Original scientific paper

Study of Forest Road Effect on Tree Community and Stand Structure in Three Italian and Iranian Temperate Forests

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Abstract

Roads are built in forests for two main reasons, but always in function of management of forest ecosystems, and these reasons are to provide access to the forest area for transportation mobility and wood extraction. This creates a relatively even network in the forest. This topic has received much attention in recent years due to its function and effect on forested rural landscapes and the related environment. Forest road network is important for various types of functional use, such as the interface between forested lands and roads. The aim of this study is to assess the effects of road existence and use on the occurrence of tree dieback and on the composition of the tree community in three forest areas (two in Italy and one in Iran). The effort to determine the dynamics of the effects caused by road use was done by examining the changes in stand structure and abundance of species. As demonstrated by the results, the edges (20 m) of the forest road network are a fine mosaic composed of different trees (qualitative and quantitative), coupled with the moderate presence of dead trees. In the three areas, from the road edges to the interior forest, a similar taxonomic composition of forest community was found. The first main difference was related to the abundance of less shadow tolerant species along the road. The second main difference was related to the tree biodiversity indices that are higher along the road. The main similarities are in the structure of live and dead trees.

Keywords: forest road, logging, tree species diversity, SIV, tree dieback intensity index

1. Introduction

The basic infrastructure of forestry operations are forest roads. Roads are built in forests for two main reasons: to provide access to the forest area for transportation mobility and to provide extraction roads. This creates a relatively even network in the forest (Heinimann 1998, Ryan et al. 2004, Cerdà 2007, Grigolato et al. 2013). It should also be considered that the road network is used for transportation purposes and is, therefore, a facility for inhabitants. Forest roads are the most costly structures in forestry. However, the construction activities involved have a heavy environmental impact on the adjacent ecosystems. These activities include earth movement that can disturb the watershed (Demir et al. 2007).

Much attention has been given to forest road networks in recent years, by observing the functional uses and effects that they have on forested rural landscapes and the related environment (Grigolato et al. 2013, Gumus et al. 2008). The primary purpose of forest road networks is to make logging operations and forest transportation more efficient. Therefore, the forest road network is important for various types of functional use, such as the interface between forest lands and roads.

Forest road network planning requires the commercial assessment of production costs, which imply silvicultural treatments. A forest road network, which is well designed and properly used, allows to use low-impact extraction and transport systems (Magagnotti et al.

2012, Picchio et al. 2011 and 2012, Marchi et al. 2014 and 2016).

Nevertheless, the undesirable effects caused by roads in forest areas affect both biotic and abiotic environmental components. There are several papers written about the negative effects caused by forest roads (Coffin 2007). For example, extensive consideration has been given to the analysis of the forest road network as a source of accelerated soil erosion and the production of sediment (Bilby et al. 1989, Pellegrini et al. 2013) and also by GIS models used in Skaugset et al. (2011). These alter the surrounding habitat in a number of ways that eventually influence the quality and suitability of the roadside areas for trees and animals. The creation of a forest edge causes a dramatic increase in the amount of solar radiation reaching the forest understory. Solar radiation, soil moisture content and soil temperature in gaps created by forest roads are significantly greater than in adjacent closed canopy plots (Osma et al. 2010, Li et al. 2010). Generally, roadsides are more disturbed, drier and warmer (Forman and Alexander 1998). Soil moisture levels are reduced within 20 meters of a forest edge, due to an increase in evapotranspiration rates as trees are exposed to higher temperatures and solar radiation (Kapos 1989). Variations in light, temperature and moisture levels have a significant impact on plant biodiversity, tree regeneration and quality of edge trees. Most of the trees that are situated along the newly created edges do not have the ability to adapt to the increased stress caused by higher temperatures and stronger winds (Laurance et al. 2007). Fast growing species, such as *Alnus*, *Rubus*, and others, are found around forest roads (Parendes and Jones 2000). Extensive tree mortality often occurs at the forest edges, with trees suffering physical damage caused by strong winds (Murcia 1995). Many other trees remain as standing dead trees, killed by excessive desiccation resulting from drier conditions and increased light exposure (Olupot 2009, Tavankar et al. 2017). Forest roads increase tree mortality via microclimatic changes (Kapos 1989, Williams-Linera 1990), mechanical damages (Chen et al. 1992) and an increased infestation by pathogens (Dickie and Reich 2005).

A recent study of Natura 2000 (European Environment Agency 2015) about European forest areas, as described in Sitzia et al. (2016), underlined that more than 60% of the assessments of forest and woodland habitats and species listed in the Habitats Directive revealed a bad or inadequate conservation status and that roads were among the most important threats to these habitats and species. However, forest roads are important for an economically viable forest management (European Commission 2015) and for the implementation of frequent and careful conservation management activities.

Moreover, the forest road network provides access necessary for water protection, wildlife habitat improvement, fire control and many recreational activities (Akay and Sessions 2004, Grigolato et al. 2013).

The edge effect of forest roads on the tree community is an important issue regarding road ecology. Roads can affect species in at least three ways: by reducing the habitat available, by affecting movement patterns, and by extending the edge conditions into the forest. The main objective of this study is to verify if, in productive and managed forests, the viability could represent not only an environmental risk, but also a possibility of increasing the biodiversity at landscape level. In fact, a fine mosaic composed of different trees (qualitative and quantitative), coupled with the presence of scattered old or dead trees provided favorable conditions also for a variety of invertebrates. Considering both environmental aspects and engineering applications for forest production and protection, the research is well within the scope of ecological engineering (Mitsch and Jørgensen 2003).

In this study, the effects were assessed of forest roads on tree community composition, structure and snag presence in three temperate forest areas, two in Italy and one in Iran. However, this work does not provide data extrapolated for any typology of forest, but aims to identify a methodology and some indexes that can be used for the development of subsequent studies on larger geographical scales.

This study specifically addresses the following questions:

⇒ Does the forest road affect the tree species diversity?

⇒ Are there any significant differences between tree species diversity along the roads and inside the forest?

⇒ Are there any significant differences between forest structure along the roads and inside the forest, in terms of live and death trees (snag)?

