tested the hypothesis that the road as a corridor can change local biodiversity, and it will be affected by a distance from the road verge and plant location up and down slope. The objective was to determine the effect of forest roads on diversity, richness and evenness of understory plant communities.

MATERIAL AND METHODS

Study area

The study area (Neka-Zalemrood forests) is located within the northern broadleaved forests of Iran (36°25' to 36°29'N latitude and 53°25' to 53°31'E longitude), south to southeast of the city of Neka and covers an area of 13,511 ha. 1,817 ha of the total area is field land and villages and 11,694 ha is forest. This zone is composed of marl, sandstone, siltstone, claystone and limestone bedrocks. Soil types of the study area are brown and washed brown forest soil with Pseudogley. Minimum altitude is about 350 m and maximum 1,430 m. The general aspect of the hillside is northern and its average slope is 25%. The average temperature is from 28.4°C in July to 0.4°C in February. Mean annual air temperature is 15.3°C. The region receives 1,110 mm of precipitation annually. Minimum and maximum rainfall is 64 to 201 mm, which occurs in August and February, respectively. The mean relative air humidity is 80%. The growing season lasts 240 days from April to November. The total length of forest roads in the study area is about 11.5 kilometres.

Data collection

Three factors, distance to road (0–20 m, 40–60 m and 80–100 m), soil parameters and location of the plant species (down-slope, up-slope and forest interior), were used to test the effects of forest roads on understory plant diversity. For this purpose, 10 segments in a 10 year-old road were selected in the study area. At each of the segments, we established two 100-m transects perpendicular to the road centre line, within which we sampled three mac-

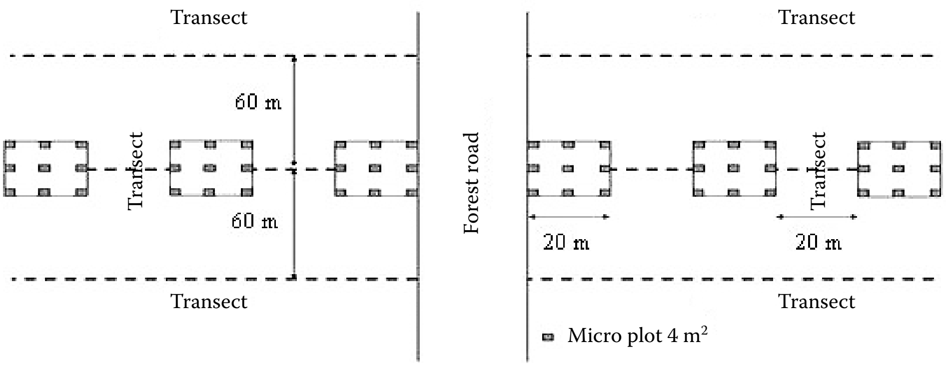

Fig. 1. Vegetation sampling protocol

roplots of an area 400 m^2. In each macroplot, nine quadrant microplots of 2 × 2 m in size were set up for regenerated tree species and herbaceous plants survey. At each plot we evaluated the percent cover of each understory species and other site characteristics, including soil parameters (Fig. 1).

Five samples of the soil (0–10 cm and 10–20 cm deep) were collected in each plot for physical and chemical analyses. Soil samples from the plot were collected in order to determine bulk density, moisture, pH, EC, $CaCO_3$, C, N, Mg and Ca. Each sample was oven-dried at 105°C for 24 h at least and then soil moisture and bulk density were calculated. pH was measured using an Orion Ionalyzer Model 901 pH meter in a 1:2.5 soil to water solution. EC (electrical conductivity) was determined using an Orion Ionalyzer Model 901 EC meter in a 1:2.5 soil to water solution. Soil organic carbon was determined using the Walkley-Black technique. The total nitrogen was measured using a semi Micro-Kjeldahl technique. Mg^{2+} and Ca^{2+} were determined with an atomic absorption spectrophotometer.

