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Impact of road network on the structure of a multifunctional forest landscape unit in southern Turkey

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Abstract: *Forest roads have many kinds of direct and indirect effects such as physical, ecological, and socio-economic effects in landscape scale. In this study the relationship between forest road network and the structure of a multifunctionally planned forest landscape, in the south of Turkey was examined. The aim of the study was to determine whether or not the correlation between road network and landscape structure across a gradient of road density, categorical road/no road approach and landscape pattern data from the managed forest landscapes existed. It was concerned with three type polygons that were forest functioning patches, compartments, and stand patches and were associated with higher road density or existing of road network. To quantify the case, it was analyzed whether the spatial structure of forest patches adjacent to roads differs from the spatial structure of forest patches away from roads. GIS was used to integrate quantitative indices of landscape structure. There was little negatively significant relationship between road density and patch area/size, patch perimeter, and shape index of patton index (PI) and no correlation with patch number and Fractal Dimension (FD). The forest road network modified spatial pattern of patch shape through PI values. The road network increased the number of patch and decreased mean patch size. The existence of road network was more effective than topography index appearing of PI and FD in the roaded areas. It was indicated to potential reverse impacts of road network on spatial structure of forest compartments in terms of shape index (FD). Highest proportions of harvestable forest areas fall into roaded areas. The results define that road networks are effective on the spatial structure of forest landscape. The forest road network of study area has all probable ecological impacts of forest roads mentioned in context.*

Key words: *Forest roads, Landscape structure, Road effects, Shape indices, Road density, Multifunctional forest*
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Introduction

Forest roads are the most important infrastructure foundation of the forest landscape to fulfill forest management practices and to supply all functions of forest resources. Undoubtedly, forest roads play a key role in forested areas and rural development. They facilitate movements of human population over the forest land, and connect natural resources with societies and economies. Forest roads have many kinds of direct and indirect effects such as physical and ecological, landscape scale, and socio-economics effects. Effects of roads in forested ecosystems in general have been well summarized in literature (Forman and Alexander, 1998; Spellerberg, 1998; Lugo and Gucinski, 2000; Gucinski *et al*., 2001; Noss, 2002; Saunders *et al*., 2002). In addition, roads generate many collateral problems for the conservation of ecosystems (Trombulak and Frissell, 2000; Forman *et al*., 2003) and landscape integrity (Jaarsma and Willems, 2002).

Depending on the traversed ecosystem, road impacts on microclimate, vegetation and fauna can vary widely. For example, forest roads create linear gaps that remove forest area, divide the ecosystem and create structural edges where abiotic and biotic conditions change more abruptly than in open bushland (Forman and Alexander, 1998; Trombulak and Frissell, 2000). Roads may also exert more subtle influences on habitat, for example by facilitating the spread of exotic vegetation (Gelbard and Belnap, 2003).

Roads facilitate the spread, frequency and intensity of disturbances on the landscape, with important consequences for organisms living there (Bennett, 1991; Miller *et al*., 1996). When the slope stability, road surfaces, and drainage patterns change, roads may increase soil erosion, sedimentation, and landslides (Norse *et al*., 1986, Misir *et al*., 2007). Roads may influence fire regimes by way of increased fire ignition (Franklin and Forman, 1987) as a result of human activities that occur in the transportation corridor, reduced fire size as a result of physical barriers to fire movement (Covington and Moore, 1992) and increased accessibility for fire suppression activities. Roads fragment the structure of entire forest structure, creating high contrast edges (Franklin, 1993) accompanied by changes in microclimate (Ranney *et al*., 1981; Chen *et al*., 1993) and reductions in the amount of forest interior (Schonewald-Cox and Buechner, 1992). Besides, roads allow access for resources of forest, *i.e.* timber and other products. In forested areas, the forest matrix dominates the landscape, but roads remove or disturb large areas through indirect effects that accumulate and interact at higher scales (Forman, 1998; Heilman *et al*., 2002; Riitters and Wickman, 2003).

Within the conservation literature, forest roads have also perceived negative influences on visual quality (Sheppard *et al*., 2004) and wildlife (McLellan and Shackleton, 1988), and other ecological effects (Riitters and Wickham, 2003). Forest roads in managed forests have a greater impact on landscape structure and have been highly associated with forest conservation issues such as forest fragmentation (Reed *et al*., 1996; Miller *et al*., 1996; McGarigal *et al*., 2001; Heilman *et al*., 2002; Wade *et al*., 2003). Forest roads can exacerbate fragmentation effects by increasing forest patch density, decreasing forest patch size, and increasing amounts of forest edge (Reed *et al*., 1996; Tinker *et al*., 1998). This assumption is the outcome of that forest roads divide forests into distinct forest patches which are smaller and farther apart by creating uncrossable barriers for some small species to move through forests (D'Eon, 2007). Dividing a continual forest into smaller fragments or polygons, small mammals, reptiles, and other organisms are located in small isolated fragments or patches with small populations (D'Eon and Glenn, 2005).

As research and analysis techniques have become more sophisticated, particularly with the advent of geographic information systems (GIS), the study of effects of roads on ecology has evolved into a unique discipline of road ecology (Forman *et al*., 2003). Road effects are far more pervasive than originally believed and include such disparate consequences as population and habitat fragmentation, accelerated rates of soil erosion, and invasion of exotic plants along roadways (Rowland *et al*., 2005).

It is possible to explain that roads as a source of human caused disturbance, or as disturbance corridors (Forman and Godron, 1986). In addition, roaded areas separate from a natural condition (Noss, 2002). Therefore, it was suggested that road density may be used as a landscape-level index for deviation from more natural conditions or disturbance on the landscape and associated effects of forest management activity (Williams and Marcot, 1991; D'Eon *et al*., 2004). Similarly, non-roaded areas or those with low road density might serve as environmental baselines against which the impact of human activities can be measured (Miller *et al*., 1996). In general, as road density increases, mean patch size decreases and total edge increases. In some cases, patch shape complexity either increases (McGarigal *et al*., 2001) or becomes more simplified (Saunders *et al*., 2002) with the exact effect of roads depending on their spatial pattern (Reed *et al*., 1996; Hawbaker and Radeloff, 2004).

The forest landscape can be dissected in forest stand/ vegetation types, forest compartments, and, functional patches within multifunctional management concept, in Turkish forestry. These patches represent a component of future mature forest patterns by imposing a new pattern on the landscape and are therefore of paramount importance to the issue of long-term landscape spatial patterns in managed forests (Nelson and Finn, 1991). Therefore, if road networks manage spatial configuration of the patches, i.e harvest patches, future forest patterns and fragmentation effects within considered areas would be directly related to road densities or road network. This is a critical consideration in the context of landscape pattern and forest fragmentation effects (D'Eon, 2007).

In this study, the relationship between forest road network and the structure of a multifunctionally planned forest landscape, in the South of Turkey was examined. The aim of the study was to determine the correlation between roads and landscape structure across a gradient of road density. Using a gradient of road densities, categorical road/no road approach and landscape pattern data from the managed forest landscapes, it was proved useful in identifying road impacts on landscape components (Krummel *et al*., 1987). It was tested the hypothesis that road density or road network influenced functional patch size and stand patch size, compartment size, shapes, and other spatial indices mostly based on road networks. It was concerned with the question of whether smaller and more complex or irregular shaped polygons (belonging to functional or stand patches and compartments) were associated with higher road density or existing of road network. To quantify the case, it was analyzed whether the spatial structure of forest patches adjacent to roads differs from the spatial structure of forest patches away from roads. If there is a difference, for example, it is understood that shapes of forest patches are complex and irregular near roads and differed from the others. These characteristics of forest stand, compartment, and patch size and shape may be of particular importance to species associated with forest interior or forest edge such as road effect zone. In this concept, GIS was used to integrate quantitative indices of landscape structure to examine the effects of forest road network on forest landscape structure in the study area.