2. Material and methods

2.1 Study areas

The first study area is the Iranian Caspian forests located in northern Iran and on the south coast of the Caspian Sea. The Caspian forests (also called the Hyrcanian forests) cover about 1.9 million ha and are rich in biological diversity, with endemic and endangered

Fig. 1 Localization of the Iranian studied area, highlighted with a circle

species and rich in many ecological niches (Heshmati 2007, Tavankar et al. 2014). The research was carried out in district n° 2 of the Nav forest area (latitude 37°41′30″ to 37°45′21″ N, longitude 48°33′44″ to 48°51′33″ E) in watershed n° 7 in the Guilan province, north of Iran, Fig. 1. The average rainfall ranged from 920 to 1,100 mm per year, with the heaviest precipitation in the summer and fall. The average daily temperature ranges from a few degrees below 0°C in December, January, and February, and up to +25 °C during the summer. The original vegetation of this area is an uneven aged mixed forest dominated by *Fagus orientalis* Lipsky and *Carpinus betulus* L., with the companion species *Alnus subcordata* C.A. May, *Acer platanoides* L., *Acer cappadocicum* Gled., *Ulmus glabra* Huds., and *Tilia begonifolia* Steven (Tavankar et al. 2014). The Caspian forests are managed as a mixed uneven aged high forest with single and group selective cutting regime. The soil of the study site is classified as brown forest (*Alfisols*) and well-drained. The texture of the soil ranges from clay loam to loamy. All roads in this forest are 5.5 m wide and are unpaved. They were constructed in the 1970s to implement shelterwood systems. The total length of the forest roads in the study area (district n°. 2) is 8.09 km and the density of the forest road is 22.9 m ha^{-1}. The last selective logging of the area was performed in 2008 with cable-skidder logging, and the roads have not been used since then. There was no grazing in this area, because it was protected by barbed wire.

The second study area is the Amiata Mountain forests, an isolated relief of volcanic origin located in Tuscany, central Italy. This forest area is covered by about 2751 ha of beech (*Fagus sylvatica* L.) forest. Due to the frequency of pure stands, their good productivity, the presence of different silvicultural typologies (high forest, coppice stands converted into high forest and aged coppices), it represents an interesting laboratory for the analysis of different management choices. The research was carried out in »Macchia faggeta« forest propriety (Abbadia San Salvatore, latitude 42°89′55″ to 42°89′64″ N, longitude 11°63′73″ to 11°64′12″ E), designated with the letter »A« in Fig. 2. The average rainfall ranged from 900 to 1600 mm per year, with the heaviest precipitation in the autumn and winter. The dry period is limited to 18 days only. The mean annual temperature is 10°C, the hottest month (August) with 18.5°C, the coldest month (January) with 1.8°C. The main vegetation of this area is an even aged mixed forest dominated by *Fagus sylvatica* L. and *Abies alba* Mill., with the companion species *Acer pseudoplatanus* L., *Acer opalus* Mill., *Carpinus betulus* L., *Ulmus glabra* Huds., *Quercus cerris* L., *Ilex aquifolium* L., *Sorbus torminalis* L., *Fraxinus excelsior* L., *Tilia plathyphyllos* Scop. and *Prunus avium* L. The Amiata forests are managed mainly (about 80%) as a mixed even aged high forest with shelterwood cutting regime. The parent material is a trachyte lava with a high silicate content and poor in basis; the slope is generally gentle but a few outcrops are present; there is no erosion and no landslides. Brown soils of good physical structure are prevalent. The texture of the soil ranges from clay loam to loamy. The main forest roads in this area are about 4 m wide and are paved with rocks. They were constructed in the 1900s. The total length of the forest roads in the study area is about 11.25 km and the density of the forest road is 18.1 m ha^{-1}. The last logging of the area was partly performed in 2010 and the rest in 2013 with cable-skidder logging and forwarding, and the roads have not been used since then. There was no grazing in this area.

Fig. 2 Localization of the Italian studied areas, highlighted with two circles, A: Macchia Faggeta, B: Pramosio

The third study area is in the Carnia Alps, the Pramosio forests located in Friuli Venezia Giulia, north Italy. This forest area is covered by about 495 ha of high forests, mainly composed of *Abies alba* Mill., *Picea abies* (L.) H.Karst. and *Fagus sylvatica* L. Due to high frequency of high forest pure stands and their good productivity, it represents an interesting laboratory for the analysis of management choices. The research was carried out in »Pramosio« forest regional propriety (Paluzza, latitude 46°56′84″ to 46°58′09″ N, longitude 13°01′80″ to 13°02′65″ E), shown with the letter »B« in Fig. 2. The average rainfall ranged from 1400 to 1900 mm per year, with the heaviest precipitation in the autumn and winter. The mean annual temperature is 8°C, the hottest month (August) with 17.0°C, the coldest month (January) with –1.5°C. The main vegetation of this area is an even aged mixed forest dominated by *Abies alba* Mill., *Picea abies* (L.) H.Karst. and *Fagus sylvatica* L., with the companion species *Acer pseudoplatanus* L., *Acer opalus* Mill., *Ulmus glabra* Huds., *Sorbus aria* L., *Fraxinus excelsior* L., *Tilia plathyphyllos* Scop. and *Larix decidua* Mill. The Pramosio forests are managed mainly (about 90%) as a mixed even aged high forest with shelterwood cutting regime. The Late Ordovician (Caradoc) to Early Carboniferous successions of the Carnic Alps, along the Italian–Austrian border in the easternmost part of the Southern Alps, consist predominantly of carbonate rocks representing shallow to open sea environments. Carbonate sedimentation persisted through into the earliest Viséan, resuming during the Late Carboniferous. Carbonate build-ups, characteristic of the Middle Devonian, persisted into the Frasnian, but ceased during early Famennian transgressive tectono-eustatic events when sediments representing open marine environments, the late Frasnian–earliest Viséan Pramosio Limestone, accumulated. This unit consists of 0.5–3 cm layers of light grey, beige to pink biomicritic limestones (wackestones and packstones) interbedded with thin (mm–cm) calcisiltitic levels. The Pramosio Limestone was previously referred to in various ways, such as the »Calcari climenie«, clymenid limestone, clymenid and goniatitid-bearing pelagic limestone. They are considered to equate with the combined Pal and Kronhof Limestones of Austrian colleagues and the »Calcari a climenie« auctorum outcropping in southwestern Sardinia. The texture of the soil ranges from clay loam to loamy. The main forest roads in this area are about 4 m wide and are paved with rocks. They were constructed in the 1900s. The total length of the forest roads in the study area is about

4 km and the density of the forest road is 22.5 m ha^{-1}. The logging in the area was performed yearly, with cable-skidder logging, cable yarder and forwarding. There was no grazing in this area.

