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Impacts of repeated timber skidding on the chemical properties of topsoil, herbaceous cover and forest floor in an eastern beech (*Fagus orientalis* Lipsky) stand

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Abstract: *In this study, long-term timber skidding effects on herbaceous understory, forest floor and soil were investigated on a skid road in a stand of the eastern beech (Fagus orientalis Lipsky). For this purpose, herbaceous understory, forest floor and soil samples were collected from the skid road and from an undisturbed area used as a control plot. The mass (kg* ha^{-1}*) of herbaceous and forest floor samples was determined, and soil characteristics were examined at two depths (0-5 cm and 5-10 cm). We quantified sand, silt and clay content, as well as bulk density, compaction, pH, and organic carbon content in soil samples. The quantities of N, K, P, Na, Ca, Mg, Fe, Mn, Zn and Cu were determined in all herbaceous cover, forest floor and soil samples. The quantities of Na, Fe, Zn, Cu and Mn in herbaceous understory samples from the skid road were considerably higher than those in the undisturbed area, while the quantity of Mg was considerably lower. These differences could have been caused by decreased herbaceous cover in addition to variations in the properties of the forest floor and soil after skidding. A lower amount of forest floor on the skid road was the result of skidding and harvesting activities. Mg and Zn contents in forest floor samples were found to be considerably lower for the skid road than for the undisturbed area. No significant differences were found in soil chemical properties (quantities of N, P, K, Na, Ca, Mg, Fe, Zn, Cu and Mn) at the 0-5 cm soil depth. Important differences exist between soil quantities of Mg at a 5-10 cm depth on the skid road and in undisturbed areas. Both 0-5 cm and 5-10 cm soil depths, the average penetrometer resistance values for the skid road was higher than for the undisturbed area. This result shows that the compaction caused by skidding is maintained to depth of 10 cm. Skid road soil showed higher bulk density values than undisturbed areas because of compaction.*

Key words: *Harvesting, Skidding, Soil, Forest floor, Herbaceous understory*

Introduction

Forest roads are crucial for effective forest management, regardless of their purpose. Forest maintenance, wood harvesting, game control, and recreational activities all require accessibility from a suitable road network (Demir, 2007). Skidding or yarding on terrain requires the construction of a relatively dense network of forest roads, including skid roads, haul roads and landings (Ketcheson *et al.*, 1999). Skid roads are defined as secondary roads that are used by skidders, who move logs from the point of felling and bucking to log landings. Skid road networks are integral components of both managed forest stands and landscapes that include forests under management (Buckley *et al.*, 2003).

Disturbance: Forest harvesting has been found to decrease soil evapotranspiration, increase soil temperature and diurnal fluctuations in soil temperature and create a large amount of debris and dead roots that are easily decomposed by soil biota (Greacan and Sands, 1980; Lenhard, 1986; Williamson and Neilsen, 2003; Mariani *et al.*, 2006). In addition, forest harvesting machinery may cause soil compaction and uneven forest floor displacement or disturbances. Common site preparation practices such as removal of harvest residue and forest floor scalping as site preparation practices can affect site organic matter (OM) content and eventually soil porosity, the two ecosystem properties that are most likely to impact soil productivity in the long term. Logging operations can cause significant and wide-spread soil disturbances, including the removal, mixing and compaction of various soil layers. Disturbances can adversely affect both soil physical properties and soil nutrient levels to such an extent that severely diminished growth of subsequent tree rotations and a significant increase in runoff and sediment load may result. The extent and severity of harvesting impacts depend on a number of factors, such as inherent soil properties, topography, the type of operation (*i.e.*, whether the forest was selectively logged or clear-

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felled, ground-based or cable-logged) the type of machinery used, the number of machine passes, and the forest conservation practices being employed (Laffan *et al.*, 2001). Removal of organic matter (OM), compaction and erosion of organic and nutrient-rich surface soil decreases forest site productivity (Pritchett and Fischer, 1987). On the other hand, increased sediment loads, while the transport of sediments to streams and subsequent sedimentation may leads to alteration of a loss of stream habitats functions and altered stream hydrology.

