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Harvesting impact on herbaceous understory, forest floor and top soil properties on skid road in a beech (*Fagus orientalis* Lipsky) stand

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Abstract: *In this study, the impact of production work on the skid roads that have been carried out for many years by manpower, animal power or machinery in a beech (Fagus orientalis Lipsky) stand have been examined. For this purpose, herbaceous understory, forest floor and soil samples were collected from the undisturbed area and the skid road. Weight per unit area (kg ha^{-1}), organic matter ratio and moisture of forest floor and herbaceous understory were measured in undisturbed area and the skid road. Soil characteristics were examined at two different depths (0-5 cm and 5-10 cm). Percentages of sand, silt and clay, electrical conductivity, weight of fine soil (<2mm), soil fraction (>2mm), root mass, organic carbon, moisture equivalent, total porosity, bulk density, moisture, compaction and pH values in the soil were determined. It has been determined that the amount of herbaceous understory and forest floor on the skid road decreased considerably compared to those of the undisturbed area. Parallel to this, the amount of organic matter in the herbaceous understory and the forest floor on the skid road decreased as well. It has been concluded that there are crucial differences between the values of compaction, bulk density, fine soil weight, total porosity and moisture equivalent of the soil samples collected from both the skid road and the undisturbed area at both depth levels, as a result of compaction of the soil caused by harvesting works.*

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

Introduction

Production work being carried out in the forest have many negative impact on the forest ecosystem is well known. It has also been determined that the production and 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; Buckley *et al.*, 2003; Gilliam, 2002; Godefroid and Koedam, 2004; Johnston and Johnston, 2004; Marshall, 2000; Messina *et al.*, 1997; Wang, 1997; Williamson and Neilsen, 2003). Skidding or yarding on terrain requires the construction of relatively dense network of forest roads including skid roads, haul roads and landings (Ketcheson *et al.*, 1999; Swift, 1988). Logging operations can cause significant and wide spread soil disturbance, including removal, mixing and compaction of the various soil layers. 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 leads to loss of stream habitat and altered stream hydrology. The soil micro flora and fauna complement each other in the comminution 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. 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).

In this study, the impact on the herbaceous understory, forest floor and soil properties in a beech stand (*Fagus orientalis* Lipsky) caused by production work on the skid roads have been researched.

Materials and Methods

Research area is in the boundaries of zone 82 of Istanbul Belgrad forest. Belgrad forest covering a surface area of 5441.71 ha is located in the Marmara geographical region between latitudes 41°09'-41°12'N and longitudes 28°54'-29°00'E (Fig. 1).

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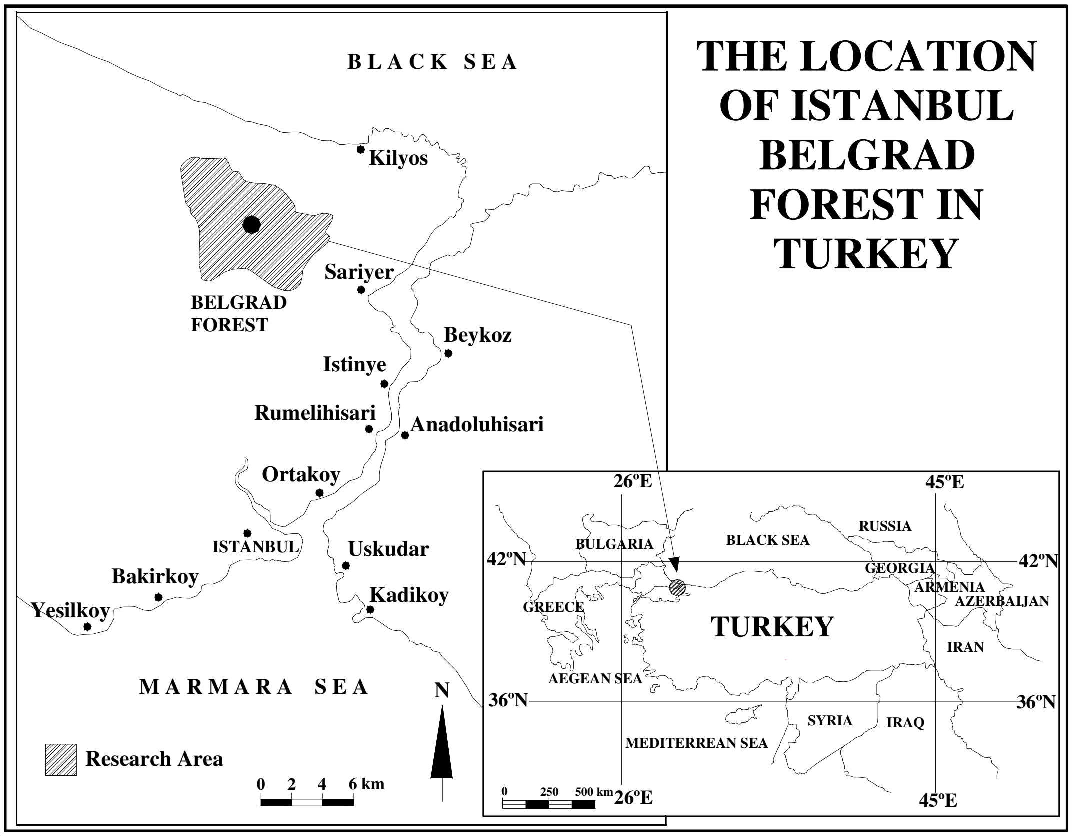

Fig. 1: The location of Istanbul Belgrad Forest in Turkey

According to the data given by Bahcekoy meteorology station, average annual precipitation is 1074.4 mm, average annual temperature is 12.8°C, average high temperature is17.8°C and the average low temperature is 9°C. The climate of Istanbul Belgrad Forest is close to sea (ocean) climate with medium water deficit in summers. Vegetation period maintains for 7.5 months (230 days) in average.