2.2 Data collection and analysis

For each studied area, four transects, each of approximately 1 km in length, were established parallel to the road. Two transects were established adjacent to the road edge (cut and fill slopes) as road stands, and two transects were established at a 50 m distance from the road edges as internal stands, as reported in others studies (Olander et al. 1998, Watkins et al. 2003, Prasad 2009, Li et al. 2010, Avon et al. 2010, Bergès et al. 2013). On each transect, 10 square sample plots (20×20 m) were established randomly.

In each sample plot, all live and dead trees (snag) were counted, species were identified, diameter at breast height (DBH) and height were measured.

The tree dieback intensity index (DTI) was computed as the ratio of dead trees and live trees in each plot.

Species importance value (SIV) for each species was calculated as reported by other authors (Ganesh et al. 1996, Krebs 1999, Pourbabaei and Abedi 2013, Pourbabaei et al. 2013, Tavankar 2015):

$$SIV = Relative\ density\ (RD_e) + Relative\ frequency\ (RF) + Relative\ dominance\ (RDo) \quad (1)$$

Where:

RDe number of individuals of a species x100/total number of individuals of all species

RF number of plots containing a species x100/ sum of frequencies of all species.

The Basal area was considered for dominancy and relative dominance (*RDo*) calculated by:

RDo basal area of a species ×100/total basal area of all species

The species diversity index was computed using the Shannon–Wiener information function (Hill 1973, Ozcelik et al. 2008, Tarvirdizadeh et al. 2014) as:

$$H' = -\sum (n_i / n) \times Ln(n_i / n) \quad (2)$$

Where:

n_i denotes the SIV of a species

n the sum of total SIV of all species.

After checking for normality (Kolmogorov-Smirnov test) and homogeneity of variance (Levene's test), the average values of stand characteristics (tree density, basal area, stand volume) were compared in two plot positions (road and internal) using paired samples *t* test. The average biodiversity index of the two positions of the plots was also compared using paired samples *t* test.

Regression analysis was applied to test the relation between tree density and DBH and to test the relationship between tree height and DBH. Chi-square nonparametric test was used to compare the dead tree index (DTI) in two positions and tree species. Number of trees (live and dead) in the plots (road and interior) were analysed by ANOVA test. Post-hoc test was conducted with Tukey HSD test method.

SPSS 19.0 software was used for statistical analysis; the results of the analysis were also presented using descriptive statistics.

3. Results

3.1 Tree species composition

The average number of tree species along the road and internal plots is shown in Fig. 3. The graph illustrates the highest variation of the number of trees in the two positions, along the road and in the internal stand. For the three areas studied, the genus *Fagus* showed a higher density, even if along the road its density decreased.

Caspian forest

Among the seven tree species that were observed in the plots, the *Fagus orientalis* showed higher density (105 trees/ha) in the internal stands, while the *Alnus subcordata* showed higher density (112.5 trees/ha) in the stand along the road. The density of *Fagus orientalis*, *Carpinus betulus*, *Tilia begonifolia* and *Ulmus glabra* was higher in the internal stand than in the road edge stand, while the density of *Acer velutinum*, *Acer cappadocicum* and *Alnus subcordata* was higher in the road edge stand than in the internal stands.

Amiata forest

Among the eleven tree species that were observed in the plots, the *Fagus sylvatica* showed higher density (120 trees/ha) in the internal stands and in the stand along the road (80 trees/ha). The density of *Fagus sylvatica*, *Abies alba* and *Ulmus glabra* in the internal stand was higher than the road edge stand, while the density of *Acer pseudoplatanus*, *Acer opalus*, *Carpinus betulus*, *Quercus cerris*, *Sorbus torminalis*, *Fraxinus excelsior*, *Tilia plathyphyllos* and *Prunus avium* was higher in the road edge stand than in the internal stands.

Pramosio forest

Among the eleven tree species that were observed in the plots, the *Picea abies* showed higher density