Statistical analysis

The SPSS package was used to perform all statistical analyses. Significant differences among treatment means were tested using analysis of variance (GLM procedure). Wherever treatment effects were significant, the Duncan's Multiple Range Test was carried out to compare the means. We used Principal Component Analysis (PCA) in PC-ORD software to find the main factors determining the reciprocal effects of soil and vegetation. Besides, our measure of plant species diversity and evenness was based on computations in ecological methodology software. Moreover, species richness was calculated in PAST software. The following equations were used for calculating biodiversity, richness and evenness indices:

$$S = 1 - \sum_{i=1}^{s} \left[\frac{n_i (n_i - 1)}{N (N - 1)} \right] \quad (1)$$

$$H' = -\sum_{i=1}^{s} \left[P_I Ln(P_I) \right] \quad (2)$$

$$M = \frac{s-1}{LnD} \quad (3)$$

$$R = \frac{s}{\sqrt{D}} \quad (4)$$

$$E' = 1 - \left(\sum_{i=1}^{S} \sum_{j=i+1}^{S} \left[\left| \frac{P_i - P_j}{S} \right| \right] \right) \quad (5)$$

$$E_{\text{var}} = 1 - \left(\frac{2}{\pi} \right) \left[\arctan \left\{ \frac{\sum_{i=1}^{S} \left(\log_e(n_i) - \sum_{j=1}^{S} \log_e(n_j) \Big/ S \right)^2}{S} \right\} \right] \quad (6)$$

where:

S – Simpson biodiversity index,
N – number of total species,
n – frequency of each specimen,
H' – Shannon biodiversity index,
P_I – each of specimen's frequency percentage ratios to total species in each community,
M – Margalef richness index,
S – number of species,
D – number of individuals,
R – Menhenick richness index,
E' – Camargo index of evenness,
P_i – proportion of species i in total sample,
P_j – proportion of species j in total sample,
S – number of species in total sample,
E_{var} – Smith and Wilson evenness index,
n_i – number of individuals in species i in sample,
n_j – number of individuals in species j in sample.

RESULTS

Biodiversity, richness and evenness of herbaceous species

In our study, thirty-six herbaceous species were recorded within the area of 100 m from the road verge. Plant cover at the distances of 0–20, 40–60 and 80–100 m from down-slope and up-slope of the road is shown in Table 1. At the both down-slope and up-slope of road verge, the ground cover of *Carex sylvatica* and *Rubus caesius* L. was higher compared to the other species. Ground cover of these two species decreased with distance and then they were very rare at a distance of 80–100 m (Table 1).

After the ANOVA, it was demonstrated that the position (down-slope and up-slope of the road) and distance to road (0–20, 40–60 and 80–100 m) had significant effects on Simpson, Menhenick, Camargo and Smith and Wilson indices ($P < 0.01$). The analysis of variance showed no differences for the Shannon-Wiener and Margalef indices at the down-slope and up-slope of the road ($P < 0.05$). The interaction effect of parameters on Menhenick and Simpson was significant ($P < 0.05$; Table 2).

The highest Menhenick and Simpson indices were detected at the distance of 0–20 m. Also, Shannon index decreased as a distance to the road increased. Margalef index was higher at the distance of 0–20 m than at the distances of 40–60 m and 80–100 m.

Table 1. Ground cover of herbaceous species across described distances from the road verge