Materials and Methods

Study area: Melli Forest Planning Unit (MFPU) referred to as study area is located in Southwestern Mediterranean Region of Turkey. The study area occures in Bucak Forest District, where one of the part of Isparta Regional Forest Directorate is located. The forest management plan of MFPU was prepared according to multiple goal forest management planning manner called as multifunctional forest management plan. There was an approved forest road network plan. In addition to this, forest harvesting operations had been continued in MFPU. Therefore, MFPU was selected as study area (Fig. 1a,b).

The MFPU locates in between 4138627-4123067 m in North latitudes, and 309111-289892 m in East longitudes, within UTM Zone-36 N. The study area occupies overall 18964.9 ha and amount of forest areas is 15734.2 ha. Detailed study area description was given in Table 1 including area distribution data by functional land use classification and permissible cuts (Anonymous, 2007a). The total area is managed by three functions and five sub-functions including separately management goals of forests that are economical, ecological and social in the sustainable forest management concept. However, terrain within mountainous forest area is generally steep and broken with slope gradients of exceeding 32%. Elevations extend from 130 to 1720 (m). The vegetation in the study area comprises of brutian pine (*Pinus brutia Ten.*) as main tree species (130-1200 m). In the upper regions (>1000 m), cedar (*Cedrus libani* A. Rich.), fir (*Abies cilicica* Carr.), and juniper (*Juniperus*

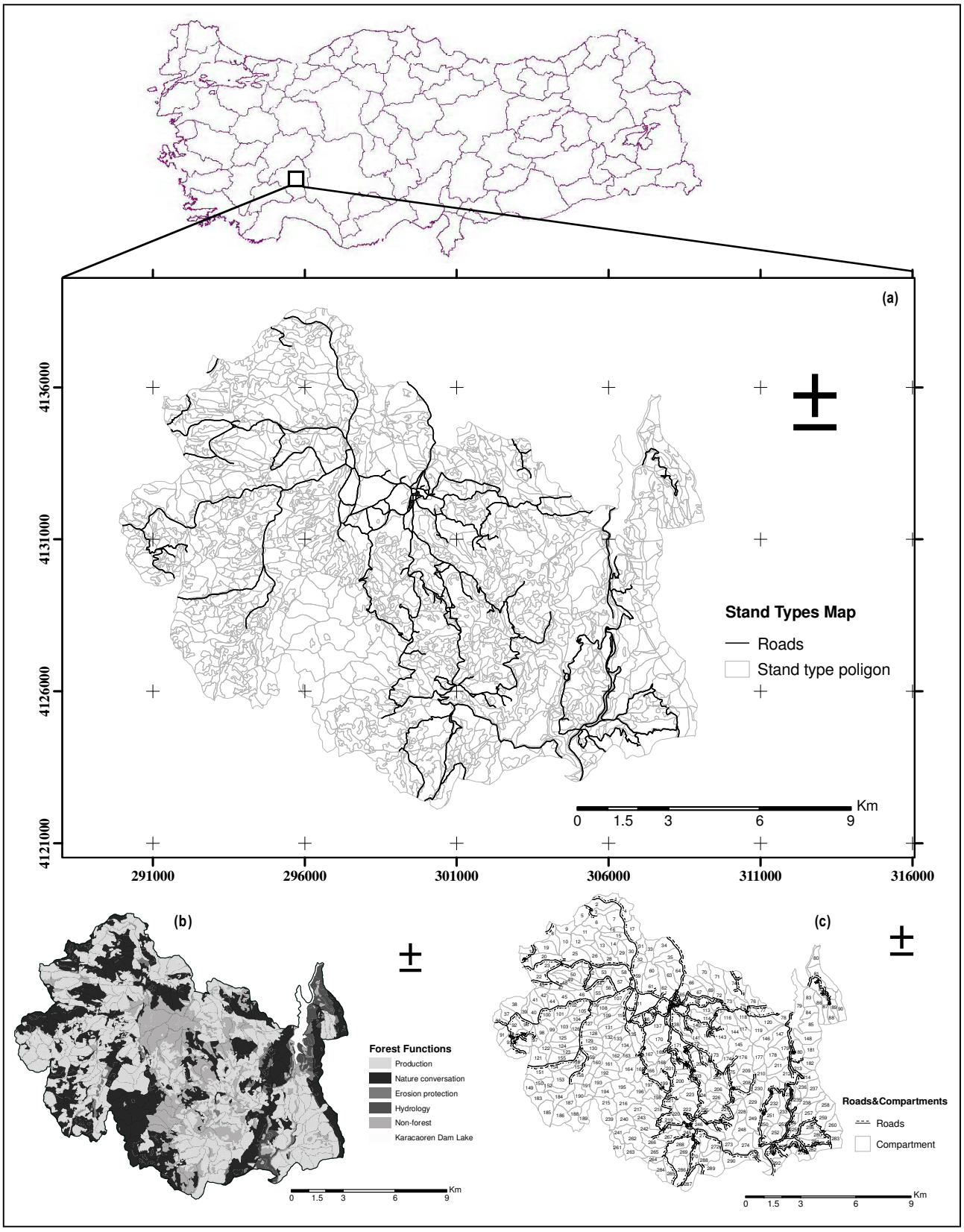

Fig. 1: Maps of Melli Forest Planning Unit. (a) Geographic location and forest stand type map (non-dissolved status) overlayed with road map, (b) Forest functions map, (c) Forest compartments map overlayed with road map

excelsa Bieb.) participate in vegetation structure (Anonymous, 2007b).

Approximately 80% of the study area is covered with productive and degraded coniferous forest, whereas 20% portion of the area is non-forest areas such that agriculture, housing, and wetlands-stream areas. In MFPU, natural development stages of forest stands range from; seedling and sapling stands (a<7.9 cm in diameter at breast height) account for about 16%, while poletimber stands (b = 8.0-I9.9 cm dbh) for 10%, thin sawtimber (c = 20.0-35.9 cm dbh) 57%, and sawtimber (d>36.0 cm dbh) 17% of total area.

Data evaluation and analysis: Dataset were derived from multifunctional forest management plan, forest road network plan, standard topographic maps (scale 1:25000) and LANDSAT (1975 and 2002 yr data) satellite images, having 30 m spatial resolution. The standard topographic maps were used by digitizing in order to form digital elevation model (DEM) and to check whether or not there is any forest, rural and public road segment is lacking in original forest road network map. ArcInfo 9.2 GIS software (ESRI, 2007) was used to digitize the maps, to save and manipulate the spatial data. A GIS database was established for quantitative analysis of the landscape structure of MFPU.

Digital vector road maps provided by National Forest Administration with scale 1:25000 for each forest planning unit were used in analysis of forest road network. It was improved digital vector map layer by converting from computer aided dimension/ CAD-based format to ArcGIS environment. Attributes for each road type (forest, rural, and public road) include length of segment, quality, grade, *etc.* Road locations and lacking of road network were controlled by means of topographic maps and forest stand type maps.