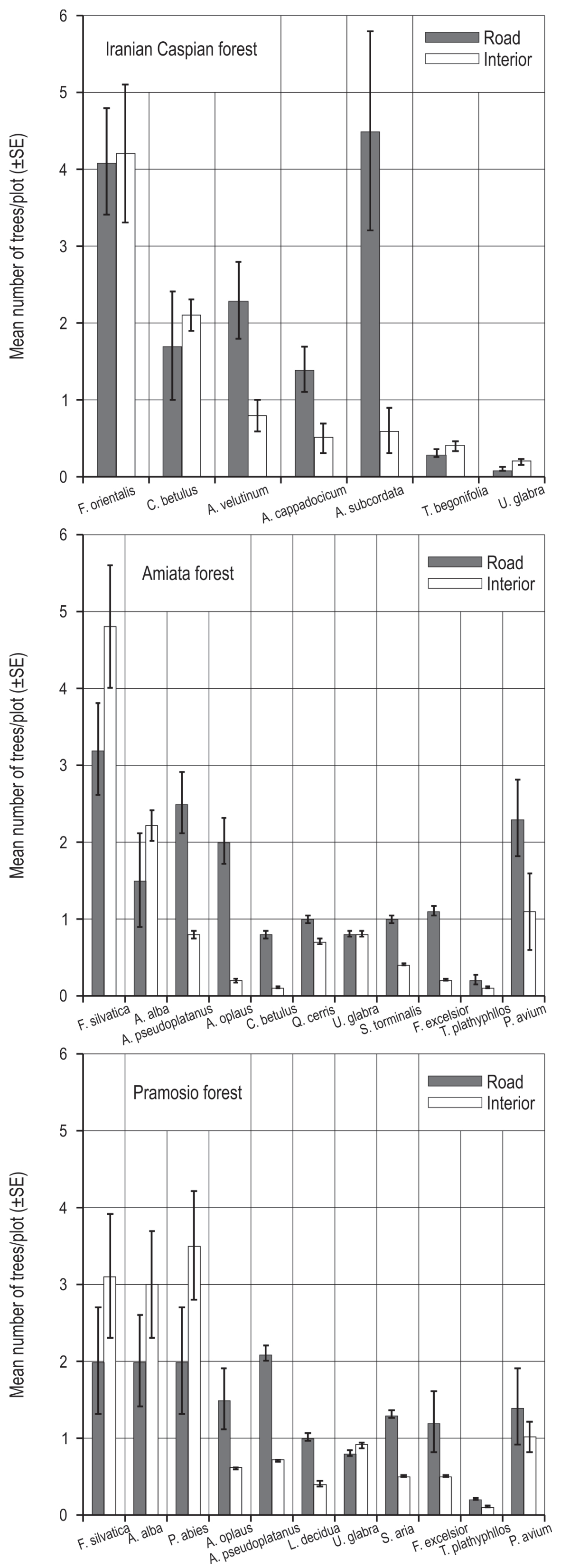

Fig. 3 Number of tree species in road and interior plots for the three areas

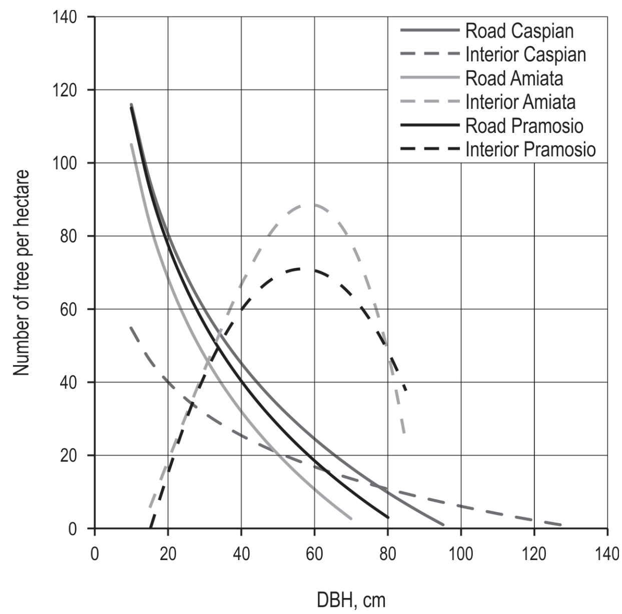

Fig. 4 Tree frequency values of DBH classes in road and internal plots for the three areas

(87.5 trees/ha) in the internal stands, while the *Acer pseudoplatanus* showed higher density (52.5 trees/ha) in the stand along the road. The density of *Fagus sylvatica*, *Abies alba*, *Picea abies* and *Ulmus glabra* in the internal stand was higher than the road edge stand, while the density of *Acer pseudoplatanus*, *Acer opalus*, *Larix decidua*, *Sorbus aria*, *Fraxinus excelsior*, *Tilia plathyphyllos* and *Prunus avium* was higher in the road edge stand than in the internal stands.

Tree frequency values of DBH classes in the road and internal plots are shown in Fig. 4. The tree number decreased with increasing DBH in the road plots of the three areas and in internal plots of the Caspian forest, while in the internal plots of Amiata and Pramosio forests, the number of trees in terms of DBH showed a Gaussian distribution, typical of even-aged forests.

The regression analyses were applied to live trees to test the relationship between tree frequency and DBH in the road and internal stands; the results shown in Table 1 are statistically significant (p<0.01).

The average volume of trees in road and internal plots and ANOVA results are shown in Table 2. The statistical test showed that the average volume of trees in the road stands was significantly (p<0.05) higher than in internal stands for the Caspian forest, while it was significantly (p<0.05) lower than in internal stands for the Amiata and Pramosio forests.

The average number of trees (live and dead) in the two plot positions (road and internal) is based on 1

Table 1 Results of non linear regression analyses applied to test the relationship between live tree frequency (y) and BDH (x) in the road and internal stands

Tree position	Study area	Regression	R^2 Adj.	p-value
Interior	Caspian forest	$y=-0.848\ln(x)+4.1468$	0.971	<0.01
	Amiata forest	$y=-0.00003x^3+0.0023x^2+0.0451x-0.8554$	0.969	<0.01
	Pramosio forest	$y=-0.0017x^2+0.188x-2.4791$	0.926	<0.01
Road	Caspian forest	$y=-2.046\ln(x)+9.3564$	0.893	<0.01
	Amiata forest	$y=-2.106\ln(x)+9.0564$	0.817	<0.05
	Pramosio forest	$y=-2.156\ln(x)+9.564$	0.789	<0.05

Table 2 Mean volume of trees in road and interior plots and ANOVA and Tukey test results

Position	Study area	Volume $m^3\ ha^{-1} \pm$ SE	*p-value*
Road	Caspian forest	361.75±13.25 a	<0.05
	Amiata forest	311.8±10.12 b	
	Pramosio forest	395.9±19.21 c	
Interior	Caspian forest	222.75±52.25 d	
	Amiata forest	345.2±9.78 e	
	Pramosio forest	405.1±14.51 c	

hectare, and ANOVA results are shown in Table 3. The results of ANOVA indicated that the density of live trees in the stands along the road was significantly higher than in the internal stands in all the three areas.

The results of ANOVA also indicated that the density of dead trees in the road stands was significantly higher than in the internal stands.

The tree death index obtained (DTI as ratio of dead trees to live trees) for each species in the plots along the road and in the internal plots is shown in Fig. 5. The species were the same as the living tree species reported in Fig. 3.