Species	Up road distance (m)			Down road distance (m)		
	0–20	40–60	80–100	0–20	40–60	80–100
Asperula odorata L.	0	1	1	1	0	2
Atropa belladonna L.	0	1	1	0	0	1
Brachypodium sylvaticum (Huds.) P. Beauv.	0	1	1	0	1	1
Bryophytes sp.	11	2	2	4	1	3
Carex sylvatica L.	26	4	3	14	5	3
Convolvulus sepium L.	0	0	1	1	0	0
Cyclamen europea L.	0	1	0	0	1	0
Equisetum arvense L.	1	1	2	1	1	2
Erigeron canadensis L.	1	0	0	0	0	0
Euphorbia amygdaloides L.	1	3	2	1	1	1
Geum urbanum L.	1	0	1	3	1	1
Hedera helix L.	1	0	0	1	0	0
Hedera pastuchovii Woron. Ex Grossh.	5	2	3	1	1	2
Hypericum androsaemun L.	7	1	1	1	0	1
Hypericum perferatum L.	1	0	0	1	0	0
Melissa officinalis L.	0	1	1	1	2	1
Mentha pulgeium L.	4	1	0	1	0	0
Mercurialis perennis L.	0	0	0	1	0	0
Oplimenus undulatifolis Ard. P. Beauv.	10	17	6	12	11	12
Oxalis acetosella L.	0	0	0	1	0	0
Petasites hybridus L. P. Gaertn.	0	1	0	0	0	0
Phyllitis scolopendrium L. Newm.	0	1	1	0	1	1
Polypodium vulgar L.	0	0	1	1	1	1
Primula heterochroma Stapf.	0	1	0	1	1	0
Pteridium aquilinum L. Kuhn.	1	1	2	1	1	2
Pteris cretica L.	1	1	1	1	1	1
Rhamnus cathartica L.	1	0	1	2	1	1
Rubus caesius L.	33	2	5	39	12	1
Rumex sanguineus L.	0	0	0	1	0	0
Sambucus ebulus L.	0	1	0	1	0	0
Senecio vulgaris L.	2	0	0	1	0	0
Solanum dulcamara L.	0	0	0	0	1	0
Setaria verticillata L. P. Beauv.	0	0	3	1	1	3
Solanum dulcamara L.	0	0	0	0	1	0
Taraxacum officinalis	0	1	1	0	0	0
Voila odorata L.	2	3	4	2	2	4

Moreover, a significant relationship was determined between Camargo index and road distance. Camargo index decreased with increasing distance to the road. Smith and Wilson index was higher at the down-slope of the road than at the up-slope. The value of this index at the distance of 80–100 m was significantly lower than that at the other distances (Table 3).

Biodiversity, richness and evenness of the regeneration of tree species

Totally 13 regenerated tree species were identified within the area of 100 m far from the road verge. At different distances from the road verge and both down and up-slope, the regeneration of

Table 2. ANOVA for the road edge effect on herbaceous biodiversity, richness and evenness

Indices		Sources	df	MS	*F*
Biodiversity	Simpson	up and down-slope of the road	1	0.100	13.48**
		distances to road	2	0.220	29.50**
		up and down-slope of the road × distances to road	2	0.025	3.59*
	Shannon-Wiener	up and down-slope of the road	1	0.150	1.41ns
		distances to road	2	2.860	26.79**
		up and down-slope of the road × distances to road	2	0.245	2.32ns
Richness	Margalef	up and down-slope of the road	1	0.210	0.49ns
		distances to road	2	5.200	11.9**
		up and down-slope of the road × distances to road	2	0.065	0.15ns
	Menhenick	up and down-slope of the road	1	0.950	9.25**
		distances to road	2	2.500	24.32**
		up and down-slope of the road × distances to road	2	0.480	4.65*
Evenness	Smith and Wilson	up and down-slope of the road	1	0.220	45.77**
		distances to road	2	0.060	12.45**
		up and down-slope of the road × distances to road	2	0.005	0.37ns
	Camargo	up and down-slope of the road	1	0.140	27.15**
		distances to road	2	0.110	20.32**
		up and down-slope of the road × distances to road	2	0.015	2.93ns

df – degrees of freedom, MS – quadratic mean or root mean square, *,** indicate significance at the 5 and 1% probability level, respectively, ns – not significant

Table 3. Diversity index for herbaceous species across described distances from the road verge

Distance to road	Simpson	Shannon-Wiener	Menhenick	Margalef	Smith and Wilson	Camargo
0–20	0.87a	2.30a	1.81a	2.82a	0.32a	0.41a
40–60	0.71ab	1.70b	1.49b	2.28b	0.27a	0.34b
80–100	0.66b	1.52b	1.09c	1.82b	0.22b	0.27c

different letters indicate a significant difference at α = 0.05 by Duncan's test

Table 4. Ground cover of regenerated tree species across described distances from the road