All road types except for skid trail located in the study area was considered. Although cleared right-of-way of national forest road types which was the "B-Type Secondary Forest Road" characteristics (Demir, 2007) vary from rural or public roads in terms of technical-geometrical standards, it was ignored the differences and all roads (forest, rural, and public roads) and their effects had to be accepted the same for relational analysis. Furthermore, the report of multifunctional forest management plan arranged for planning period between 1997-2007, and between 2007-2016, forest cover/stand type maps, forest functions map and forest compartment map (Anonymous, 2007b). Digital vector map of the road network was overlayed on the other polygon maps to quantify relation between landscape structure and roads. Then, it was calculated road density and measured spatial metrics related to road network.

Roads divide entire forest landscape into pieces. One patch polygon intersected by a road segment becomes two or more polygons. The effects of roads on the forest's polygon structure was investigated by placing 20 m for forest compartments and stands and 500 m forest functions patches impacts along the roads on each combined map. Determining a depth of road edge influence into a patch polygon bordered by a road segment separates the polygon into two sections, an area of road impact that is adjacent road where is called roaded area with at least one border part of a polygon and the other one is an interior area that is roadless area. It was chosen 20 m and 500 m road impact zone because (1) road platform with a forest or rural road is 20 m of which is 10 m on right side and 10 m left (GDF, 2008), and (2) opening-up and accessibility ratio of forest by a road is normally 250 m as double edged.

Quantification of landscape structure is the main element for the determination of relation between forest road network and landscape structure. The study area was defined as a landscape, boundaries of which were based on drainage pattern that is natural line drawn along heights or stream land and administrative border to manage all forest resources. Forest management planning unit has an individual drainage pattern and a forest landscape characteristics (Baskent and Jordan, 1995). In this respect, the study area was found as land units for studying the impacts of roads on forest landscapes considered the experimental unit in a mensurable experiment (D'Eon, 2007). The study area was described by delineating into three distinct polygon classifications, which are (1) forest function patch polygons, (2) forest compartment polygons, and (3) forest stand and stand patch polygons. The entire forest landscape was divided into fragments through functions, compartments, and stand characteristics. In the quantification and analysis process, each polygon type was separately evaluated to calculate indices of landscape structure. GIS software was used in quantification and analysis of the indices with vector-based data.

In order a landscape can be characterized, it was used the landscape composition referring to variety and abundance of patch types and configuration referring to the placement or spatial characteristics of a patch within a landscape (Dunning *et al*., 1992; McGarigal and Marks, 1995). Some quantitative indices were also used to measure the landscape structure depending on the size and shapes of function patches, forest compartment, and stand patches with road network and road density across all forest landscape.

Landscape structure measurements fell into several categories, which are area metrics (area of stand and function patches, compartments, and landscape), shape metrics (shape indices such as shape complexity indices), density-related metrics (number of patches and mean patch area), edge metrics (perimeter of polygons), and diversity metrics (Shannon's and Simpson's diversity index) (McGarigal and Marks, 1995; Miller *et al*., 1996; Blanco Jorge and Garcia, 1997; Gustafson, 1998;Trani and Giles, 1999; Elkie *et al*., 1999; Ozcelik *et al*., 2008). However, it was calculated some variables that are road density, opening-up ratio, and topography index to analyze effects of road network on landscape pattern. Descriptions of the indices mentioned above are shown in Table 2.

The map of forest function patches was overlayed with road map. Road density was calculated according to each functions patch. Each function polygon was scattered into entire landscape by sub-

function types. Therefore, five sub-functions class were formed to facilitate the measuring and analysis processes (Dam lake polygon in the landscape was excluded from analysis). Sub-functions land were fragmented in the landscape, so neighbour polygons were dissolved by GIS tools to obtain function patches that were contiguous and similar characteristics polygons. Although roads were not considered to constitute the function patch boundaries, all indices belonging to function patches were calculated in respect to patch, class, and landscape metrics (McGarigal and Marks, 1995) evaluated by using the mean values table (Table 3).

To measure the impacts of roads on forest compartments, roaded/non-roaded approach was used, as well. The compartments were delineated into two class/groups as roaded (Group-I) and unroaded (Group-II). Roaded compartments are adjacent to road within 10 m buffering area. Not only proportion of a compartment area located in buffer zone, but also whole compartment area was used as roaded compartment. Roads may be used as compartment boundaries or across the compartments and dissected into two or more fragments (Fig. 1c). Unroaded or roadless compartments are away from roads. Each group results were presented by mean values (Table 3) and compared by each other "Independent Samples t-test" was used to determine differences between two groups. Within each group, "bivariate correlation analysis" was realized to expose relation between class indices (SPSS, 2004).

Stand patches were described using pre-existing stand boundaries in the vector-based forest stand type map by means of ArcGIS tools. It was investigated how stand size and shape impacted from road network across all forest stand types. Thus, dissolved forest (stand) patch map was overlayed by road map. Roads were not generally considered to form stand boundaries. However, two same stand type taking part in both left and right side of a road segment, sometimes, could be harvested or regenerated in different time and silvicultural operations. It could be told that forest roads fragment the forest stands two or more part. Therefore, roaded/non-roaded approach was also used to quantify how road network influenced the spatial structure indices of forest stand patches. Two classes were developed, which were roaded where stands or patches adjacent to road within 10 m buffer zone and non-roaded area was roadless area away from road effect zone. To compare roaded and non-roaded patches "Independent Samples t-test" and "Bivariate correlation" procedure were preferred in statistical programme SPSS 13.0 (SPSS, 2004).

Results and Discussion

The total road length actively used in forest, rural, and public transportation infrastructure was found as 213.25 km although forest road network in this study area has been not completed, yet. The proportion of completed section of planned forest road was 66.8% at the beginning of 2008. Road density in entire forest landscape was averaged at 11.24 m ha^{-1}. Forest road ratio in total road length was 61.66 and 84% of which was dirt (unpaved) road characteristics. The forest roads lied down through stream channel and valley, therefore, characteristic of the 50% of forest road was valley road and the rest of which was ridge or hillside road.

One of the most important ecological impacts of forest road is surface erosion and sediment production because roads speed up water flows and sediment transport and increases peak discharges and downstream flooding (Jones and Grant, 1996; Forman and Alexander, 1998; Gucinski *et al*., 2001). The abundance of dirt road in the forest landscape can cause or intensify the risk of surface erosion and sediment production or other corresponding effects. Because 57% of the total road length has over 10% road gradient and average hillslope ratio is 36%, which dictates that the study area locates at steep terrain. In addition, although Demir (2007) and Gumus *et al*. (2008) suggested to hillside or ridge road building in the multifunctionally planned forest units, the half of road length was valley road in MFPU. For that reason, it is obvious that forest roads have potential impacts on forest landscape ecology in this study area, as well.

MFPU has been managed to multifunctional forest management planning concept in the sustainability of forest resources framework (GDF, 2008; Anonymous, 2007a). The entire MFPU landscape has been delineated with three functions of MFPU that are ecological (37% of total area), economical (46% of total area), and social (17% of total area) and five sub-functions with eight management goals (Table 1). The sub-function polygons scattered into landscape was dissolved in order to be formed the function patches.