Table 3 Mean number of trees (live and dead) near the road and in the forest interior for each area; ANOVA and Tukey test (different letters show significant statistic differences) were done for the total number of trees to compare the studied areas, while the two positions (road and interior) were compared separately for tree typology

Position	Study area	Total number of trees n ha^{-1}±SE	*p-value*	Tree typology	Number of trees n ha^{-1}±SE	*p-value*
Road	Caspian forest	532.5±20.5 a	<0.01	Live trees	352.5±32.5 a	<0.01
				Dead trees	180.0±17.5 b	
	Amiata forest	495.4±23.8 b		Live trees	410.0±28.1 a	
				Dead trees	70.0±27.5 b	
	Pramosio forest	452.5±18.1 c		Live trees	387.5±15.3 a	
				Dead trees	65.0±22.4 b	
Interior	Caspian forest	240.0±12.2 d		Live trees	182.5±20.0 a	<0.01
				Dead trees	57.5±7.5 b	
	Amiata forest	345.7±18.1 e		Live trees	285.2±12.2 a	
				Dead trees	60.5±25.4 b	
	Pramosio forest	402.5±15.8 f		Live trees	357.5±12.3 a	
				Dead trees	45.0±10.1 b	

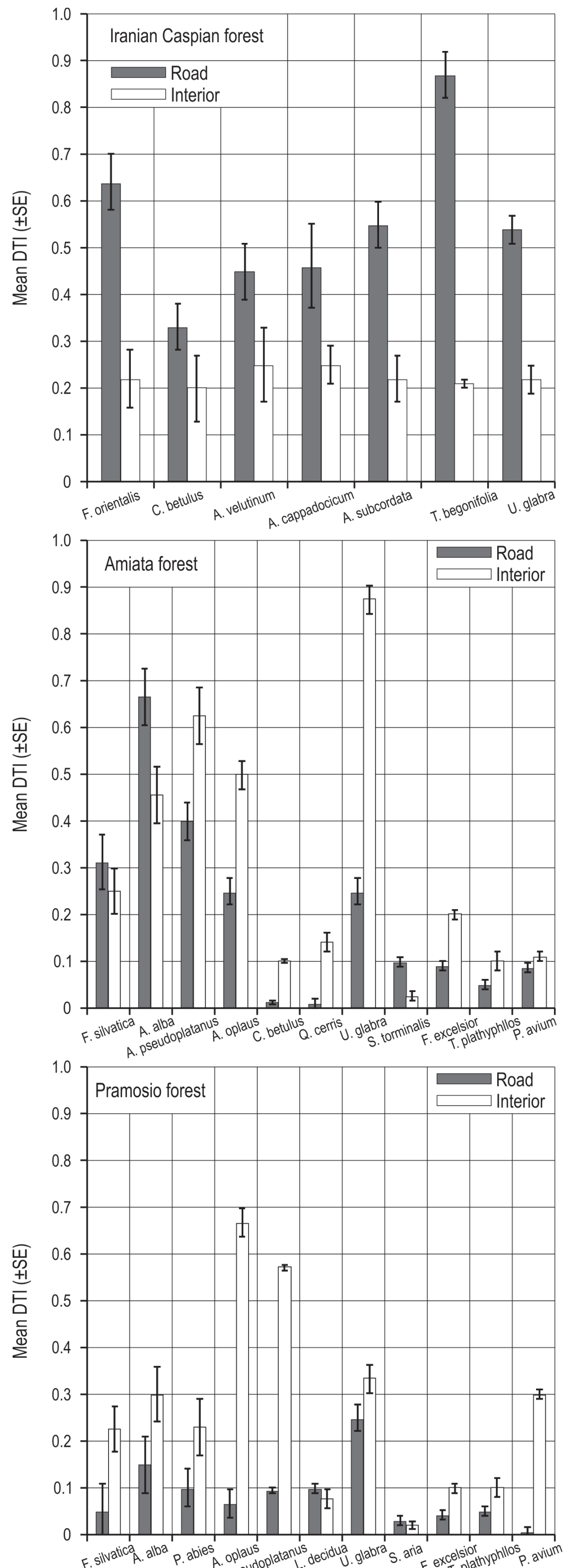

Fig. 5 Tree dieback intensity index of tree species in road and interior plots for the three areas

Caspian forest

The DTI in the plots along the road was 0.51, and it was significantly higher (X^2=5.94, p<0.05) than the value of the tree death index of the internal plots (0.32). The index of tree death of all tree species in the »road plots« was higher than in the internal plots. The maximum value of the index of tree death (0.82) was obtained in *Tillia begonifolia* and the minimum (0.22) was obtained in *Carpinus betulus*. In the »road« plots, the DTI in *Fagus orientalis* was 0.62, while in the internal plots, it was 0.23 (X^2=9.69, p<0.01). Except *Carpinus betulus*, the index of tree death was significantly higher in the road plots than in the internal plots.

Amiata forest

The DTI in the plots along the road was 0.17, and it was not significantly higher (X^2=2.83, p>0.05) than the value of the tree death index of the internal plots (0.21). The DTI in *Fagus sylvatica, Abies alba* and *Sorbus torminalis* was higher in the »road plots« than in the internal plots, while for the other eight species, the DTI in the internal plots was higher than in the road plot. The maximum value of the index of tree death (0.88) was obtained in *Ulmus glabra* and the minimum (0.01) was obtained in *Carpinus betulus*. in the »road« plots, the DTI in *Fagus sylvatica* was 0.31, while in the internal plots it was 0.25 (X^2=7.13, p>0.05).

Pramosio forest

The DTI in the plots along the road was 0.17, and it was not significantly higher (X^2=2.47, p>0.05) than the value of the tree death index of the internal plots (0.13). The DTI in *Acer opalus, Acer pseudoplatanus* and *Prunus avium* was higher in the »internal plots« than in the road plots, while for the other eight species the DTI in the internal plots was similar to that in the road plots.

The maximum value of the index of tree death (0.70) was obtained in *Acer opalus* and the minimum (0.01) was obtained in *Prunus avium, Fraxinus excelsior* and *Sorbus aria*. In the »road« plots, the DTI in *Fagus sylvatica* was 0.10, while in the internal plots it was 0.20 (X^2=8.95, p<0.05).