Several studies have documented the changes of exchangeable soil cations after harvesting. In general, the results suggest that whole-tree harvesting may lead to the depletion of nutrient pools, although the results are somewhat ambiguous (Larsen, 2002; Mroz *et al.*, 1985; Olsson *et al.*, 1996a,b; Staaf and Olsson, 1994). The soil micro flora and fauna complement each other in the comminution of litter, the mineralization of essential plant nutrients, and the conservation of these nutrients within the soil system. Harvesting directly affects physical break-down of organic matter (OM) and nutrient mineralization through these processes through the reduction and redistribution of OM, compaction of soil, changes in plant cover, and modification of microclimates, all of which affect the distribution, composition and activity of soil biological communities (Marshall, 2000). The extent of disturbances resulting from ground-based timber harvesting systems varies with factors such as the slope and terrain, timber harvesting machines, methods of designating skid roads (SR), and harvesting seasons. Ground-based skidding may result in soil penetration resistance and other structural changes in the soil that influence soil water retention and reduce soil aeration, drainage, and root penetration (Froehlich *et al.*, 1986). Soil damage in forest roads, skid roads (SR) and landings includes the removal of the organic layer and topsoil, soil compaction, and erosion of the exposed soil. Soil damage affects hill slope infiltration and both surface and subsurface flow (Binkley, 1986). The degree of OM loss and soil compaction from the forest floor directly influences the weathering rates of minerals, nutrient mineralization rates and, consequently, plant growth rates (Arocena, 2000; Hendrickson *et al.*, 1989; Zabowski *et al.*, 1994).

The aim of this study was to examine the impacts of repeated timber skidding works that have been carried out for many years on plant cover and both forest floor and soil chemical properties on a skid road in a eastern beech (*Fagus orientalis* Lipsky) stand comprised of in the Istanbul Belgrad Forest in Turkey.

Materials and Methods

Belgrad Forest is located in the Istanbul province in the Marmara geographical region of Turkey, between latitude of 41°10' 90"– 41 11' 20" N and longitude of 28°15' 40"–29 10' 00" E, covering an area of 5441.71 ha. The study area was located within the boundaries of zone 64 of this forest. According to long-term data provided by the Bahcekoy Meteorology Station, the nearest meteorology station to the research area, the mean annual precipitation in this area is 1074.4 mm, while the mean annual temperature is 12.8°C, the mean maximum temperature is 17.8°C and the mean minimum temperature is 9°C. Istanbul Belgrad Forest's climate is thus similar to sea climate with medium water deficits in summers. On average, the vegetation period is 7.5 months (230 days) in length.

This study was conducted in September 2004 and the research area was comprised of a pure eastern beech (*Fagus orientalis* Lipsky) stand with a canopy cover of 0.8, an average tree diameter of 23.12 cm, an average tree height of 24.14 m, and a stand density of 1400 trees ha^{-1}. The average altitude of the research area was 140 m, and the slope was 10-15% with a southwest aspect. Dominant herbaceous vegetation species on the undisturbed area and skid road were *Hedera helix* L., *Ruscus aculeatus* L., *Ruscus hypoglossum* L., *Rubus* ssp., *Viola* ssp. L., *Galium odoratum* (L.)Scop., *Salvia forskahlei* L., and *Trachystemon orientale* (L.) G. Don. The skid road width is 3.0 m. The skid road (SR) passes through the stand in a west-east direction and has been used to skid the logs out of the area since 1956. It was estimated that 135 m^3 $year^{-1}$ of timber is harvested and skidded every year in harvesting activities on the skid road (SR) (Anonymous, 2005).

This study examined the impact of skidding on the forest floor, herbaceous cover and the surface soil layer (up to a 10 cm depth) by comparing these factors on the skid road (SR) and in an undisturbed area (UA). The SR and the UA were sampled at seven different points at 10 m intervals. For this purpose, seven samples were taken from herbaceous cover, forest floor, soil depths of 0-5 cm, and soil depths of 5-10 cm in areas at least 30 m away from the skid road where there was no direct skidding impact (at least one tree length away from the skid road edge).

Herbaceous cover samples were taken by cutting the above-ground parts of all plants in a 1 m^2 area on each sampling unit (SU). Forest floor samples were taken from a 0.25 m^2 area on each SU by collecting all of the forest floor down the mineral soil. Forest floor biomass calculation and chemical analysis were conducted the same procedure for herb samples. Forest floor and herbaceous samples were oven-dried for 24 hr at 65°C until they reached a constant weight, the weight values shown in the relevant tables of herbaceous cover, forest floor and were then ground and passed through a 1-mm mesh screen before undergoing chemical analysis. These samples were analyzed for total N using the semi-micro kjeldal method (Jackson, 1962) with Kjeltec Auto 1030 Analyzer equipment (Tecator, Sweden). For determination of P, K, Na, Ca, Mg, Fe, Mn, Cu, Zn, the samples were digested in a solution of HNO_3-HCl_4. K and Na concentrations were determined by flame photometry, while P was assessed using the vanado-molybdophosphoric yellow color method with Spectronic 20D spectrophotometer equipment, and Ca, Mg, Mn, Fe, Cu, Zn were analyzed with Perkin-Elmer 3110 atomic absorption spectrometer equipment (Kacar, 1972).

