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Interactions of Forest Road, Forest Harvesting and Forest Ecosystems

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1. Introduction

Forestry developed with the goal, ultimately, of maximizing the long-term economic return from the forest, a goal that has remained virtually unchanged to the present day, despite the growth in understanding of ecosystem function (Farrell et al. 2000). Forest ecosystems supply a wide range of commodities sought by an expanding human population, including structural materials, fuels, and medicines, along with a wide range of critical ecosystem services including nutrient cycling, climate regulation, maintaining water balances and carbon sequestration (Klenner, 2009). The concept of sustainable forest management, which may be defined as the use and regulation of forests and forest areas, at local, national and global levels, in such manner and to such extent as to protect their biological diversification, their productivity, rejuvenation capacity and survival energy as well as their potential to fulfill their ecological, economic and social functions, both at present and in the future, while not causing any harm to other ecosystems, is well recognized by all countries in the world (Demir, 2007).

The use of the forests and other elements in the landscape is driven by our human needs in local, regional and global perspectives. The way we use the forest as a natural resource is determined by a number of factors. These factors, which in their character are social, economic, biological and ecological, can be seen as forces and constraints (Andersson et al. 2000). Forests, which are renewable natural assets, are formed by gathering of a large number of living and non-living creatures. However, this formation is not a random mass, but whole, a system. When making use of the forest ecosystem for various purposes, care must be taken not to spoil the forest structure. As it is the case in every engineering activity, in carrying out the road planning and construction works, the requirements regarding compatibility with nature and safety and economy must be met. The compatibility with nature, that is, the requirement that the road to be constructed as a result of the works carried out should have the characteristics enabling it to perform its expected functions is thus recognized to be of primary concern. To meet this requirement, first the purpose of construction of planned facility must be precisely defined. Meeting the second requirement regarding safety involves the construction of planned facilities according to relevant standards within the prescribed period to enable them to serve in line with the contemplated purpose (Hasdemir and Demir, 2005).

Developing and maintaining the economic activity that is vital for the quality of modern life would be difficult without roads. Roads are critical component of civilization. Roads provide access for people to study, enjoy, or contemplate natural ecosystems. In fact, the development of human civilization has benefited from transportation systems that evolved from root trails to complex highway systems (Crisholm, 1990; Grübler, 1994). Building and maintaining roads have become controversial, however, because of public concerns about their short and long term effects on the environment and the value that society now places on road less wilderness (Cole and Landres, 1996). Oppositions to road building and pressure to decommission roads in rural landscapes will continue to increase as road less areas decrease in relation to roaded ones. Decisions about road alignment, building, maintenance, or decommissioning are complex because of the many trade off involved (Lugo and Gucinski, 2000).

Traditionally, the planning of rural road network is based on economic and social considerations. In the last years, traffic volumes showed a considerable growth, despite an extension of the road networks. Meanwhile, some harmful effects of these networks and their traffic flows appeared. Traffic unsafety, emissions and noise affect local people, flora and fauna (Jaarsma, 1994; Jaarsma and van Langevelde, 1996; Jaarsma, 1997). Evaluating the ecological effects of roads requires rigorous analysis and an understanding of the ecology of roads, that is, the interplay between all of the living components, the function of roads, and the environmental factors that regulate processes along the road corridor (Forman et.al. 1997).