The variation of tree death index in DBH classes considering the road and internal plots is shown in Fig. 5. DTI values decrease with increasing of DBH in the road and internal stands. The values of tree death in road plots were higher than in internal plots in all DBH classes. For the two areas (Pramosio and Amiata) with even-aged management, the DTI values were higher for the DBH class <50 cm and they were similar for interior and road plots. For the Caspian forest with uneven-aged management, the DTI values were high-

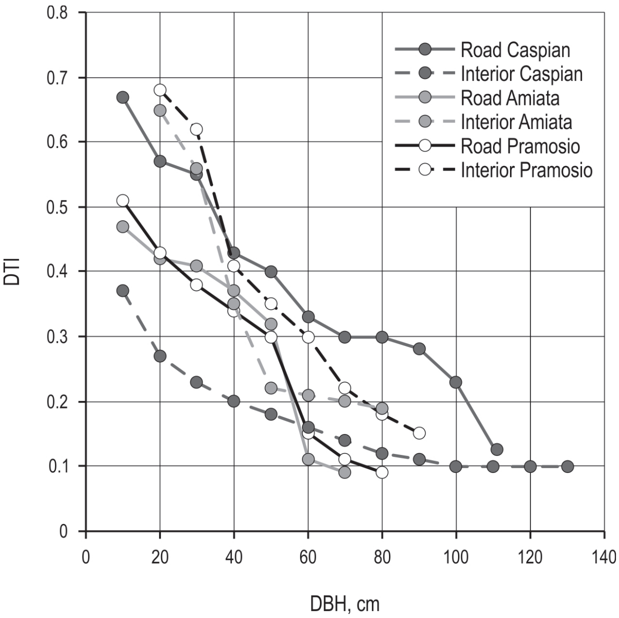

Fig. 6 Variation of DTI (adimensional index) in DBH classes considering road and internal plots for the three areas

er for the DBH class <60 cm in road plots, while the DTI values were under the value of 0.4 for all the DBH classes in the interior plots.

Species Importance Value (SIV) of the tree species in the road and internal stands is shown in Fig. 7 for the three areas, where the SIV of the secondary species is slightly higher in the road plots.

Caspian forest

The SIV of *Fagus orientalis* was the highest in both the road and internal plots. The SIV of *Fagus orientalis*, *Carpinus betulus* and *Ulmus glabra* was higher in the internal plots than in the road plots. However, the SIV of *Acer velutinum, Acer cappadocicum* and *Alnus subcordata* was higher in the road plots than in the internal plots. The SIV of *Tilia begonifolia* was almost equal along the road and in internal plots. The mean value of tree species diversity, shown in Fig. 8 and Table 4 (Shannon-Wiener index), in the road and internal plots was 1.42±0.18 and 1.01±0.29, respectively. The evenness value, shown in Table 4, in the road and internal plots was 0.81±0.02 and 0.64±0.05, respectively.

Amiata forest

The SIV of *Fagus sylvatica* was the highest in the interior plots, while the SIV of *Fagus sylvatica* and *Prunus avium* was the highest in the road plots. The SIV of *Acer pseudoplatanus*, *Acer opalus*, *Carpinus betulus*, *Quercus cerris*, *Ulmus glabra*, *Sorbus torminalis*, *Fraxinus excelsior*, *Tilia plathiphyllus* and *Prunus avium* was