Soil penetration resistance was measured at the same locations where herbaceous cover and forest floor samples were taken, and was measured at two different soil depths (0-5 cm and 5-10 cm) using a pocket penetrometer. Two sets of soil samples were taken from 0-5 cm and 5-10 cm depths with the aid of 100 cm^3 steel soil cores. In total, 300 cm^3 of soil were taken for each sample at the two soil depths at each SU. All samples were collected in September 2004. All samples were put in polyethylene bags and labeled. Soil samples were dried at 105°C for 24 hr. The weight values shown in the relevant tables of soil samples are for oven-dried samples.

To determine the chemical properties, soil samples were air-dried, ground and sieved with a 2 mm screen before analysis. Particle size distribution was determined using the hydrometer method of Bouyoucos' (Bouyoucos, 1962), while the actual acidity was assessed using a pH meter with glass electrodes in 1/2.5 distilled water (Jackson, 1962), and soil organic carbon was determined using the wet combustion method of Wackley-Black (Wakley and Black, 1934). N was evaluated by the semi-micro kjeldal method (Jackson, 1962) using an Kjeltec Auto 1030 Analyzer (Tecator, Sweden) and P was assessed by the Bray and Kurtz No.1 method (Perkins, 1970) using a Spectronic 20D spectrophotometer. K^+, Na^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, and Mn^{2+} were evaluated by the ammonium acetate method (Jackson, 1962) using a Jenway PFP 7 flame photometer for K^+ and Na^+, and a Perkin-Elmer 3110 atomic absorption spectrometer for Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}. Cu^{2+} and Zn^{2+} were determined using the double-acid ($HCl+H_2SO_4$) method with Perkin-Elmer 3110 atomic absorption spectrometer equipment (Perkins, 1970).

The observed values for each of these chemical properties in the undisturbed area and on the skid road were compared statistically at a 0.05 significance level with independent samples t-tests. Statistical analysis were made by SPSS software. The mean values for all properties are shown in the relevant tables.

Results and Discussion

Properties of herbaceous cover: The total herbaceous biomass on UA was about 3.6 times greater than that of SR, as shown in Table 1 (Demir *et al.*, 2007a). There were no significance differences in N, P, and K content. Compaction of topsoil on the SR might cause the area to be less suitable for germination and rooting of herbaceous vegetation, thus leading to decreased density of herbaceous cover in comparison to the UA.

N, P, K and Ca concentrations of herb were similar between the sites. However herb on the SR had 63% higher Na and 66% higher Cu than that of UA. Herb's Fe, Zn, Mn concentrations on the SR were also more than 13, 2 and 2.5 higher than those of UA, respectively. Only Mg concentration of herb on the SR was 26% lower than that of the UA. (Table 1). The reduced herbaceous cover on the SR indicates a lower density of plants and accordingly, the area per plant on the SR was higher than in the undisturbed area. The larger area per plant could have been the result of increased nutrient content in plant tissues. The lower Mg content could have been due to lower Mg concentration in the soil on the skid road, or antagonistic effects between Mg and Mn (Kacar and Katkat, 1998). Changes in the physical and chemical properties of the soil after skidding and decreased amounts of herbaceous cover or forest floor could also cause these variations. Increased herbaceous cover would increase the competition for nutrients. Several other reports have described the effects of skidding on herbaceous cover (Buckley *et al.*, 2003; Godefroid and Koedam, 2004; Gilliam, 2002; Johnston and Johnston, 2004; Nugent *et al.*, 2003).