2. Forest road ecosystems

Forest road can be defined as ecosystems because they occupy ecological space (Hall et.al.1992), have structure, support a specialized biota, exchange matter and energy with other ecosystems, and experience temporal change. Forest road ecosystem are built and maintained by people (Haber, 1990). Forest road ecosystem includes both the paved and unpaved rights of way and adjacent structure, including other infrastructure, ditches, drainage features, and other components that provide the means for vegetation to establish and provide habitat for associated plants and animals (Fig.1). Forest roads are crucial for effective forest management, regardless of its main objectives. Forest maintenance, wood harvesting, game control, recreational activities - all require the accessibility provided by a suitable road network. Forest roads, in former times planned and constructed for the needs of wood harvesting and transport, are the key factor for recreational access to and activities in forest environments. Leisure activities in urban forests include hiking, biking, horse-riding, jogging and inline-skating (Janowsky and Becker, 2003). The opening of forests to exploitation is usually realized by means of well-planned forest road networks. The parameters and location requirements of forest road networks vary depending on variations in landscape conditions and according to the technology used and administrative activities. These requirements and planning approaches may be related to economic, ecological and management characteristics (Potocnik, 1996). The road network is a form of land use, which planning strongly depends on for other land uses. These decide the desirable density of the network (mesh size) and the capacity of the road links (pavement width). Simultaneously, all human land uses are strongly dependent on this network. Economic developments, and efficient use of land resources and, as a social aim, accessibility of rural areas, need a well-

developed road network. Most regions in industrialized countries have, from a quantitative point of view, a sufficient rural road network (road density, mesh size) (Jaarsma, 1997). The model in Fig.1 highlights the six-way flow of materials, energy, and organisms along the road corridor; vegetation zone; the interaction with the human economy and human activity; external forces that converge on the road corridor. The structure and functioning of a road varies according to its design, use, type of surface, and location (Lugo and Gucinski, 2000). Forest roads are also corridors that can connect contrasting ecosystem types. Since forest roads provide a fairly homogeneous condition through the length of the corridor, they provide opportunity for organisms and materials to move along the corridor, thus increasing the connectivity among those ecosystems that interface with the forest road (Lugo and Gucinski, 2000; Merriam, 1984).

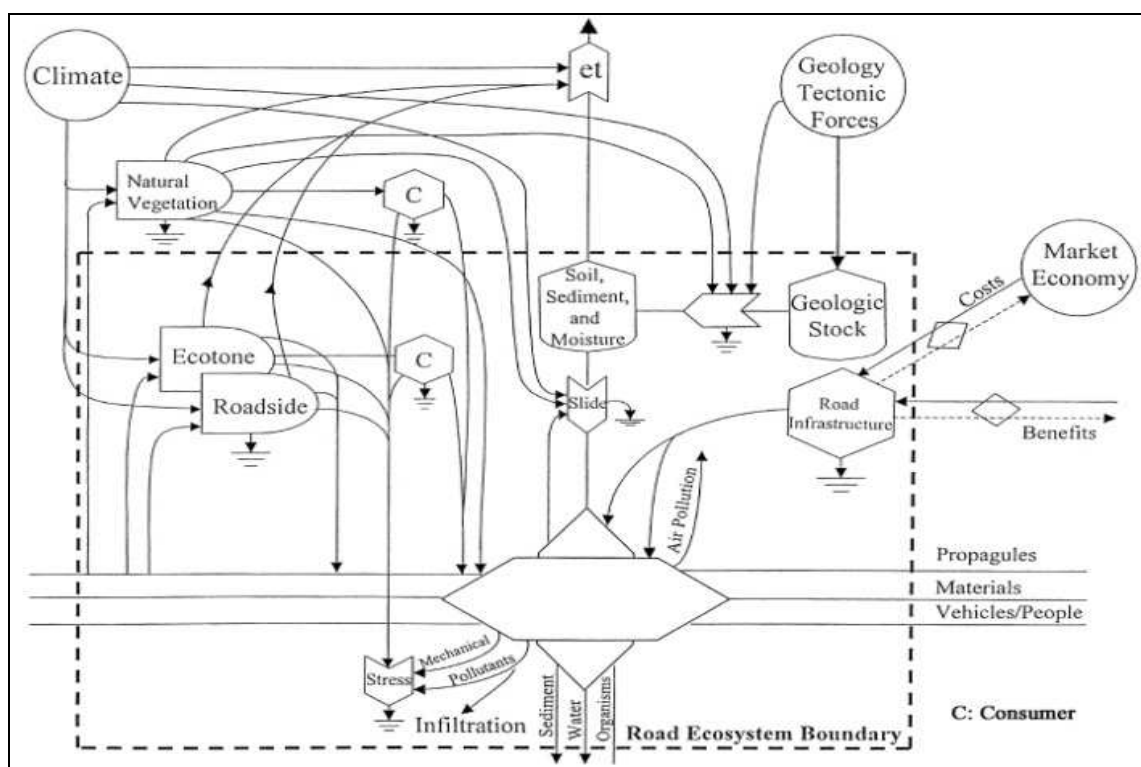


Fig. 1. Model of road ecosystem (Lugo and Gucinski, 2000).