As shown in Table 3, it was obtained 359 function patches for different five sub-functions. The road density ranged from 4.59 to 16.22 m ha^{-1} in the study area. The road density of forest production patches referring to harvestable areas was calculated as 14.86 m ha^{-1}. Assuming 5 m road width (GDF, 2008) for all, road themselves occupied 0.56% of the study landscape. It was approved that 1% of a production forest land could be separated to built up forest road for optimal forest road density in Road Communique-No:292 which include guidelines for planning, construction, and maintenance of forest roads (GDF, 2008). Therefore, this ratio showed that new forest road construction could be built in this study area. Because, opening-up ratio of production function patches was 47%, which displayed weak opening-up ratio (Erdas, 1997; Eker and Acar, 2006) with existing forest roads. Barely, new roads into forested landscape often lead to economic development as well as deforestation and habitat fragmentation (Forman and Alexander, 1998).

In the ecological sub-functions patches that were nature conservation, erosion protection and hydrological polygons, road density was lower than economical and social function patches. The ecological effects of forest roads during construction and utilization process (Lugo and Gucinski, 2000) was taken into consideration, the road density ranging from 4 to 11 m ha^{-1} was suitable for these patches. Furthermore, Bennett (1991) and Mech (1989) suggested low road density, *e.g.* 6 m ha^{-1}, for naturally functioning landscape. Inherently, to reduce road impacts on the patches having ecological priority, road density had low ratio. Ecological sensitive patches

Table - 1: Distribution of area and permissible cutting in Melli forest planning unit (MFPU)

Functions	Sub-functions	Management goals	Area (ha)		Permissible cutting (m^3)	
			Productive	Degraded	Ten years	Annual
Economical	Forest crop production	Qualified wood production	6422.4	1842.6	193674	19367.4
		Non-wood forest products	-	218.6	-	-
		Seed stand	223.5	17.6	3731	373.1
Ecological	Nature conservation	Gene protection forest	99.3	15.1	-	-
		Protection areas	779.8	5310.3	272	27.2
	Erosion Prevention	Soil conservation	232.1	27.8	1773	177.3
	Hydrological	Protection of water resources	415.3	129.8	3190	319.0
		Sub-total of forested areas	15734.20		202640	20264
Social	Non-forest areas		3230.7			-
		Total	18964.90		202640	20264

Table - 2: Description of Indices used in landscape pattern analysis

Index name	Description
Road density (*RD*)	Dividing of road length (m) to area (ha). [*RD= RL/A*] *RL*= Road length, *A*= Area (Erdas, 1997).
Opening-up ratio (*OpR*)	Proportion of area within a 250 m buffer zone with proportion of total landscape area. [$OpR\ (\%)= (A_{buf}/A_t)*100$] where *OpR* is the factor relavent the proportion of area occupied in the 250 m buffer zone (A_{buf}) to the proportion of area occupied on the total area (A_t). If the *OpR* = 80-100 %, opening-up ratio of road network or segment is excellent (whole landscape area is accessible) (Eker and Acar, 2006) .
Area (*A*)	Refers to polygon area of a given function patch, compartments, stand patch or entire landscape (ha)
Perimeter (*P*)	Refers to perimeter of a given polygon (m or km)
Patch number (*PN*)	Equals the number of patches (polygons) corresponding class or group
Topography index (*TI*)	$TI_c = [(\Sigma S_{pc} * A_{pc})/A_{tc}]*100$ where TI_c is the index of topography of unit *c*, S_{pc} is the slope of a *p* polygon of stand in unit *c*, A_{pc} is the area of a polygon of stand *p* in unit *c*, and A_{tc} is the total area of unit *c* (Eker and Acar, 2006). Higher values of TI_c state more complex topography (Miller *et al*., 1996).
Min. size	Minimum patch, stand, and compartment size (ha)
Mean size	Average/mean patch, stand, and compartment size (ha)
Max. size	Maximum patch, stand and compartment size (ha)
Patton index (*PI*)	*PI* is the shape index and define polygon (stand, compartment or patch) shape complexity by comparing the perimeter of a stand to perimeter of a circle of the same area (Patton, 1975) and uses this formula; $PI= (P/2\sqrt{\pi A})$ where *P* is the perimeter of a polygon and *A* is the area. A value of 1.0 refers to perfect circle. It may increase without limit. The index value increases from 1.0 with shape complexity (D'Eon, 2007). *PI* was calculated for each polygon in one unit and the "area weighted average *PI*" for each unit.
Fractal dimension (*FD*)	*FD* is also a shape index. It was used to define the degree of shape complexity of a forest polygon such as stand or compartment (Krummel *et al*., 1987; Mladenoff *et al*., 1993). The formula of *FD* is $logP=1/2\ (D)(logA)$ where *P* is the polygon perimeter and *A* polygon area. The *FD* value ranges from 1.0 that indicates a straight line with least complexity to maximum 2.0 that becomes plane filling with most complex shape. Fractal dimension index is appealing because it reflects shape complexity across a range of spatial scales. While FD average value of a function patch was presenting, "area weighted mean Fractal Dimension" ratio was used.
Shannon diversity index (*SHDI*)	$SHDI= -\Sigma(P_i*logP_i)$ *SHDI* >= 0, without limit. *SHDI* = 0 when the landscape contains only 1 patch (no diversity). *SHDI* increases as the number of different patch types (patch richness, PR) increases or the proportional distribution of area among patch types becomes more equitable, or both. *SHDI* equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion. *SHDI* is a popular measure of diversity in community ecology, applied here to landscapes. Shannon's index is somewhat more sensitive to rare patch types than Simpson's diversity index (Mcgarigal and Marks, 1995).
Simpson diversity index (*SIDI*)	$SIDI=1 - \Sigma P_i^2$ where 0 £ *SIDI* < 1 *SIDI* = 0 when the landscape contains only 1 patch (no diversity). *SIDI* approaches 1 as the number of different patch types (patch richness, PR) increases and the proportional distribution of area among patch types become more equitable. *SIDI* equals 1 minus the sum, across all patch types, of the proportional abundance of each patch type squared (Mcgarigal and Marks, 1995; Elkie *et al*., 1999).
Roaded area	Pach, stand, and compartment area located in adjacent to road through at least one edge of the polygon. This value was determined by buffer zone drawn to left and right side of road as 10 and 250 m. If a border of a polygon is located in buffer zone, whole polygon structure is included to evaluation process.
Unroaded area	Patch, stand and compartment area is away frok roads. That is roadless area or called interior area.

needed a road density even if it was low because timber harvesting had been occasionally managed to stabilize sustainability of water acquisition. The presence of low road density for ecologically sensitive areas may the best indicator of suitable ecological values.

However, there is the higher road density in social functioning forest patches to access agricultural and housing areas. On the other hand, with higher road density, human access and disturbance effects in the remote areas of forests may increase (Mech, 1989). Hydrological effects of road network on aquatic ecosystems and other detrimental impacts of roads on flora and fauna habitats are negatively impressed by high road density (Jones and Grant, 1996; Forman and Alexander, 1998).

It was decided that road density had an overall index averaging patterns and measuring road network structure over an area. Therefore, the road density was correlated with patch indices (mean values of which were given in Table 3). There was little negative significant relationship between road density and patch area/size, patch perimeter, and shape index (Patton Index) ($p<0.01$; $r = -0.207$; $r = -0.205$ and $r = -0.240$, respectively). In addition, it was found significant stronger inverse relationship between road density and topography index ($p<0.01$; $r = -0.736$). The reason of the negative correlation between road density and topography index depends on the ecological functioning patches located in steep terrain with high slope, the other in moderate terrain with low slope, the forest roads become dense in the low slope ground, and the majority of forest road has valley road characteristics.