Table - 1: Properties of herbaceous cover

Characteristics	Unit	SR	UA	Asymp. Sig. 2-tailed	
Herbaceous mass	(kg ha^{-1})	216.87^a	780.45^b	0.000	***
N	(%)	2.100^a	1.982^a	0.568	NS
P	(ppm)	150.99^a	132.10^a	0.391	NS
K	(ppm)	9898.63^a	7774.20^a	0.475	NS
Na	(ppm)	178.15^a	109.64^b	0.015	*
Ca	(ppm)	13555.61^a	17263.74^a	0.317	NS
Mg	(ppm)	2148.58^a	2913.03^b	0.015	*
Fe	(ppm)	3168.51^a	232.13^b	0.003	**
Zn	(ppm)	74.89^a	36.19^b	0.010	*
Cu	(ppm)	16.58^a	9.98^b	0.015	*
Mn	(ppm)	1619.77^a	635.25^b	0.003	**

(SR: Skid road. UA: Undisturbed area. Values shown are means. Significance levels are grouped as NS non significant, *0.05-0.01, **0.01-0.001 and ***>0.001, values in "SR" and "UA" columns followed by the same letter are not statistically different at 0.05 significance level)

Table - 2: Forest floor properties

Characteristics	Unit	SR	UA	Asymp. Sig. 2-tailed	
Forest floor mass	(kg ha^{-1})	7935.86^a	13577.30^b	0.014	*
N	(%)	1.326^a	1.551^a	0.064	NS
P	(ppm)	61.49^a	65.40^a	0.655	NS
K	(ppm)	1382.57^a	1604.26^a	0.482	NS
Na	(ppm)	126.90^a	129.03^a	0.949	NS
Ca	(ppm)	14753.91^a	16244.59^a	0.406	NS
Mg	(ppm)	2131.09^a	2603.30^b	0.035	*
Fe	(ppm)	6438.86^a	9011.96^a	0.406	NS
Zn	(ppm)	84.86^a	109.00^b	0.002	**
Cu	(ppm)	19.10^a	24.39^a	0.110	NS
Mn	(ppm)	3188.14^a	3112.47^a	0.949	NS

(SR: Skid road. UA: Undisturbed area. Values shown are means. Significance levels are grouped as: NS non significant, *0.05-0.01, **0.01-0.001 and ***>0.001, values within the "SR" and "UA" columns followed by the same letter are not statistically different at 0.05 significance level)

Properties of the forest floor: The mean forest floor mass was higher in the undisturbed area (13577.30 kg ha^{-1}) than on the skid road (7935.86 kg ha^{-1}) (Table 2). UA's forest floor mass 2 times higher than that of SR's forest floor. The lower mass of the forest floor on the skid roads indicates that the forest floor has diminished due to skidding works. In addition, some of the trees along the skidding route were cut during the opening of the SR to ensure easy transportation and skidding of the harvested timbers. This might have resulted in a lower tree density along the SR as compared to the UA. The decreased forest floor mass on the SR might have also been the result of a smaller number of trees (Demir *et al.*, 2007a). There were no significant differences in soil chemical properties (N, P, K, Na, Ca, Mg, Fe, Zn, Cu and Mn) at depths of 0-5 cm.

Table - 3: Soil properties investigated at depths of 0-5 cm.

Characteristics	Unit	SR	UA	Asymp. Sig. 2-tailed	
Sand	(%)	58.04^{a}	58.96^{a}	0.744	NS
Silt	(%)	20.74^{a}	22.29^{a}	0.530	NS
Clay	(%)	21.21^{a}	18.74^{a}	0.257	NS
pH	pH	5.49^{a}	5.74^{a}	0.431	NS
Bulk density	(g cm^{-3})	0.903^{a}	0.797^{b}	0.042	*
Penetrometer resistance	(kg cm^{-2})	2.17^{a}	1.32^{b}	0.000	***
Organic carbon	(%)	10.20^{a}	11.50^{a}	0.209	NS
N	(%)	0.358^{a}	0.289^{a}	0.180	NS
P	(ppm)	3.83^{a}	4.40^{a}	0.749	NS
K	(ppm)	105.41^{a}	142.05^{a}	0.655	NS
Na	(ppm)	19.21^{a}	19.63^{a}	0.443	NS
Ca	(ppm)	1706.44^{a}	1638.22^{a}	0.949	NS
Mg	(ppm)	263.52^{a}	331.67^{a}	0.225	NS
Fe	(ppm)	1.11^{a}	0.83^{a}	0.798	NS
Zn	(ppm)	112.71^{a}	72.43^{a}	0.110	NS
Cu	(ppm)	0.86^{a}	0.91^{a}	0.608	NS
Mn	(ppm)	250.83^{a}	179.85^{a}	0.110	NS