3. Forest road impacts on forest ecosystems

Forest roads create many collateral problems adversely affecting the conservation of ecosystems and landscape integrity (Smith and Wass, 1980; Thompson, 1991). Like all ecosystems, roads are constantly changing as do the relations between the road ecosystem and adjacent ecosystems. The major phases of road development are building, operating, maintaining, and abandonment. Forest road building is often the most environmental traumatic to adjacent ecosystems because earth movement and other activities can disturb whole watersheds. Changes -mechanical, geochemical, hydrologic, biotic, and so on- to the immediate land area and any adjacent upstream and downstream ecosystem affected by building activities can be predicted. During this phase, the road is primarily a disturbance and agent of change (Lugo and Gucinski, 2000).

3.1 Wildlife

Forest roads segments can be part of forest road networks criss-crossing the landscape. A forest road network system has environmental effects and ecosystem properties that appear to transcend those of its individual segments. For example, some wildlife species, such as bear, wolf, or mountain lion, respond more to forest road density than to individual road segments (Forman et.al.1997). Similarly, forest road networks are more relevant to issues of forest fragmentation or to hydrological effects than are isolated forest road segments (Jones, 1998). Roads create barriers and additional that in turn causes fragmentation of the landscape and its populations (Jaarsma and Willems, 2002).

3.2 Vegetation

Maintaining forest roads, particularly if improperly done, act as periodic disturbances to both the road biota and landscape as a whole. Maintenance activities can approximate building activities in the amount and extent of disturbance, and they can prolong environmental effects to adjacent ecosystems. Not maintaining forest roads, however, can hinder the primary function of the road and also significantly affect the environment. For example, poorly maintained drainage systems in wet montane roads can induce mass-wasting events large enough to destroy the road and affect adjacent forest and aquatic systems. Such events sometimes exceed those observed during forest road building (Larsen and Parks, 1997).

Forest road use itself affects the landscape, for example through spills of toxic substances, pollution, dust, or effects on plants and animals by the presence of people. Forest roads as part of long-range transportation networks are likely to introduce alien species. The type and intensity of use are associated with particular environmental effects. For example, logging truck traffic is known to facilitate the transport of fungal root diseases and heavy vehicular traffic increases the risk of dispersing roadside weeds and different types and intensities of pollution (air, soil, or water) or chemical spills (Lugo and Gucinski, 2000). Furthermore, a dense forest road network for example, has a more likely effect on fragmentation than a low density network (Forman et.al.1997; Forman and Hersperger, 1996). High density road networks are more likely to affect hydrological parameters than low density ones. However, forest road density is less important to fragmentation of forest where topography dominates the structure and size of vegetation stands (Miller et al. 1996).

Road abandonment allows successional processes to recapture the road corridor. The speed and direction of succession after a road is abandoned depends on the type of road, landscape, and environment. Some road segments may be overgrown with vegetation quickly, but the pavement can arrest succession in others. Rehabilitation techniques are usually needed to accelerate succession to reach management goals after abandonment (Luce, 1997). With time, the road ecosystem ages and matures. As it does, and regardless of disturbances, segments of the road can adjust to conditions, blend with the landscape, and reach a new ecological and hydrological state (Olander et al.1998).

Finally, like other ecosystems, roads produce long term legacies on the landscape (Hutchinson, 1973). The environmental gradients believed to be most important in describing the ecological space in which roads function as ecosystem are shown in Fig 2.