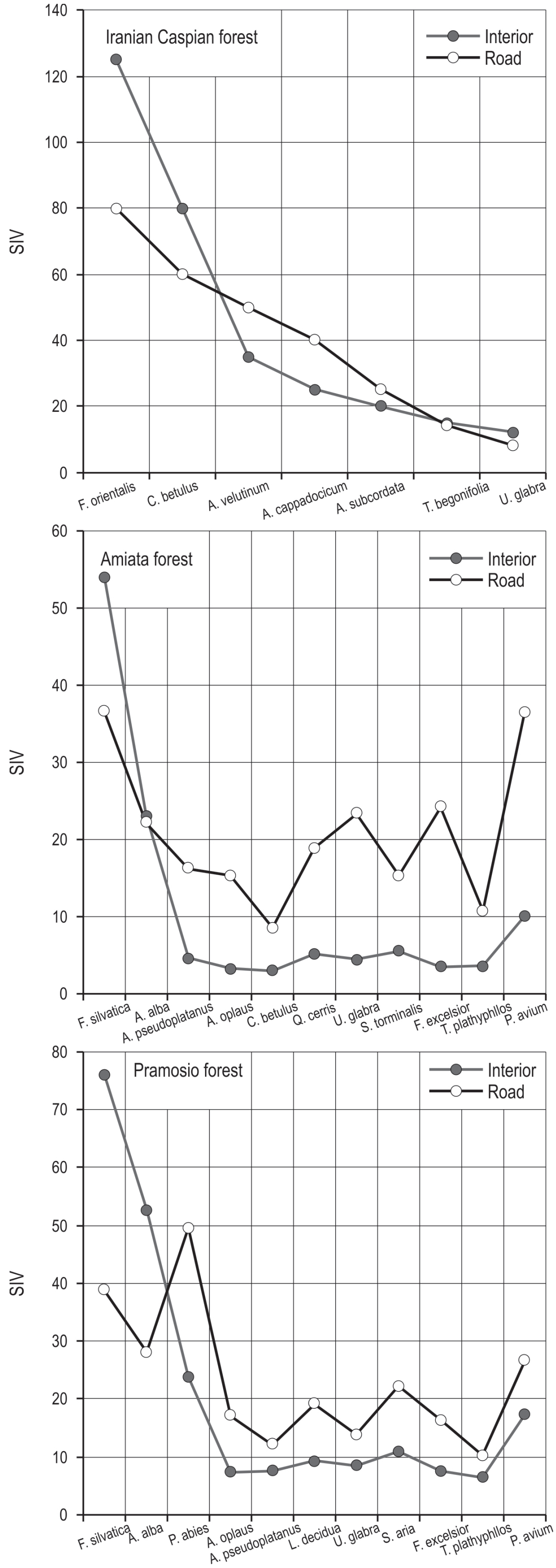

Fig. 7 SIV values along the road and in interior plots for the three areas

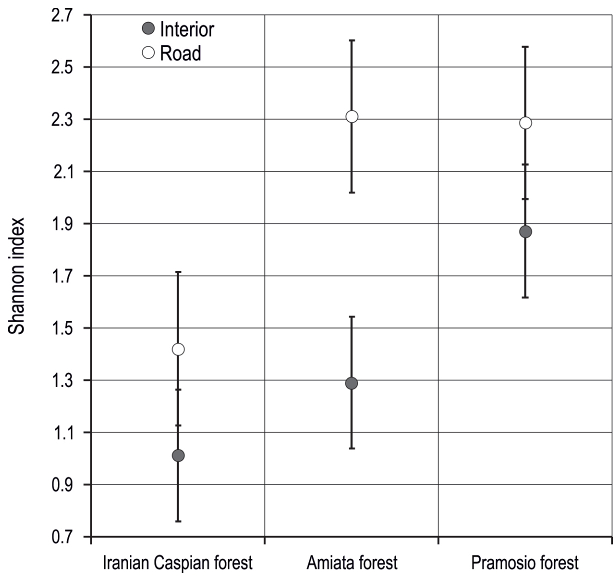

Fig. 8 Shannon-Wiener index values along the road and in interior plots for the three areas (in the graph, the indicators represent the mean values and the bars the standard deviations)

higher in the road plots than in the interior plots. The SIV of *Abies alba* was almost equal along the road and in internal plots. The mean value of tree species diversity, shown in Fig. 8 and Table 4 (Shannon-Wiener index), in the road and internal plots was 2.31±0.21 and 1.29±0.11, respectively. The evenness value, shown in Table 4, in the road and internal plots was 0.96±0.08 and 0.54±0.01, respectively.

Pramosio forest

The SIV of *Fagus sylvatica* was the highest in the interior plots, while the SIV of *Picea abies* was the highest in the road plots. The SIV of *Picea abies*, *Acer pseudoplatanus*, *Acer opalus*, *Larix decidua*, *Ulmus glabra*, *Sorbus aria*, *Fraxinus excelsior*, *Tilia plathiphyllus* and *Prunus avium* was higher in the road plots than in interior plots. The SIV of *Fagus sylvatica* and *Abies alba* was lower in the road plots than in interior plots. The mean value of tree species diversity, shown in Fig. 8 and Table 4 (Shannon-Wiener index), in the road and internal plots was 2.29±0.27 and 1.87±0.25, respectively. The evenness value, shown in Table 4, in the road and internal plots was 0.95±0.11 and 0.78±0.07, respectively.

4. Discussion

4.1 Structure

The results indicated a similar taxonomic composition of forest community between the plots along the road and the internal ones. These results accord with the results obtained by Tehrani et al. (2015) in the Patom district (Iran). The species observed were the same near the road and in the internal plots of the forest but the frequencies of the tree species were different. The road effect on the abundance of the species was evident. It is interesting to note that exotic species were not found. Watkins et al. (2003) examined the roadside edge effect on plant distribution and noticed a lower canopy cover and more light and, as a result, a different species composition from that of the internal area. Delgado et al. (2007) have detected short and abrupt changes from the road edge to the internal area of forests in temperature, light and canopy traits. The clearing made for the road in the study areas made it possible for the pioneer tree species (*Alnus subcordata*, *Acer velutinum, Acer cappadocicum, Acer pseudoplatanus, Acer opalus, Larix decidua, Sorbus aria* and *Prunus avium*) to reach a higher number than that found in the internal forest. The road produced a greater abundance of these less tolerant shadow tree species due to decreased competition, providing more resources for some species, which were less abundant in the internal zone. For the Caspian forest *Alnus subcordata* and for the Amiata (Apennines) and Pramosio (Alps) forests, *Acer pseudoplatanus, A. opalus* and *Prunus avium* are the most abundant species in the stand near the road. This was probably due to their capability of fast growing and growing in mineral soils.

Caspian forest

The structure of the two plot positions was also different. The analysis of the tree density distribution in DBH classes (Fig. 4) showed a similar uneven aged structure, a legacy of the previous period of the road construction. The stand along the road showed larger tree diameters than those in the internal area. However, the internal area exhibited a higher complexity due to the number of trees with a diameter larger than 80 cm. The tree heights were greater in the internal area for trees over 25 cm DBH and the average volume of the trees was significantly lower in the internal plots.

Amiata forest

The structure of the two plot positions was also different. The analysis of the tree density distribution in DBH classes (Fig. 4) showed an uneven aged structure only for the road plots, a legacy of the previous period of the road construction or the effect of a major light exposure, while it showed an even aged structure only for the interior plots. The stand along the road showed lower tree diameters than those in the interior area. However, the internal area exhibited a higher composition of big trees, a diameter larger than 70–80 cm. The tree heights were greater in the internal area for trees over 25 cm DBH and the average volume of the trees was significantly higher in the internal plots.

Pramosio forest

The structure of the two plot positions was also different. The analysis of the tree density distribution in DBH classes (Fig. 4) showed an uneven aged structure only for the road plots, a legacy of the previous period of the road construction or the effect of a major light exposure, while it showed an even aged structure only for the interior plots. The stand along the road showed lower tree diameters than those in the interior area. However, the internal area exhibited a higher composition of big trees, a diameter larger than 70–80 cm. The tree heights were greater in the internal area for trees over 25 cm DBH and the average volume of the trees was significantly higher in the internal plots.

The snags are an important component in providing wildlife habitat and can be assumed as an attribute of forest biodiversity and naturality, even in managed forests (Tavankar et al. 2014). Snags species in plots along the road and in internal plots are the same as those observed in living trees, but the dead trees were significantly higher in plots near the road than in internal stands. The results indicated that the tree death was three times greater in the stands near forest roads (<20 m) than in internal stands, in Caspian forest, while this increase ranged from 16% to 44% in Amiata and Pramosio forests, respectively. The greater tree mortality in association with forest roads and clearings compared to internal areas has also been reported in a variety of forest ecosystems (Temperate forests, Chen et al. 1992, Boreal forests, Esseen 1994, Tropical rainforests, Ferreira and Laurance 1997, Tropical dry forests, Prasad 2009). In Puerto Rico, roads in tropical forests affected the composition of adjacent vegetation over a distance of 10 m (Olander et al. 1998).