(SR: Skid road. UA: Undisturbed area. Values shown are means. Significance levels are grouped as: NS non significant, *0.05-0.01, **0.01-0.001 and ***>0.001, values within the "SR" and "UA" columns followed by the same letter are not statistically different at 0.05 significance level)

Table - 4: Soil properties investigated at depths of 5-10 cm

Characteristics	Unit	SR	UA	Asymp. Sig. 2-tailed	
Sand	(%)	51.33^{a}	64.08^{b}	0.011	*
Silt	(%)	30.88^{a}	21.54^{b}	0.012	*
Clay	(%)	17.77^{a}	14.37^{a}	0.216	NS
pH	pH	5.07^{a}	5.33^{a}	0.311	NS
Bulk density	(g cm^{-3})	1.09^{a}	0.951^{b}	0.009	**
Penetrometer resistance	(kg cm^{-2})	2.69^{a}	1.79^{b}	0.000	***
Organic carbon	(%)	7.32^{a}	9.30^{a}	0.098	NS
N	(%)	0.198^{a}	0.212^{a}	0.406	NS
P	(ppm)	1.08^{a}	1.65^{a}	0.136	NS
K	(ppm)	54.72^{a}	85.91^{a}	0.085	NS
Na	(ppm)	15.90^{a}	17.75^{a}	0.096	NS
Ca	(ppm)	579.13^{a}	940.96^{a}	0.180	NS
Mg	(ppm)	143.85^{a}	252.17^{b}	0.009	**
Fe	(ppm)	0.74^{a}	0.84^{a}	0.608	NS
Zn	(ppm)	37.86^{a}	37.86^{a}	1.000	NS
Cu	(ppm)	1.19^{a}	1.22^{a}	0.654	NS
Mn	(ppm)	188.72^{a}	155.55^{a}	0.277	NS

(SR: Skid road. UA: Undisturbed area. Values shown are means. Significance levels are grouped as: NS non significant, *0.05-0.01, **0.01-0.001 and ***>0.001, values within the "SR" and "UA" columns followed by the same letter are not statistically different at 0.05 significance level)

Forest floor on the SR had 22% Mg and 28% Zn lower concentrations than that of UA, respectively (Table 2). This might lead to reduced uptake of Mg by plants, and consequently less Mg in the litterfall. Decreases in the Mg and Zn content of the forest floor could be attributed to skidding-induced compaction of soil and to mineralization and humidification with changing microclimate conditions and affected soil organisms. Skidding and logging works have shown different effects on the forest floor according to various studies (Arocena, 2000; Ballard, 2000; Bengtsson *et al.*, 1998; Jacobson *et al.*, 2000; Johnston and Johnston, 2004; Marshall, 2000; Rab, 2004).

Soil properties: No significant differences were found between the UA and SR in the investigated soil properties (sand, clay, silt, and pH) and in the organic carbon content for samples from depths of 0-5 cm (Table 3).

The lack of a significant difference between the skid road and the undisturbed area in terms of mean organic carbon content might suggest the absence of organic matter from the skid road. The lack of organic carbon content might also have been caused be the slow decomposition of the beech forest floor, which has been previously suggested for Belgrad Forest (Irmak and Cepel, 1968; Kantarci, 1987). Slow decomposition of the beech forest floor and high forest floor content per unit area could prevent the loss of soil organic C from the long-term effects of skidding on the road. The lack of significant differences between the skid road and the undisturbed area with regard to sand, silt and clay content in the soil at depths of 0-5 cm might have arisen from a lack of carrying on the skid road by skidding. The forest floor protects the soil against erosion and during skidding. The mean penetrometer resistance value was 60% higher for the skid road (2.17 kg cm^{-2}) than the undisturbed area (1.32 kg cm^{-2}) (Table 3).

Soil at depths of 0-5 cm is compacted to a great extent after skidding. Soil bulk density of the SR was about 13% higher than that of the UA (Table 3). Thus, skiding of harvesting materials for many years resulted an apparent soil compaction on the designated SR (Demir *et al.*, 2007a). However, soil nutrient analysis did not reveal a significant differences between the sites. Significant differences were not found for many of the chemical properties of the soil (N, P, K, Na, Ca, Mg, Fe, Zn, Cu and Mn) collected at depths of 0-5 cm. The lack of differences in these properties was likely caused by the existence of the forest floor on the SR, although the amount of forest floor was significantly less than in the UA. However, the decreased amount of forest floor did not prevent the compaction of the top soil. There were no significant differences in soil samples between the SR and the UA at depths of 0-5 cm in terms of chemical properties, probably because the skid road was covered by trees and litter fall, and because of the slow decomposition of beech forest floor.