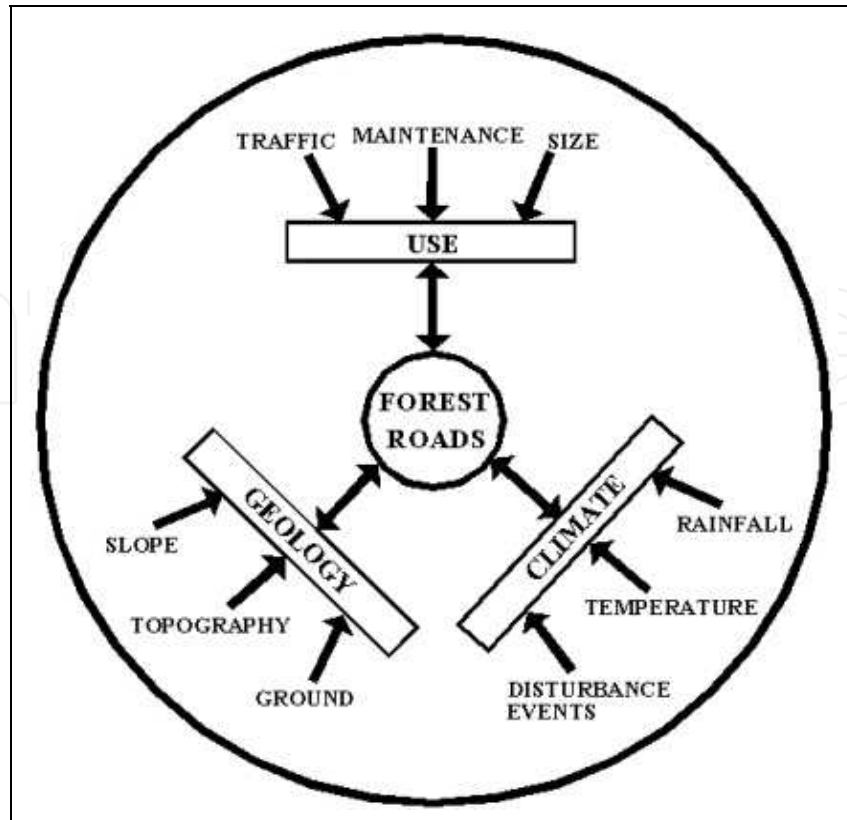


Fig. 2. Parameters of forest road ecosystems (Demir, 2007).

Forest road effects on surrounding environments and road function as ecosystem are mainly influenced by climate, geologic conditions, and uses or functions of the road. Climatic conditions are mainly the precipitation and temperature regime, and the frequency and intensity of climatic disturbance events. Geologic side is the type of substrate such as volcanic, limestone, or alluvial and the topography (Fig.3).

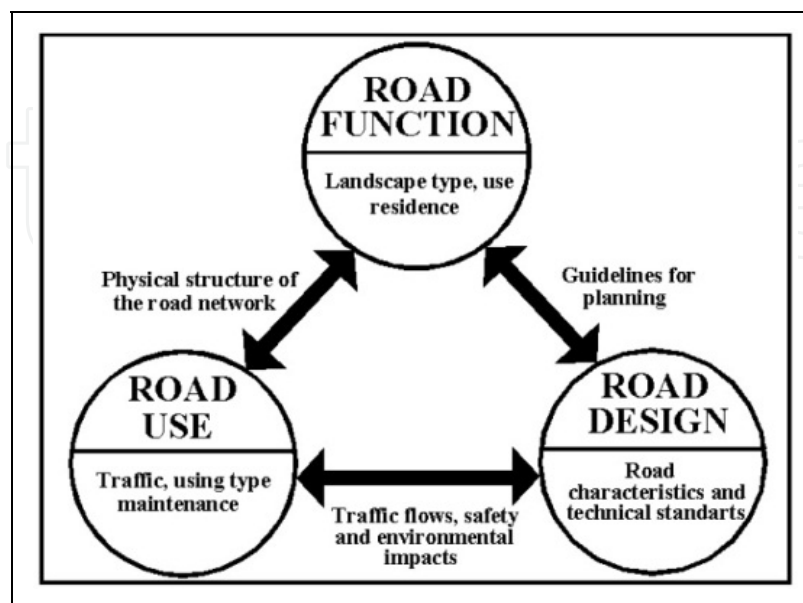


Fig. 3. Relationships between road function, design and use (Demir, 2007).