However, there was no correlation between road density and patch number and FD, on the contrary to Krummel *et al*. (1987) and Mladenoff *et al*. (1993). The PI had a inevitable stronger significant correlation with patch area and patch perimeter ($p<0.01$; $r = 0.809$ and $r = 0.854$), and weak significant correlation with topography index ($p<0.01$; $r = 0.150$). PI had more powerful relationship with road density than topography index. Unexpectedly, FD had no correlation with any patch indices, as similarly. According to Table 3, when shape index (PI and FD) of function patches was evaluated, the higher values indicated more complex and irregular patch shapes. In addition, there were differences in mean patch size for sub-function polygons with the highest and the lowest road densities, but the trend in these differences was not consistent. Nature conservation patches with the lowest road density had larger patch size (73.86 ha) than non-forest patches with the highest road density (16.82 ha) and mean patch size in entire landscape (52.82 ha), but for the production functioning patches this trend was reversed. When road density was used as naturalness index, the underlying hypothesis was that disturbance could propagate anywhere along the roads (Miller *et al*., 1996).

At the end of spatial analysis, production patches existed in higher proportion (50.56%) in the road buffer (250 m right and left side) and 20.6 and 28.84% for ecological and social functioning patches. The proportion of area occupied by function patches differed from the composition of the landscape. This consequence displayed that forest road had been mainly built up for harvest operations. Likewise, D'Eon (2007) found that road density was highly correlated with harvesting quantity, but not with spatial patch indices. It is result of road planning to access all available resources in a forest area independent of short-term harvest patch indices. As well, in the study area, multifunctional forest management planning began by planning road networks tends to be constructed for optimal opening-up ratio or maximum accessibility to forest resources. Thus, forest road network was independent of function patches' spatial structure in planning phase.

To test whether or not the road network affected landscape structure and fragmented of the functions patches, forest functions map intersected by forest road network map. That is, polygons of forest sub-function patches were divided into small polygons. As shown in Table 4, road network increased the number of patch average by 81% (from 19 to 97 %) and decreased mean patch size ranged from 64 to 8 %. Reed *et al*. (1996) stated that these measures could be used as indicator to delineate that roads caused a degree of fragmentation.

Furthermore, area weighted mean shape index values ranged from 0 to 16% for PI and 0.001 to 3.1% for FD. The slight changes on the shape indices indicated a trend towards simple and regularly shaped patch boundaries. This finding was a result of positive relationships between PI index value and patch area and perimeter. As the patch area and perimeter decreased, PI index value decreased as well, which referred to more rough and simply shaped patch boundaries (Krummel *et al.*, 1987). Therefore, it was obvious that dividing of forest land into patches by roads changed the patch shape index (PI) and affected landscape structure.

Due to the fact that entire function patches were divided into two or more similar small patches or polygons by road network, Shannon and Simpson's Diversity Indices were used to determine whether or not there was diversity changing on function's polygon numbers. There was a little differences (0.04 %) between two groups, which was not accepted an important differences. The diversity of polygons belonging to patches didn't change.

The landscape structure metrics demonstrated an evident pattern of fragmentation of landscape by roads. These impacts were illustrated by the increase in patch numbers, which happened as roads dissected large patches of forest functions into smaller fragments. A greater patch number corresponded with decrease in mean patch size/area. The decreasing of mean patch area indicated increase edge effects of roads. This indication was a significant reduction in the amount of interior forest habitat such as native of micro or macro flora and fauna (Mladenoff *et al*., 1993; Reed *et al*., 1996; Saunders *et al*., 2002). The diversity indices were found insignificant with road network impacts in this study area. However, it was put forward that forest road network changed spatial pattern of patch shape through Patton Index values.

To encourage hypothesis of the study and support the results, it relationship between forest network and spatial structure of forest compartments was investigated. The entire forest landscape was

Table - 3: Landscape index values of sub-functions patches

Sub-functions (Management goals)	Road density (m ha^{-1})	Patch area (ha)	Patch number	Maximum patch size (ha)	Mean patch size (ha)	Minimum patch size (ha)	Area weighted mean Patton Index Value	Area weighted mean fractal dimension	Opening-up ratio (%) (within 250 m buffer)	Area weighted mean topography index (%)	Ratio of portion in roaded area (%)
Production	14.86	8723.77	44	2673.24	198.27	0.607	3.948	1.796	47	33.49	50.56
Nature conservation	4.59	6204.39	84	1169.169	73.86	0.723	3.832	1.770	20	43.58	15.75
Erosion protection	4.77	260.23	31	29.96	8.39	0.71	1.835	1.595	26	61.65	0.86
Hydrological	10.86	545.83	8	355.77	68.23	2.80	4.249	1.722	48	41.75	3.99
Non-forest areas	16.22	3230.70	192	878.20	16.82	0.36	3.274	1.716	76	18.04	28.84
General	11.24	18964.90	359	-	52.82	-		1.751	42	34.96	

Table - 4: The comparison table for divided and undivided functions patches by forest roads

	I (Undivided patches)						II (Divided patches by road)					
Sub-functions (Management goals)	Patch number	Mean patch size (ha)	Area weighted mean shape index (Patton)	Area weighted mean fractal dimension	Shannon diversity index	Simpson diversity index	Patch number	Mean patch size (ha)	Area weighted mean shape index (Patton)	Area weighted mean fractal dimension	Shannon diversity index	Simpson diversity index
Production	44	198.27	3.948	1.796	0.533	0.638	128	71.79	2.560	1.767	0.537	0.642
Nature conservation	84	73.86	3.832	1.770			123	55.40	3.406	1.764		
Erosion protection	31	8.39	1.835	1.595			37	7.64	1.835	1.594		
Hydrological	8	68.23	4.249	1.722			18	51.43	3.419	1.715		
Non-forest areas	192	16.82	3.274	1.716			343	10.14	2.193	1.663		
General	359						649	-				

Table - 5: Forest compartments and their spatial characteristics

Compartments and their spatial characteristics	Compartment number	Average stand number per compartment	Total compartment size (ha)	Total compartment perimeter (km)	Mean compartment size (ha)	Maximum compartment size (ha)	Minimum compartment size (ha)	Area weighted mean shape index	Area weighted mean fractal dimension	Topography index (Slope gradient) (%)
Roaded area	219	7.3	14414.26	906.057	65.82	205.86	29.48	1.473	1.243	32.92
Roadless area	73	5.1	4550.64	278.770	62.31	89.627	35.87	1.368	1.236	39.21
Total	292		18964.90	1184.828						

Table - 6: Spatial characteristics of dissolved stand patches

Characteristics	Patch number	Minimum patch size (ha)	Mean patch size (ha)	Maximum patch size (ha)	Area weighted mean shape index value	Area weighted mean fractal dimension	Patch density (100 ha)
Roaded area	421	0.45	21.38	713.53	2.643	1.677	2.22
Roadless area	833	0.36	11.96	567.26	2.086	1.661	4.39