Species	Up road distance (m)			Down road distance (m)		
	0–20	40–60	80–100	0–20	40–60	80–100
Acer cappadocium Gled.	0	1	1	0	0	2
Acer velutinum Boiss.	8	14	18	6	33	11
Alnus subcordata C. A. Mey.	1	0	0	1	1	0
Carpinus betulus L.	29	23	34	35	26	23
Diospyros lotus L.	1	4	3	1	3	6
Fagus orientalis Lipsky	5	11	9	2	5	10
Ficus carica L.	0	0	0	1	0	0
Parrotia persica C. A. Mey.	9	4	4	5	6	10
Prunus divaricata Ledeb.	0	0	0	0	0	0
Quercus castanifolia C. A. Mey.	0	1	1	0	0	1
Salix alba L.	0	0	0	0	0	0
Tilia begonifolia Stev.	0	0	0	0	0	0
Ulmus glabra Huds.	0	0	0	0	1	0

Carpinus betulus L. was significantly higher than that of the other species (Table 4).

It was demonstrated that the location of the regeneration of tree species (down- and up-slope of the road) and distance to the road had significant effects on Simpson, Shannon-Wiener, Menhenick and Margalef indices. The interaction effect of parameters on different indices was not significant, except for Shannon-Wiener index (Table 5). Species richness and diversity at the distance of 0–20 m was remarkably higher than at the other distances ($P < 0.05$), while no significant difference was found among distances for evenness indices ($P < 0.05$). Species richness and diversity decreased with increasing distance from the road verge (Table 6).

Characteristics of the soils

Position, distance to the road and soil depth interactions did not have a significant effect on soil parameters ($P > 0.05$). Analysis of variance showed no significant differences among distances for the bulk density (Table 7). Water content was high at the soil depth of 0–10 cm. Soil pH was highest at the distance of 0–20 m. The highest electrical conductivity (EC) was detected at the distance of 0–20 m. The soil EC was significantly higher at the depth of 0–10 cm compared to 10–20 cm. Nitrogen in soil was mainly influenced by distances to the road and plot position at the edge of road (up-slope and down-slope). Mg and Ca content of soil was negatively correlated with distances to the road (Table 8).

Multivariate analysis of ecological data

Fig. 2 shows the PCA graph of soil parameters and biodiversity indices with eigenvalues > 1. It shows that soil parameters and biodiversity indices loaded heavily on component 1. This component accounted for 79.97% of the total variance. Only

Table 5. ANOVA test for the road edge effect on the biodiversity of regenerated tree species

Indices		Sources	df	MS	*F*
Biodiversity	Simpson	up and down-slope of the road	1	0.470	26.74**
		distances to road	2	0.075	4.37*
		up and down-slope of the road × distances to road	2	0.035	1.99ns
	Shannon-Wiener	up and down-slope of the road	1	0.310	6.86**
		distances to road	2	0.510	11.26*
		up and down-slope of the road × distances to road	2	0.017	0.37**
Richness	Margalef	up and down-slope of the road	1	0.620	19.71**
		distances to road	2	0.110	3.72*
		up and down-slope of the road × distances to road	2	0.005	0.21ns
	Menhenick	up and down-slope of the road	1	1.790	71.17**
		distances to road	2	0.320	12.73**
		up and down-slope of the road × distances to road	2	0.020	0.85ns
Evenness	Smith and Wilson	up and down-slope of the road	1	0.090	2.26ns
		distances to road	2	0.003	0.07ns
		up and down-slope of the road × distances to road	2	0.030	0.80ns
	Camargo	up and down-slope of the road	1	0.050	2.55ns
		distances to road	2	0.005	0.26ns
		up and down-slope of the road × distances to road	2	0.010	0.55ns

df – degrees of freedom, MS – quadratic mean or root mean square, *,** indicate significance at the 5 and 1% probability level, respectively, ns – not significant

Table 6. Diversity index for regenerated tree species across described distances from the road

Distance to road	Simpson	Shannon-Wiener	Menhenick	Margalef
0–20	0.70a	1.31a	0.79a	0.80a
40–60	0.63ab	1.08ab	0.64b	0.72ab
80–100	0.60b	0.96ab	0.55b	0.70b

different letters indicate a significant difference at α = 0.05 by Duncan's test

Table 7. ANOVA tests of treatment effects on the physical and chemical properties of soil