3.3 Soil

Forest roads produce the highest production of sediment yield to streams from forest lands (Binkley and Brown, 1993; McClelland et al. 1999; Reid and Dune 1984). Road construction removes the forest vegetation, disturbs forest floor, and damages soil structure, which dramatically increases the sediment yield (Grace, 2002; Megahan 1974). Sediment delivered to streams from road sections leads to number of dramatic effects on water quality (Megahan 1974). On unsealed roads, road surface erosion is generally the dominant source of sediment (Ramos Scharrón and MacDonald, 2007). Road surface and ditch areas still continue to deliver sediment to the streams as long as the road is used. The production of sediment produced from road surface highly depends on traffic density, road surface type, road dimensions, and road gradient. The ditches receive the sediment yield from the cut-slope areas, depending on road section length, ground slope, and vegetation and rock cover density. In slope roads with ditch keep the runoff water away from the fill-slope which may cause much smaller sediment yield than road surface and cut-slope areas (Akay et al. 2008). Sediment can be eroded from all road features. The factors affecting surface erosion from roads include rainfall intensity and duration, snowfall, the characteristics of surface materials, the hydraulic characteristics of the road surface, road slope, traffic, construction and maintenance, and the contributing road area (MacDonald and Coe, 2008). Previous studies indicated that sediment production rates from unpaved road surfaces were several orders of magnitude higher than undisturbed hill slopes (MacDonald et al. 1997; MacDonald 2001). Changes in vegetation cover also might have played a role in declining sediment production (Ramos Scharrón, 2010). Ditches are potentially important sediment sources particularly when erosion is caused by scour from road runoff. Ditches may deepen or widen, or be filled with deposited sediment during rainfall events (Croke et al. 2006; Lane and Sheridan 2002). Several studies found the sediment production between 0.01 and 105 kg m⁻² yr⁻¹ depending on the several observation time, different cut slopes characteristics, cover density and parent material (Table 1).

Sediment production from unpaved roads was significantly related to total rainfall, road segment slope and graded or no graded (Ramos Scharrón and MacDonald 2006). Ramos Scharrón and MacDonald (2006) obtained a different result measured sediment production rates for graded roads ranged from 5.7 to 580 Mg ha⁻¹ yr⁻¹ for roads with slopes of 2% and 21%, respectively. The sediment production rate for ungraded roads was about 40% lower than for comparable graded roads. Abandoned road segments had a mean erosion rate of 12 Mg ha⁻¹ yr⁻¹. Reid and Dunne (1984) report that a heavily used road contributes 130 times as much sediment as an abandoned road and a paved road, along which cut slopes and ditches are the only sources of sediment, yields less than 1% as much sediment as a heavily used road with a gravel surface.

Kartaloğlu (2011) has been determined that through sediment traps established on unpaved (UPFR) and paved forest road (PFR) ditch and in an undisturbed (UA) area at Belgrad forest-Istanbul, Turkey between date of November 2009 to October 2010 (12 months) (Fig.4 and 5). In this research reported that significantly differences were found on sediment productions among experiment sites (UPFR, PFR and UA). Annual sediment production was 0.654 t ha⁻¹ yr⁻¹ on UPFR, 0.334 t ha⁻¹ yr⁻¹ on PFR and 0.056 t ha⁻¹ yr⁻¹ on UA. Total sediment production of UPFR was 1.96 times higher than to PFR and 11.68 times higher than UA. Kartaloğlu (2011) stated that monthly sediment production on UPFR significantly

higher than the PFR an UA for each month and it clearly shows that stabilizing cover on forest road led to less sediment production and more soil protection. Significantly differences on monthly sediment production were determined among experiment sites in all observation period (12 months).