Table - 7: Spatial characteristics of non-dissolved stand polygons

Characteristics	Stand number	Minimum stand size (ha)	Mean stand size (ha)	Maximum stand size (ha)	Area weighted mean shape index value	Area weighted mean fractal dimension	Stand density (100 ha)
Roaded area	688	0.17	13.08	196.39	1.962	1.642	3.628
Roadless area	1159	0.33	8.60	85.67	1.695	1.629	6.112

Table - 8: Analysis of MFPU by land cover and land use classification

		Forest land cover					Land use			
		Stand development stages								
Characteristics		a (Seedling and sapling)	b (Polytimber)	c (Thin Sawtimber)	d (Sawtimber)	Degraded forest	Agricultural lands	Residential lands	Wetlands	Open and rocky lands
Roaded area	*Number of patch*	42	24	104	44	122	53	15	1	16
	Area (ha)	918.26	725.80	1916.05	313.36	2396.77	2076.14	152.97	196.39	304.42
Roadless area	*Number of patch*	39	21	239	122	254	124	1	-	33
	Area (ha)	392.78	96.17	2773.77	1038.87	5165.05	353.19	3.98	-	139.27

divided into 292 forest compartments, polygon boundaries of which was drawn up by natural border of terrain such as stream and ridge and artificial border such as forest roads and fire safety strips (Fig. 1c). To measure whether or not road network affected spatial structure of forest compartments, both forest compartment and forest road network map were merged. The compartments were classified into two groups, which were roaded and unroaded compartments and then compared with each other. If road segment had been a border of a compartment or reached out through a compartment, these compartments were referred to as roaded area, which were under the influence of road edge and were adjacent to road. The unroaded compartments were the area that remained after removing the area of road edge influence, which was defined by buffering 10 m with a depth-of-edge influence distance from road line (abstracted with mean values in Table 5).

The results regarding the differences between roaded and roadless compartments displayed that there was no statistically significant differences between compartment size, perimeter, and shape index (PI) of both group, by means of independent t-test. However, it was found a significant differences among topography index values ($p<0.01$) and FD values ($p<0.05$). The reason of the difference on topography indices was based on that the right-of-way belonging to forest roads had low hillslope and the road density increased in production forest and non-forest functioning area with low hillslope.

In addition to comparison of inter-groups, each group roaded and non-roaded compartments were evaluated by oneself through bivariate correlation analysis. It was found non significant relationship between topography indices, PI and FD values by roaded compartments. On the other hand, there was little negative significant relationship between topography index and PI ($p < 0.01$; $r = -0.369$), and also with FD values ($p<0.01$; $r = -0.357$) by non-roaded compartments. Moreover, shape indices both PI and FD existed in higher proportion of the roaded area than on the non-roaded area. While the topography index with area and perimeter of a compartment were a considerable factor on revealing of PI and FD values in the non-roaded areas, but not in the roaded areas. That is, the existence of road network was more effective than topography index appearing of PI and FD in the roaded areas. This evidence and statistical differences among two groups indicated potential reverse impacts of road network on spatial structure of forest compartments in terms of shape index (FD).

The proportion of the compartment adjacent to roads was found as 75%. The forest roads passed through and dissected 98 compartments into two or more sub-compartments. In the other compartments within buffering roaded area, roads lied down along compartment boundaries or as parallel. It was observed that the road length surrounding compartment boundaries was 82.51 km, that is 37% of total length was used as compartment border. The perimeter of all compartments was calculated at 1184.828 km, 7% of which was constituted by roads. When the road map was intersected by forest compartments map, the road line divided compartment polygons, then, the new polygons number of sub-compartments reached from 292 to 390. Thus, it was deduced that roads would be edge effect zone, which could be effective on ecosystem. Because, the road effect zone is the area that has significant ecological impacts extending outward from a road. The zone is asymmetric with convoluted boundaries and unequal effect distance due to slope, wind, and habitat suitability on opposite sides of a road (Forman, 1995).

On the contrary, there was no physically concrete boundary separating compartments except for stream and ridge. Therefore, the edge-effect zone couldn't be appeared. The boundaries of a forest compartments were constituted by topographical conditions and forest operations were managed in compartments based, so it was inevitable that the edge effects of road network could be occurred and caused to forest fragmentation, in course of time. Forest roads constitute open area within forest structure because of their edge-related effects. The edge effect zone along roads has potential harmful microclimatic and biological changes by increasing of evaporation and temperature, decreasing of soil moisture in intact forest landscape (Chen *et al*., 1993; Forman and Alexander, 1998; Noss, 2002). Road edge has tendency to continue distinguished impacts for a long time such that soil erosion (Bilby *et al*., 1989), noise (Reijnen *et al*., 1996), disturbance by human activity (Saunders and Hobbs, 1991), and population changes (Forman and Alexander, 1998). All factors depending on road network create deleterious habitat circumstances on the landscape (Reed *et al*., 1996).

However, the number of stand within roaded compartments was more than non-road compartments. The forest harvesting operations were conducted by structure of stand within a boundary. Therefore, it was possible that a compartment was partly harvested in different times and different location of the same compartment. This result clarified that there could be a different forest canopy and different stratified structure for animal species. D'Eon (2007) implied that harvesting of patch area are the important to the issue of fragmentation such as patch size and spacing.

The entire forest landscape had been divided into small stands. The physically adjacent stands having the same characteristics were dissolved and obtained stand patches. To determine whether a correlation between spatial size and structure was, roaded and non-roaded stand patches (Table 6) were classified by principles mentioned above. The number of stand patches, total areas, and patch density of roaded areas was lower than non-road areas, whereas PI, FD, minimum, mean, and maximum patches size was higher.

When the independent sample t-test was applied to inspect the differences, it was observed that there was a significant difference ($p<0.01$) between patch size, PI and FD values by roaded and non-road stand patches. For the roaded and roadless areas, PI and FD values were higher and shape of stand boundaries was the complex and irregular shaped. However, in roaded stand patches, PI and FD were higher than non-roaded patches. To be sure of the results, the same tests were repeated for the non-dissolved forest stands. There was a significant difference ($p<0.01$) between patch size, PI and FD values by roaded and non-road stand polygons as well (Table 7). These results showed that stand or patch size and shape indices values were higher in roaded areas, which affected composing of complex and irregular shaped polygons. When the accepted roads to be stand boundaries it was shown a large increase in the number of small stands with simpler shapes, which tend to fragment the landscape.

Williams and Marcot (1991) also found that mean patch sizes differed when comparing stands in roaded areas vs. non-roaded areas. They reflected that roadless areas were thought to represent baseline or more natural areas (Miller *et al*., 1996). On the other hand, in dissolved stand patches, using a classification by land use/ forest land cover 9 scales were developed (Table 8).

Approximately 70% of the roaded area was covered with productive and degraded forest, whereas 23% portion of the area was agriculture, and the rest of the roaded area was non-forest areas such that housing, and wetlands-stream areas. In roaded stand areas, natural development stages of forest stands range from; 14.6% for seedling and sapling stands, 12% for poletimber stands, 30.5% for thin sawtimber and 4.9% for sawtimber. The 95% of the non-roaded areas was covered by forest areas and the rest of the area was covered by other land use types. Approximately 54.5% of forest cover land was also degraded.