There were significant differences between the skid road and the undisturbed area with respect to sand and silt percentages in soil samples at a 5-10 cm depth as shown in Table 4. Similar to the findings at the 0-5 cm soil depth, the average penetrometer resistance value for the SR was higher 50% than that the UA. This result shows that the compaction caused by skidding is maintained to depth of 10 cm. Skid road soil showed higher bulk density values than undisturbed areas because of compaction (Table 4).

Contrary to the findings at depths of 0-5 cm, the content of sand and silt was different between the SR and the UA. The sand percentage of the SR was 24% lower than that the UA; however, the silt percentage of the SR was 43% higher than that the UA. This significant difference might have resulted from compaction-induced mixing of different textured soils. No significant differences in soil properties were observed between the skid road and the undisturbed area with respect to clay and pH (Table 4) (Demir *et al.*, 2007a).

Similar skidding and harvesting works in forestry operations such as skidding and harvesting generally result in increase the soil compaction. Despite our findings at both soil depths, it is generally claimed that skidding causes a decrease in the organic matter content of the soil (Arocena, 2000; Ballard, 2000; Bengtsson *et al.*, 1998; Buckley *et al.*, 2003; Croke *et al.*, 2001; Godefroid and Koedam, 2004; Horn *et al.*, 2004; Jacobson *et al.*, 2000; Ilstedt *et al.*, 2004; Laffan *et al.*, 2001; Nugent *et al.*, 2003; Rab, 2004; Rohand *et al.*, 2004; Xu *et al.*, 2002; Williamson and Nielsen, 2003). In the current study there was a significant difference between soil samples taken from the SR and the UA depths of 5-10 cm with respect to Mg concentrations. As shown in Table 4, the sand content decreased while the silt content increased on the SR; thus texture became finer. There were no significant differences for other soil chemical properties, similarly to the results obtained for soil depths of 0-5 cm (Table 4).

Long-term skidding activities in beech stands of *Fagus orientalis* Lipsky in Istanbul's Belgrad Forest have caused a significant decrease in the amount of forest floor and herbaceous cover on a SR. Furthermore, there were important changes in soil properties at the two examined soil depths (0-5 and 5-10 cm). The major effect observed at soil depths up to 10 cm was the soil penetration resistance. Higher volume and fine soil weight values were found at both soil depths for the SR as compared to the UA, indicating soil penetration resistance. Regeneration operations and development are affected negatively by soil penetration resistance, which also hinders the uptake of nutrients and water and subsequently slows root growth (Jacobson *et al.*, 2000; Marshall, 2000; Messina *et al.*, 1997; Wang, 1997; Williamson and Neilsen, 2003). Inadequate physical conditions resulting from soil penetration resistance impede soil organism and microorganism activity, and eventually cause decreases in decomposition (Bengtsson *et al.*, 1998; Marshall, 2000). Some of the results of this study were in agreement with previous studies, while other results differed from those found in previous research. The present results and previous reports show that the long-term effects of skidding on the chemical properties of topsoil, forest floor and herbaceous understory are complex and varied with respect to the research site and forest stand type (Buckley *et al.*, 2003; Demir *et al.*, 2007a; Demir *et al.*, 2007b; Gilliam, 2002; Godefroid and Koedam, 2004; Jacobson *et al.*, 2000; Johnston and Johnston, 2004; Mariani, 2006; Marshall, 2000; Makineci *et al.*, 2007; Nugent *et al.,* 2003;). Long-term skidding activities therefore resulted in a loss of herbaceous cover and forest floor in the studied beech stand. Skidding activities were also shown to compact the topsoil to a great extent. It is clear that compaction has negative effects on the water and air balance of the soil. Decreases in the amount of forest floor and herbaceous cover can negatively affect forest ecosystems (by decreasing the activities of soil organisms, erosion, etc.). Various protection and rehabilitation techniques can be tried to counter these effects. Attaching a conical skid cap at the end of the timber that is being skidded or using slides may prevent or lessen the negative impact to SR, and could prevent losses of forest floor and herbaceous understory due to soil penetration resistance (Demir *et al.*, 2007b; Ilstedt *et al.*, 2004; Kolka and Smidt, 2004; Makineci *et al.*, 2007; Pinard *et al.*, 2000). Avoiding the long-term use of SR may also decrease these effects.

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