Location	Cutslope description	Reported sediment production rate	Normalized sediment production (kg m ⁻² yr ⁻¹)	Reference
Georgia, USA	Unvegetated	102-230 Mg ha ⁻¹ yr ⁻¹	5,1-11	Diseker and Richardson (1962)
Oregon, USA	6-7 yr old cutslopes	153 Mg ha ⁻¹ yr ⁻¹	15	Wilson (1963)
	New cutslopes	370 Mg ha ⁻¹ yr ⁻¹	37	Wilson (1963)
Oregon, USA	5 yr old cutslopes	0.5 cm yr ⁻¹	7,5	Dyrness (1970 and 1975)
	1 yr old cutslopes	0.7 cm yr ⁻¹	10	Dyrness (1970 and 1975)
Idaho, USA	45 yr old cutslopes, soil	0.01 m ³ m ⁻² yr ⁻¹	15	Megahan (1980)
	45 yr old cutslopes, granite	0.011 m ³ m ⁻² yr ⁻¹	16	Megahan (1980)
Washington, USA	55-70 degrees	16.5 mm yr ⁻¹	25	Reid (1981)
Papua New Guinea	NA	70 mm yr ⁻¹	105	Blong and Humphreys (1982)
Idaho, USA	NA	11 mm yr ⁻¹	16	Megahan et al. (1983)
New South Wales, Australia	NA	2.4-3.9 mm yr ⁻¹	3,6-5,8	Riley (1988)
New Zeland	Unvegetated, granite	NA	5,2-15	Fahey and Coker (1989 ve 1992) Smith and Fenton (1993)
Idaho, USA	Cover density 0.1-89%, 55-104% gradient	0.1-248 Mg ha ⁻¹ yr ⁻¹	0,01-25	Megahan et al. (2001)
St. John, USA	Unvegetated, 2-5 m high	NA	2-17	Ramos-Scharrón and MacDonald (2007)

Table 1. Estimated cutslope contribution to sediment yields at the road segment (Ramos-Scharrón ve MacDonald, 2007).



Fig. 4. Sediment traps on forest road and collected sediments on sediment traps at Belgrad Forest-Istanbul, Turkey (Kartaloğlu, 2011).



Fig. 5. Collected sediments on sediment traps at Belgrad Forest-Istanbul, Turkey (Kartaloğlu, 2011).

4. Forest harvesting impacts on forest ecosystems

4.1 Vegetation

Production work being carried out in the forest have many negative impact on the forest ecosystem is well known. Skidding or yarding on terrain requires the construction of relatively dense network of forest roads including skid roads, haul roads and landings (Demir et al. 2007a; Demir et al. 2008; Ketcheson et al., 1999; Makineci et al. 2007a; Makineci et al. 2007b; Swift, 1988). It has also been determined that the forest harvesting, timber production and timber skidding negatively affect the amount and variety of forest floor and herbaceous understory as well as youth development and living conditions of the soil organisms (Arocena, 2000; Bengtsson et al., 1998; Gilliam, 2002; Godefroid and Koedam, 2004; Johnston and Johnston, 2004; Marshall, 2000; Messina et al., 1997; Wang, 1997; Williamson and Neilsen, 2003).

Several studies have documented varying degrees of reduced tree growth on non-rehabilitated skid roads, ranging from 15% to 59% averaged over the trail, when compared to trees grown on undisturbed soil in the same cut block (Smith and Wass, 1980; Thompson, 1991). The wide variation in previous findings may be due to species and site-specific responses to soil disturbance, variations in the severity of disturbance, or other growth limiting factors that may magnify or alleviate the impacts of soil disturbance (Lewis, 1991; Dykstra and Curran, 2000). Sat Gungor et al. (2008) stated that ground based skidding destroyed the soil and ecosystem and the timber skidding limits recovery and growth of plant cover on skid roads. However, some herbaceous plant species show healthy habitat, and they can revegetate and survive after the extreme degradation in study area. Earlier results clearly show that skidding has particularly negative impacts on herbaceous cover, forest floor and soil. These effects of skidding on skid road have been demonstrated to have detrimental impacts on native flora and herbaceous plant establishing and maintaining were limited. Similarly, Mariani et al. (2006) reported that organic layer removal reduced abundance of herbs and shrubs.