Soil parameters	Sources	df	MS	*F*
Bulk density	up and down-slope of the road	1	0.011	0.58^{ns}
	distances to road	2	0.009	0.50^{ns}
	soil depth	1	0.006	0.54^{ns}
	up and down-slope of the road × distances to road	2	0.003	0.20^{ns}
Moisture	up and down-slope of the road	1	0.620	0.06^{ns}
	distances to road	2	3.035	0.32^{ns}
	soil depth	1	142.22	15.29^{**}
	up and down-slope of the road × distances to road	2	0.560	0.06^{ns}
pH	up and down-slope of the road	1	0.049	0.21^{ns}
	distances to road	2	3.185	13.68^{**}
	soil depth	1	0.130	0.59^{ns}
	up and down-slope of the road × distances to road	2	0.360	1.55^{ns}
EC	up and down-slope of the road	1	17016	2.22^{ns}
	distances to road	2	50837	6.65^{**}
	soil depth	1	49155	6.43^{*}
	up and down-slope of the road × distances to road	2	751.81	0.09^{ns}
Lime ($CaCO_3$)	up and down-slope of the road	1	24.150	2.86^{ns}
	distances to road	2	21.160	2.51^{ns}
	soil depth	1	1.210	0.14^{ns}
	up and down-slope of the road × distances to road	2	1.710	0.20^{ns}
C	up and down-slope of the road	1	0.070	0.14^{ns}
	distances to road	2	0.075	0.13^{ns}
	soil depth	1	28.22	50.31^{**}
	up and down-slope of the road × distances to road	2	0.060	0.11^{ns}
N	up and down-slope of the road	1	690.95	82.57^{**}
	distances to road	2	21.59	2.58^{ns}
	soil depth	1	10.27	1.22^{ns}
	up and down-slope of the road × distances to road	2	27.26	3.25^{*}
Mg	up and down-slope of the road	1	8.280	0.44^{ns}
	distances to road	2	141.87	7.65^{**}
	soil depth	1	11.520	0.62^{ns}
	up and down-slope of the road × distances to road	2	5.230	0.28^{ns}
Ca	up and down-slope of the road	1	2.400	0.12^{ns}
	distances to road	2	85.590	4.16^{**}
	soil depth	1	194.40	10.23^{**}
	up and down-slope of the road × distances to road	2	7.290	0.38^{ns}

df – degrees of freedom, MS – mean square, *,** indicate significance at the 5 and 1% probability level, ns – not significant

Table 8. Changes in chemical properties of soil across described distances from the road verge

Distance (m)	pH	EC	N	Mg	Ca
0–20	7.0^{a}	280^{a}	10.0^{a}	10.9^{a}	16.5^{a}
40–60	6.5^{b}	200^{b}	6.0^{b}	5.9^{b}	14.1^{ab}
80–100	6.5^{b}	210^{b}	6.6^{b}	7.4^{b}	12.5^{b}

different letters indicate a significant difference at the level α = 0.05 among different distances from the road verge as determined by Duncan's multiple range test