Watkins et al. (2003) studied the effects of forest roads on understory plants in a managed hardwood landscape in the Chequamegon National Forest, Wisconsin (U.S.A.). They reported that roads appeared to be associated with a disturbance corridor that affected site variables up to 15 m into the hardwood stands.

The dead tree index (DTI) for species in the internal plots were similar, indicating a homogeneous pressure on different species. The disturbance effect on the area near the road was denoted both by more abundance of dead trees in the plots along the road and by the variation of the dead tree index of the species.

Caspian forest

The higher dead tree index per plot was found along the road for *Tilia begonifolia*. A high DTI was exhibited in the »rare« species, such as *U. glabra*, in *Alnus subcordata* and in *Fagus orientalis*. Only *Carpinus betulus* showed a low DTI, with hardly any significant statistical difference in comparison with internal plots. The difference in dead tree index and in snag presence could be assigned to the effect of the road on community along the roads that have been influenced by microclimatic characteristics due to the linear clearing in the forest. The snag distribution by diameter classes showed that on average the young trees (DBH<30 cm) were more sensitive to the construction of forest roads than the older trees. The negative effects of forest roads on trees can be a very important issue in forests managed for biodiversity conservation and tourism.

Amiata forest

A higher dead tree index per plot was found in the interior plots for *Ulmus glabra*. A high DTI was exhibited also for *Abies alba* along the road. A high DTI in the interior plots was exhibited in the heliophilous species, such as *Acer pseudoplatanus* and *A. opalus*. The difference in dead tree index and in snag presence could be assigned to the effect of the road on community along the roads that have been influenced by microclimatic characteristics due to the linear clearing in the forest, but also by logging activities, mainly thinnings in the interior plots. The snag distribution by diameter classes showed that, on average, small trees (DBH<30 cm) were more frequent along the road, while big trees (DBH>50 cm) were more frequent in the interior plots.

Pramosio forest

A higher dead tree index per plot was found in the interior plots for *Acer opalus*. A high DTI was also exhibited for *Acer pseudoplatanus* and *Ulmus glabra* in the interior plots. For the *U. Glabra,* a medium-high DTI was also exhibited along the road. The difference in dead tree index and in snag presence could be assigned to the effect of road on community along the roads that have been influenced by microclimatic characteristics due to the linear clearing in the forest, but also by logging activities, mainly thinnings in the interior plots. The snag distribution by diameter classes showed that, on average, small trees (DBH<30 cm) were more frequent along the road, while big trees (DBH>50 cm) were more frequent in the interior plots.

4.2 Species diversity

Between the two plot positions, there was no difference in tree species richness, as indicated by other authors (Tehrani et al. 2015, Watkins et al. 2003). However, the tree community of the plots along the road showed not only different densities of tree species, but also different Species Importance Value. The rare species showed similar SIV along and in the internal plots. The differences found in the abundance of species indicate that there was no disturbance. The species importance value (SIV) of pioneer tree species was higher in the plots along the road than in the internal stands. Watkins et al. (2003) observed that a road side edge has a different species composition due to the changed microclimate conditions. Najafi et al. (2012) reported that the density of tree regeneration changed significantly over a 7.5 m distance. The researchers also concluded that the construction of forest roads may cause the presence of light-demanding species, such as *Acer* sp. (Maple), which were found to be present closer to the road edges, while the density of shade tolerant species, such as *Fagus spp.* (Beech), increased with the distance from the road.

Bergès et. al. (2013) sampled 30 pairs of 2000 m^2 plots, one on the road and the other 30 m inside the forest, on two road surfacing materials (limestone gravel and bare soil) and three stand ages (young, middle-aged and mature) in Scots and Corsican pine stands in a large managed forest in northern France. They reported that the species richness of all plant groups was always higher on roads compared to forest stands, and that the forest plot communities were nearly completely nested within the roadside plot communities.

Avon et al. (2010) studied the effect of forest road distance on plant understory diversity at 20 sites in young and adult oak stands in a French lowland forest with a long history of management and road construction. They reported that the main road effect extended less than 5 m into the forest stand.

Li et al. (2010) reported that the effect distance reached up to 20–34 m, regardless of the road grade in Great Hingan Mountains in China.

Shannon and evenness indices are two models to measure species diversity. They account for the degree of homogeneity in species abundance and can be used to measure the human effect on ecological systems. The tree species diversity, tested by Shannon-Wiener and evenness indices, showed different situations, confirming that there were statistically significant differences in all the three areas (Table 4 and Fig. 8) between road and interior plots. The highest diversity was found in road plots in the Amiata forest, while the lowest diversity was found in interior plots in the Caspian and Amiata forests. On average, the highest diversities found in the road plots, evenness from 0.81 to 0.96, showed very similar values to those of more complex forest ecosystems. The forest roads did not affect negatively the species diversity. A similar result was found by Tehrani et al. (2015).

5. Conclusion

In this study, the effects of forest roads on forest tree species composition, structure and snag presence were assessed in three forest areas, two in Italy (Apennines and Alps) and one in Iran. The main objective of this study was to verify if, in productive and managed forests, the forest road network could represent not only an environmental risk, but also a possibility of increasing the biodiversity at landscape level. As demonstrated by the results, the edges of the forest road network are a fine mosaic composed of different trees (qualitative and quantitative), coupled with the moderate presence of dead trees.

The answers to the specific questions posed in this study are detailed below:

⇒ the forest road affects the tree species diversity and there are significant differences between tree species diversity along the roads and inside the forest

⇒ there are significant differences between forest structure along the roads and inside the forest, mainly in terms of live trees and in part in terms of death trees

⇒ in the three areas, from the road edges to the interior forest, a similar taxonomic composition of forest community was found. The first main difference was related to the abundance of less shadow tolerant species along the road. The second main difference was related to the biodiversity indices, which are higher along the road, probably as a result of the »edge effect« (Brockerhoff et al. 2008). The main similarities in structure of live and dead trees are the result of the previous period of road construction

⇒ this methodology and these indexes could be used to develop further studies on larger geographical scales and to consider all the ecosystem aspects linked to the forest road network for a valid forest road planning.

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