Soil compaction can also severely reduce plant growth by restricting root growth may be due to oxygen stress and lower the percentage of water and air space in the soil (Berzegar et al. 2006). Also, Kozlowski (1999) mentioned a reduced total photosynthesis when soils become increasingly compacted, as a result of smaller leaf areas.

Yilmaz et al. (2010) reported that significant differences on widths of annual rings, dbh growth and increment values are found same tree species when in an undisturbed area and adjacent to a road under the same microclimate and site conditions, supporting the notion that long term timber skidding reduces the annual ring width, dbh growth and increment of nearby trees. The trees growing there commonly display better growth and diameter increment than the trees growing on the skid road. Tree growth and increment on the undisturbed area was found to be about 60% greater than the skid road.

4.2 Soil

Logging operations can cause significant and wide spread soil disturbance, including removal, mixing and compaction of the various soil layers (Demir et al. 2007b ; Demir et al. 2010; ; Makineci et al. 2007c; Makineci et al. 2007d; Makineci et al. 2008) . Ground based skidding, timber harvesting and logging operations in forest ecosystems cause the reduction and redistribution of organic matter, changes in plant cover, organic layer and soil properties, and modification of microclimate (Buckley et al., 2003). Timber harvesting can adversely affect both soil physical properties and soil nutrient levels. Logging can cause diminished growth of subsequent tree rotations, significant increase in runoff and sediment loads (Laffan et al., 2001). Erosion of organic and nutrient rich surface soil and compaction decrease forest productivity (Pritchett and Fisher, 1987) and the transport of sediment to streams and subsequent sedimentation lead to loss of stream habitat and altered stream hydrology. The soil micro flora and fauna complement each other in the commination of litter, mineralization of essential plant nutrients and conservation of these nutrients within the soil system. Harvesting directly affects these processes through the reduction and redistribution of organic matter, compaction, changes in plant cover, and modification of microclimate (Marshall, 2000).

The extent of severe disturbance from ground based timber harvesting systems varies due to slope and terrain, timber harvesting machines, methods of designating skid roads and harvesting season. Forest harvesting and ground based skidding may result in soil compaction and other soil structural changes, influencing soil water retention, and reducing soil aeration, drainage and root penetration (Froehlich et al., 1986). Soil damage on forest roads, skid roads and landings includes the removal of the organic layer and topsoil, soil compaction and erosion of the exposed soil. The soil damage affects hill slope infiltration and surface and subsurface flows (Binkley, 1986).

5. Conclusion

Sustainable forest management requires an adequate understanding not only of the forest ecosystem but also of the interaction between different disciplines. The planning process and finding the appropriate balance of different interests for the use of our forest and landscape resources will be vital to the achievement of the goal of sustainable forest management. The main purpose in the planning of forest roads is that, when the unfavorable effects of planned and constructed forest roads on the forest ecosystem are compared with the benefit to be derived from the roads constructed as a result of planning within the concept of sustainable forest management, such benefit must be within the acceptable limits. In this context, it has become evident that the density and road space criteria presently employed to provide each piece of a forest area with a systematic forest road network in order to enable it to fulfill its planned functions shall not be equally applicable to every area. In summary, it is recommended that the purposes of management of forests should be put forth in detail, and the road density and road space values to enable the realization of these purposes should be determined separately (Demir, 2007).

Roads affect both the biotic and the abiotic components of landscapes by changing the dynamics of populations of plants and animals, altering flows of materials in the landscape, introducing exotic elements, and changing levels of available resources, such as water, light and nutrients (Coffin, 2007).