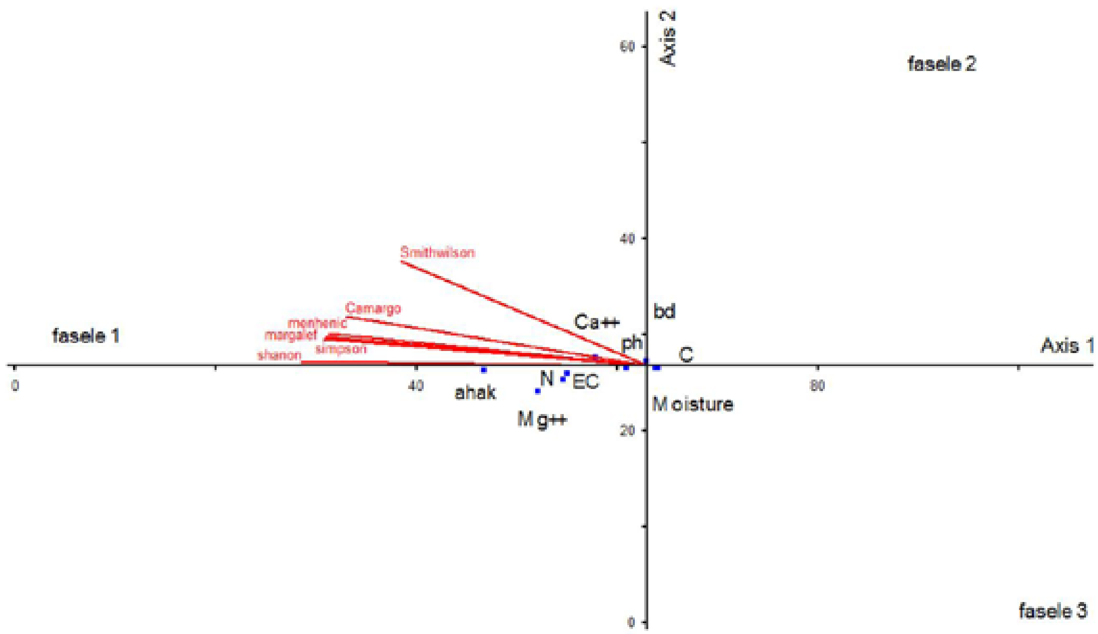

Fig. 2. PCA analysis of biodiversity indices of herbaceous species for roadside soils

$CaCO_3$ loading on component I had a significant effect on diversity and richness indices.

PCA was performed for soil properties across sampled plots to determine the main soil factors that influence the biodiversity of regenerated tree species. Based on the significant threshold for variables, only pH, EC, $CaCO_3$, N, Mg and Ca loading on component I had a significant effect on diversity and richness indices (Fig. 3).

DISCUSSION

After the road construction, the processes of regeneration and succession play an important role in increasing forest changes (Lozano et al. 2005). The roadside may be a refuge for more species, and the pattern of vegetation distribution is affected by road age and distance from the road verge (Zeng et al. 2010). In this study we found that biodiversity of herbaceous and tree regeneration decreased with increasing distance from the road (Table 3). A similar finding to this result was reported by Zeng et al. (2010). They indicated that species richness and diversity indices of the road verge group (0 m from the road) were higher than those of the other distance groups. The main reasons for the presence of different species along roads are often changes in physical and chemical properties of soil (Ullman et al. 1995), light conditions (Delgado et al. 2007), as well as microclimate (Pauchard, Alaback 2006).

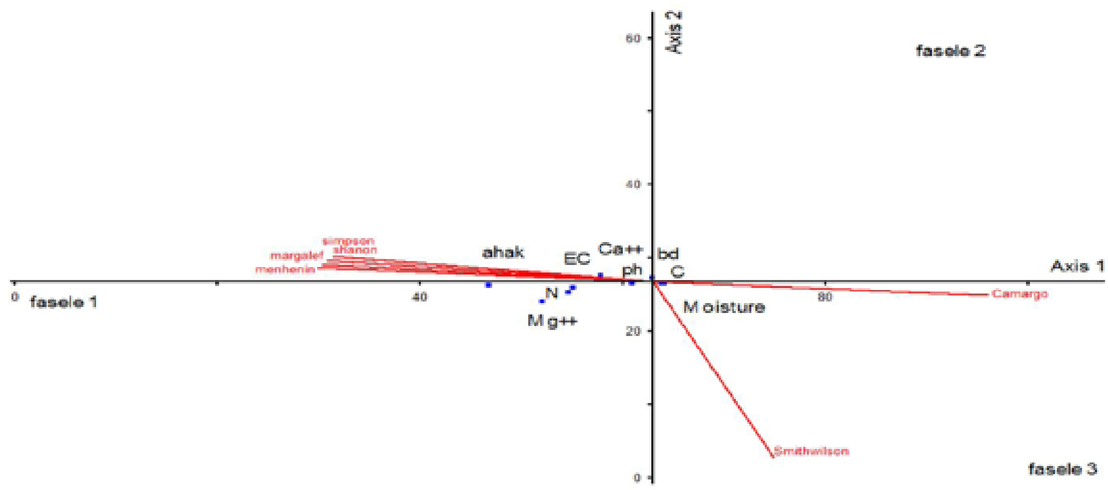

Fig. 3. PCA analysis of biodiversity indices of regenerated tree species for roadside soils