About 70% for "a", 88.3% for "b", 40.85% for "c", and 23.6 for "d" class, located in roaded areas. In addition, only 31.7% of the degraded areas taken part in roaded areas. Seedling-sapling (a) and poletimber (b) stand development stages constituted sufficiently higher proportion of the buffering roaded area than in the forest landscape. Furthermore, 85% of the agricultural areas existed in roaded areas. This is reason of the highest road density in social functioning patches. Although forest roads reveal a small fraction of the landscape in terms of area, their impacts extends far beyond their immediate boundaries. In this study area, large proportion of forest area lies down along road edge. Therefore, it is obvious that vegetated area (70% of total area) with forest tree species opens to the impacts of road network.

The forest road networks have human-caused effects on the landscape structure. For example, complex patch shapes have attributed to human disturbance. Ripple *et al*. (1991) found that extensive timber harvest areas were associated with more irregular patches. In the MFPU area, highest proportions of harvestable forest areas fall into roaded or adjacent to roaded areas. However, the functioning patches having higher road density, compartments and stand patches in roaded areas have higher complex and irregular shaped polygons. The results define that road networks are effective on the spatial structure of forest landscape. The forest road network of study area has all probable ecological impacts of forest roads mentioned in context. However, quantifying the divergence from naturalness in roaded areas needs an understanding of the factors controlling the structure of unroaded landscapes, especially in terrain of great topographic relief (Miller *et al*., 1996).

At the landscape level, primary ecological effects of a road network are the disruption of landscape process and loss of biodiversity. Interrupting horizontal natural process, such as groundwater flow, streamflow, fire spread, foraging, and dispersal, alters the landscape spatial pattern (Forman and Alexander, 1998). As well, the road network dissects the entire land, leading to habitat fragmentation and shrinkage. It may create distinctive spatial patterns

on the landscape structure, such as converting convoluted to rectilinear shapes and composing more total edge (Reed *et al.*, 1996).

On the basis of results, it is possible to conclude that high forest road density and existing road network can ecologically affect the spatial structure of forest functioning patches, compartments, and also forest stands, in the long run. When taken into consideration that it has been completed, yet, only 66% proportion of total forest road length need for Turkish Forests (21.2 million ha) it is suggested that, for the new roads, the forest road should be planned so as to functioning forest patches, lied down along boundary of a compartment instead of intersecting through a compartment. The assessment criteria should be developed in order to be used in planning and construction to minimize ecological impacts of roads.

References

Anonymous: Forest road Network Plan of Melli Forest District, Regional Forest Directorate of Isparta (2007a).

Anonymous: Multifunctional Forest Management Plan of Melli Forest District, Regional Forest Directorate of Isparta (2007b).

Baskent, E.Z. and G.A. Jordan: Characterizing spatial structure of forest landscapes. *Can. J. For. Res*., **25**, 1830-1849 (1995).

Bennett, A.F.: Roads, roadsides and wildlife conservation: A review. *In*: Nature conservation 2: (*Eds*.: D.A. Saunders and R.J. Hobbs). The Role of Corridors. Surrey Beatty and Sons, Chipping Norton. pp. 99-117 (1991).

Bilby, R.E., K. Sullivan and S.H. Duncan: The generation and fate of road-surface sediment in forested watersheds in Southwestern. *For. Sci*., **35**, 453-468 (1989).

Blanco Jorge, L.A. and G.J. Garcia: The study of habitat fragmentation in Southeastern Brazil using remote sensing and geographic information systems (GIS). *For. Ecol. Manage*., **98**, 35-47 (1997).

Chen, J., J.F. Franklin and A. Spies: Contrasting microclimates among clearcut, edge, and interior of oldgrowth Douglas, fir forest. *Agric. For. Meteorol*., **63**, 219-237 (1993).

Covington, W.W. and M.M. Moore: Postsettlement changes in natural fire regimes: Implications for Restoration of Old-growth P. ponderosa Forests. *In*: Old-Growth Forests in the Southwest and Rocky Mountain Regions (*Eds*.: M.R. Kaufmann, W.H. Moir and R.L. Bassett). Proceedings of a Workshop, Portal, Arizona, March 9-13, 1992. USDA Forest Service, Gen. Tech. Rep. RM-213. pp. 81-99 (1992).

Demir, M.: Impacts, management and functional planning criterion of forest road network system in Turkey. *Transport Research Part-A*, **41**, 56-68 (2007).

D'Eon, R.G., D. Hebert and S.Viszlai: An ecological rationale for sustainable forest management concepts at riverside forest products, Southcentral British Columbia. *Forestry Chronicle*, **8**, 341-348 (2004).

D'Eon, R.G. and S.M.Glenn: The influence of forest harvesting on landscape spatial patterns and old-growth-forest fragmentation in southeast British Columbia. *Landscape Ecol*., **20**, 19-33 (2005).

D'Eon, R.G.: Harvest block spatial configuration as a function of logging road density: Do larger more aggregated blocks create less road. *BC J. Ecosys. Manage*., **8**, 50-60 (2007).

Dunning, J.B., B. Danielson and H.R. Pulliam: Ecological processes that affect populations in complex landscape. *Oikos*, **65**, 169-175 (1992).

Elkie P.C., R.S. Rempel and A.P. Carr: Patch Analyst Users Manual: A tool for quantifying landscape structure. NWST technical manual TM-002. Ontario http://flash.lakeheadu.ca/~rrempel/patch (1999).

Eker, M. and H.H. Acar: Operational planning method for timber harvesting. *SDU Fac. For. J*., **2**, 128-140 (2006).

Erdas, O.: Orman Yollari Cilt-I (In Turkey). (Forest Roads Vol. I). Karadeniz Technical Üniversity, Faculty of Forestry, 187/25 (1997).

ESRI: http://www.esri.com (2007).

Forman, R.T.T. and M. Godron: Landscape ecology. John Wiley and Sons, New York (1986).

Forman, R.T.T.: Land Mosaics-the Ecology of Landscapes and Region. Cambridge, UK., Cambridge Univ. Press (1995).

Forman, R.T.T. and L.E. Alexander: Roads and their major ecological effects. *Ann. Rev. Ecol. Systematics*, **29**, 207-231 (1998).

Forman, R.T.T., D. Sperling and J.A. Bissonette, A.P. Clevenger, C.D. Cutshall, V.H. Dale, L. Fahrig, R.L. France, C.R. Goldman, K. Heanue, J. Jones, F. Swanson, T. Turrentine, T.C. Winter: Road Ecology: Science and Solutions. Washington, DC: Island Press (2003).

Franklin, J.F.: Preserving biodiversity: species, ecosystems, or landscapes. *Ecol. Appli*., **3**, 202-205 (1993).

Franklin, J.F. and R.T.T. Forman: Creating landscape pattern by forest cutting: Ecological consequences and principles. *Landscape Ecol*., **1**, 5-18 (1987).

GDF: Teblig No. 292 - Orman Yollarinin Planlanmasi, Yapimi ve Bakimi (In Turkish). [Communique No:292 – Planning, Construction, and Maintenance of Forest Road, General Directorate of Forestry of Turkey, www.ogm.gov.tr (2008).

Gelbard, J.L. and J. Belnap: Roads as conduits for exotic plant invasions in a semiarid landscape. *Conser. Biol*., **17**, 420-432 (2003).

Gucinski, H., M.H. Brooks, M.J. Furniss and R.R. Ziemer: Forest roads: A synthesis of scientific information. U.S. Department of Agriculture, Forest Service, General Technical Report PNW-GTR-509, Portland, Oregon (2001).