In the recent years, an ever-increasing trend has been observed in public consciousness regarding environment. This has led to the creation of a medium of constant controversy between the foresters and environmentalists. The main issue of controversy is centered on the argument that the construction of forest roads destroys the natural environment to a great extent, causes soil erosion, completely destroys the habitat and impairs the integrity of landscape. As stated also in the declaration issued by UNCED (United Nations Conference on Environment and Development), the utilization of nature's renewable resources is a key component of development based on environment. It is, however, an essential requirement that access to relevant areas be provided for utilization of resources concerned. Therefore the construction of forest roads can in no case be abandoned. It follows, however, that relevant forestry organizations are obliged to figure out new ways that could be approved by the public and would cause no harm to the environment (Heinimann, 1996).

Coffin (2007) stated that roads have many direct ecological effects on adjacent aquatic and terrestrial systems, as network structures, they also have far reaching, cumulative effects

on landscapes (Riitters and Wickham, 2003). Some major effects to landscapes that directly relate to roads include the loss of habitat through the transformation of existing land covers to roads and road-induced land use and land cover change (Angelsen and Kaimowitz, 1999) and reduced habitat quality by fragmentation and the loss of connectivity (Theobald et al., 1997; Carr et al., 2002). Together they point to the larger issue of the synergistic effects of roads and road networks on ecosystems at broader scales (Forman et al., 2003).

In tropical forested areas, econometric models of land use and land cover change have revealed important relationships between biophysical and economic variables relative to roads. In rural areas, particularly in developing countries, the presence of roads has been most strongly correlated with processes of land cover change by facilitating deforestation (Chomitz and Gray, 1996; Angelsen and Kaimowitz, 1999; Lambin et al., 2001; Mertens and Lambin, 1997). There are a variety of different effects of roads in boreal, temperate, Mediterranean, tropical and sub-tropical or alpine forest ecosystems.

In this study, tried to give interactions of forest roads, forest harvesting and forest ecosystems. Furthermore, the study results were tried to give related to the subject in the world and Turkey. Despite the negative impacts of forest roads, forest harvesting and wood transports the realization of sustainable forestry on these structures, and studies are needed. Forest roads construction, forest harvesting and wood transports eliminating the negative effects to the realization of appropriate technique.

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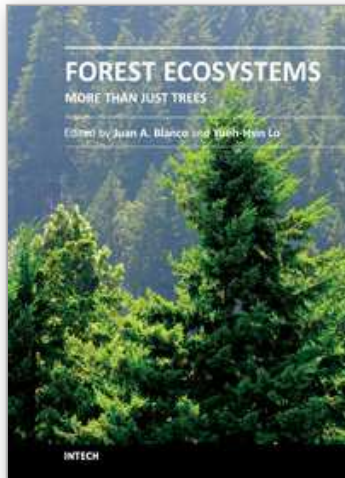
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The common idea for many people is that forests are just a collection of trees. However, they are much more than that. They are a complex, functional system of interacting and often interdependent biological, physical, and chemical components, the biological part of which has evolved to perpetuate itself. This complexity produces combinations of climate, soils, trees and plant species unique to each site, resulting in hundreds of different forest types around the world. Logically, trees are an important component for the research in forest ecosystems, but the wide variety of other life forms and abiotic components in most forests means that other elements, such as wildlife or soil nutrients, should also be the focal point in ecological studies and management plans to be carried out in forest ecosystems. In this book, the readers can find the latest research related to forest ecosystems but with a different twist. The research described here is not just on trees and is focused on the other components, structures and functions that are usually overshadowed by the focus on trees, but are equally important to maintain the diversity, function and services provided by forests. The first section of this book explores the structure and biodiversity of forest ecosystems, whereas the second section reviews the research done on ecosystem structure and functioning. The third and last section explores the issues related to forest management as an ecosystem-level activity, all of them from the perspective of the other parts of a forest.

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