The biodiversity of plant species in the first 20 m was higher than in the second and third 20 m (Fig. 1). The reason may be that the values of plant species biodiversity, richness and evenness indices have the highest correlation with the increasing gap area (Shabani et al. 2009). A decrease in biodiversity associated with canopy closure is especially pronounced in stands of adjacent roads (Wallace, Good 1995; Ferris et al. 2000). The abundance of *Rubus caesius* L. and *Carex sylvatica* L. increased significantly at the distances of 0–20 m from the road compared to other distances (Table 1). Similar findings were reported for *Rubus hyrcanus L.* in Lattalar forests of Iran (Parsakhoo et al. 2009). Moreover, our results agree with results from previous studies, where transportation corridors had a high abundance of non-native plants (Hansen, Clevenger 2005; Truscott et al. 2005; Pauchard, Alaback 2006). Lee et al. (2012) reported that the abundance of nitrogen (N) tolerant species and grasses at roadsides was associated with N enrichment from vehicle exhausts at two of the sites. In contrast to plant species richness, the abundance of forb and moss species declined at roadside locations. Avon et al. (2010) proved that the plant composition strongly differed between the road verge and forest interior habitats. We found that the diversity of plant species at the down slope of the road was higher than upslope of the road (Table 2). Li et al. (2010) reported that the plant species diversity of shrub stratum and herb stratum within the effect zone was greater than that in adjacent habitats, with the Shannon-Weiner index increased by 21% and 60%, respectively. The response of shrub stratum to the road effect was more stable than that of the herb stratum, but no significant change was observed in the tree stratum. *Chamaenerion angustifolium* was the indicative species of road-effect zone communities.

Lime and moisture content of soil did not show a significant difference at 0–10 and 10–20 cm depths and different distances from the road. Bulk density did not change with increasing distances from the road. Nitrogen in the first 20 m and at the down slope of the road was higher than in the second 20 m (Table 8). Nitrogen concentrations in soil were recorded at higher than normal levels in roadside areas, and were related to the nitrogen oxides emitted in vehicle exhausts (Van Schagen et al. 1992). Organic carbon at a depth of 0–10 cm was higher than at 10–20 cm. Soil pH increased with increasing distance from the road. This result is opposite to Auerbach et al. (1997) findings. They reported that pH commonly increases in roadside soils.

The PCA test showed that changes in biodiversity occur in the first 0–20 m from the road. Lime, magnesium content, nitrogen, EC, calcium content and pH had the greatest effect on biodiversity (Fig. 3). Mirzaei et al. (2008) assessed the relationship between plant biodiversity and soil characteristics. Results showed that, in the southern aspect, ground vegetation diversity had a negative relationship with clay and sand while it showed a positive correlation with silt. Nowadays instead of shelterwood system, a tree selection system is advised for management of mountainous Hyrcanian forests of Iran, but the forest road density to perform this system is low. Constructing more roads causes damage and alters the regime in plant communities (Pormajidian et al. 2009). So, it is recommended to conduct further research covering other sites in Iran, in the country having diverse eco-agro-climatic zones.

CONCLUSIONS

Different responses of plant species to a distance from the road verge can help us to correctly evaluate the ecological effect of the road corridor on local biodiversity. Based on our findings, thirty-six herbaceous species and 13 regenerated tree species were observed within the area of 100 m from the road verge. At the different distances from the road verge and both down and up-slope, the ground cover of *Carex sylvatica* and *Rubus caesius* L. as well as regeneration density of *Carpinus betulus* L. were higher compared to other species. Richness and diversity indices were higher at the distance of 0–20 m than at the distances of 40–60 m and 80–100 m. Camargo and Smith-Wilson indices decreased when increasing distance to the road. These results are expected to provide critical information for decision makers and land managers for managing plant species and maintaining the integrity of biological communities. Moreover, it is suggested that the timing of 10 years after the road construction is optimal for controlling and/or eradicating the noxious invasive species.

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