Gustafson, E.J.: Quantifying landscape spatial pattern: what is the state of the art. *Ecosys*., **1**, 143-156 (1998)

Gumus, S., H.H. Acar and D. Toksoy: Functional forest road network planning by consideration of environmental impact assessment for wood harvesting. *Environ. Monit. Assess*., **142**, 109-116 (2008).

Hawbaker, T.J. and V.C. Radeloff: Roads and landscape pattern in northern Wisconsin based on a comparison of four road data sources. *Conser. Biol*., **18**, 1233-1244 (2004).

Heilman, Jr. G.E., J.R. Strittholt, N.C. Slosser and D.A. DellaSala: Forest fragmentation of the conterminous US: Assessing forest intactness through road density and spatial characteristics. *Biosci*., **52**, 411-422 (2002).

Jaarsma, D. and G.P.A. Willems: Reducing habitat fragmentation by minor rural roads through traffic calming. *Landscape Urban Plan.*, **58**, 125-135 (2002).

Jones, J.A. and G.E. Grant: Peak Flow Responses to clearcutting and roads in small and large basins, western cascades, oregon. *Water Res. Res*., **32**, 959-974 (1996).

Krummel, J.R., R.H. Gardner, G. Sugihara, R.V. O'Neill, and P.R. Coleman: Landscape patterns in a disturbed environment. *Oikos*, **48**, 321-324 (1987).

Lugo, A.E. and H. Gucinski: Function, effects, and management of forest roads. *For. Ecol. Manage.,* **133**, 249-262 (2000).

McGarigal, K. and B.J. Marks: FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure, U.S. Department of Agriculture, Forest Service, General Technical Report PNW-351 (1995).

McGarigal, K., W.H. Romme, M. Crist and E. Roworth: Cumulative effects of roads and logging on landscape structure in the San Juan Mountains, Colorado (USA). *Landscape Ecol*., **16**, 327-349 (2001).

McLellan, B.N. and D.M. Shackleton: Grizzly bears and resource extraction industries: effects of roads on behavior, habitat use and demography. *J. Appl. Ecol*., **25**, 451-460 (1988).

Mech, L.D.: Wolf population survival in an area of high road density. *Am. Midl. Nat*., **121**, 387-389 (1989).

Misir, N., M. Misir, U. Karahalil and H. Yavuz: Characterization of soil erosion and its implication to forest management. *J. Environ. Biol*., **28**, 185-191 (2007).

Miller, J.R., L.A. Joyce, R.L. Knight and R.M. King: Forest roads and landscape structure in the southern Rocky mountains. *Landscape Ecol.*, **11**, 115-127 (1996).

Mladenof, D.J., M.A. White, J. Pastor and T.R. Crow: Comparing spatial pattern in unaltered old-growth and disturbed forest landscape. *Ecol. Appl.,* **3**, 294-306 (1993).

Nelson, J.D. and S.T. Finn: The influence of cutblock size and adjacency rules on harvest levels and road networks. *Can. J. For. Res*, **21**, 595-600 (1991).

Norse, E.A., K.L. Rosenbaum, D.S. Wilcove, B.A. Wilcox, W.H. Romme, D.W. Johnston and M.L. Stout: Conserving Biological Diversity in Our National Forests. The Wilderness Society. Washington, D.C. (1986).

Noss, R.: The Ecological Effects of Roads, Wildlands Center for Preventing Roads. http://www.eco-action.org/dt/roads.html (2002).

Ozcelik, R., A.U. Gul, J. Merganic and K. Merganicova: Tree species diversity and its relationship to stand parameters and geomorphology features in the eastern Black sea region forests of Turkey. *J. Environ. Biol.*, **29**, 291-298 (2008).

Paton, D.R.: A diversity index for quantifying habitat "edge". *Wildlife Society Bulletin*, **3**, 171-173 (1975).

Ranney, J.W., M.C. Bruner and J.B. Levenson: The importance of edge in the structure and dynamics of forest islands (*Eds*.: R.L. Burgess and D.M. Sharpe). Forest Island Dynamics in Man-Dominated Landscapes, Springer-Verlag, New York. pp. 97-95 (1981).

Reed, R.A., J. Johnson-Barnard and W.L. Baker: Fragmentation of a forested rocky mountain landscape, 1950-1993. *Biol. Conserv.*, **75**, 267-277 (1996).

Reijnen, R., R. Foppen and H.Meeuwsen: The effects of traffic on the density of breeding birds in Dutch agricultural grasslands. *Biol. Conserv.*, **75**, 255-260 (1996).

Riitters, K.H. and J.D. Wickham: How far to the nearest road? *Frontiers Ecol. Environ*., **1**, 125-129 (2003).

Ripple, W., G. Bradshaw and T. Spies: Measuring forest landscape patterns in the Cascade range of Oregon, U.S.A. *Conserv. Biol.*, **57**, 73-88 (1991).

Rowland, M.M., M.J. Wisdom, B.K. Johnson and M.A. Penninger: Effects of Roads on Elk: Implications for Management in Forested Ecosystems. The Starkey Project: a synthesis of long-term studies of elk and mule deer. Reprinted from the 2004 Transactions of the North American Wildlife and Natural Resources Conference, Alliance Communications Group, Lawrence, Kansas, USA. pp. 42-52 (2005).

Saunders, D.A. and R.J. Hobbs: Nature Conservation 2: The Role of Corridors. Chipping Norton, Australia: Surrey Beatty (1991).

Saunders, S.C., M.R. Mislivets, J. Chena and D.T. Cleland: Effects of roads on landscape structure within nested ecological units of the Northern Great Lakes Region-USA. *Biol. Conserv.*, **103**, 209-225 (2002).

Schonewald-Cox, C.M. and M. Buechner: Park protection and public roads. *In*: Conservation biology (*Eds*.: P.L. Fiedler and S. Jain). The Theory and Practice of Nature Conservation, Preservation and Management. Chapman and Hall, New York. pp. 373-396 (1992).

Sheppard, S., P. Picard and R.G. D'Eon: Meeting visual quality and timber requirements with radial-strip partial cutting in coastal British Columbia: A postharvest assessment. *Fores. Chronicle*, **80**, 215-223 (2004).

Spellerberg, I.F.: Ecological Effects of Roads and Traffic: A Literature Review. *Global Ecol. Biogeography Letters*, **7**, 317-333 (1998).

SPSS: SPSS Professional Statistics, 13.0, SPSS Inc., Chicago (2004).

Tinker, D.B., C.A.C. Resor, G.P. Beauvais, K.F. Kipfmueller, C.I. Fernandes, and W.L. Baker: Watershed analysis of forest fragmentation by clearcuts and roads in a Wyoming forest. *Landscape Ecol.*, **13**, 149-165 (1998).

Trani, M.K. and R.H. Giles: An analysis of deforestation: Metrics used to describe pattern change. *For. Ecol. Manage*., **114**, 459-470 (1999).

Trombulak, S.C. and C.A. Frissell: Review of ecological effects of roads on terrestrial and aquatic communities. *Conserv. Biol.*, **14**, 18-30 (2000).

Wade, T.G., K.H. Riitters, J.D. Wickham and K.B. Jones: Distribution and causes of global forest fragmentation. *Conserv. Ecol.*, **7**, 7 (2003).

Williams, B. and B. Marcot: Use of biodiversity indicators for analyzing and managing forest landscapes. Transactions of the North American Wildlife and Natural Resources Conference, **56**, 613-627 (1991).