The period of study is September 2004 and research area is oriental beech (*Fagus orientalis* Lipsky) stand having canopy cover as 0.8, average diameter as 23.12 cm, average height as 24.14 m and stand density as 1400 trees/ha. Average altitude of the research area is 140 m, slope is 10-15% with SW aspect. Dominant herbaceous vegetation species on the undisturbed area and skid road are *Hedera helix* L., *Ruscus aculeatus* L., *Ruscus hypoglossum* L., *Rubus* sp., *Viola* sp., *Galium odoratum* (L.) Scop., *Salvia forskahle* L. and *Trachystemon orientale* (L.) G.Don. The skidding road passing through the stand in West-East direction has long been used (since 1956) to skid the logs out of the area. It was estimated that 135 m^3 timbers was skidded annually in harvest activities on the skid road. The harvested timbers are also being towed by tractors with a rope along with skidding by means of manpower and animals. To examine the impact of skidding on the skid road, the forest floor, herbaceous understory and the upper soil layer (down to 10 cm depth) in comparison with the undisturbed stand, the skid road was sampled at 7 different points at 10 m intervals (7 samples were taken from each of herbaceous understory, forest floor, 0-5 cm soil and 5-10 cm soil). Soil samples from 7 different points were taken again at 10 m intervals (from each of the herbaceous understory, forest floor, 0-5 cm soil and 5-10 cm soil) from the undisturbed area protected from skidding at least 25-30 m away from the skid road (at least one tree length away to ensure prevention of side impact). Herbaceous understory samples were taken by cutting above ground parts of all herbaceous understory in 1 m^2 area and the samples of the forest floor were taken from 0.25 m^2 area by collecting all the forest floor in that area. Soil compaction at the places where herbaceous understory and forest floor samples were taken was measured at 0-5 cm and 5-10 cm depths by using a pocket penetrometer. Soil samples were taken from 0-5 cm and 5-10 cm with the aid of 100 cm^3 steel soil cylinders. A total of 300 cm^3 soil sample was taken for each of the sampling points. All samples were collected in September 2004. All samples were put in polyethylene bags and labeled. Samples brought to the laboratory from the research area were promptly weighed (within one hour) and percentage of moisture and weight of oven dried samples were calculated from the difference between the values of wet and oven dried samples after making the herbaceous understory samples dried under 65°C and forest floor and soil samples dried under 105°C for twenty four hour in an oven. Organic matter amount were found by loss on ignition method after grinding and burning under 550°C the herbaceous understory and forest floor samples. Soil samples were sieved through 2 mm sieves and thus, fine soil (<2mm), root (roots were weighed after rinsing with distilled water and dried under 105°C for 24 hr) and coarse soil fraction (>2mm) weights were found. Texture (by Bouyoucos hydrometer method), organic carbon (by Walkley and Black wet digestion method), bulk density, total porosity, moisture equivalent, pH and electrical conductivity values were measured in the laboratory (Karaoz, 1989a, 1989b, 1992).

The values for the undisturbed area and the skid road were compared statistically at $p<0.05$ significance level by using independent sample t test.

Results and Discussion

Properties of herbaceous understory: Above ground amount of the total herbaceous understory was 216.87 kg ha^{-1} on the skid road and 780.45 kg ha^{-1} in the undisturbed area (Table 1). The undisturbed area had approximately 3 times larger herbaceous understory than that of the skid road. Decrease in the amount of herbaceous understory on the skid road points out that the harmful impacts of skidding has dropped such amount. Furthermore, properties of the changed forest floor after skidding as well as the soil properties may be effective on the decrease of the herbaceous understory. As for the mean moisture values of the herbaceous understory, the moisture ratio (81.43%) of the herbaceous understory on the skid road was higher compared to the undisturbed area (67.78%) (Table 1). It is anticipated that the herbaceous species found on the skid road are of a kind that is not affected by the spoiled soil properties which, at the same time, are capable of developing deeper roots; these species might have a higher rate of moisture by using the soil moisture in deeper layers. Nevertheless, existence of more herbaceous understory in the undisturbed area might be effective as it will raise moisture competition (Buckley *et al.*, 2003; Gilliam, 2002; Godefroid and Koedam, 2004).

The mean organic matter content in the undisturbed area (85.63%) was considerably higher than that of the skid road (81.42%) (Table 1). Subject to the notable differences between the organic matter content and herbaceous understory amounts, the organic matter amount in unit area (kg ha^{-1}) was higher in the undisturbed area (669.81 kg ha^{-1}) (Table 1). The reason why the skid road had a higher content of organic matter is more likely because of the different herbaceous species on the skid road and in the undisturbed area. Many similar researches have set the negative impact of skidding on the herbaceous understory (Buckley *et al.*, 2003; Gilliam, 2002; Godefroid and Koedam, 2004; Johnston and Johnston, 2004; Nugent *et al.*, 2003).

Properties of forest floor: Mean forest floor weight in unit area has been found considerably higher in the undisturbed area (13577.30 kg ha^{-1}) than the skid road (7935.86 kg ha^{-1}) (Table 2). Less forest floor on the skid roads shows that the forest floor has decreased because of carrying caused by skidding. In addition, some of the trees along the skidding route were cut during opening of the skid roads to ensure easy transportation and skidding of the harvested timbers. This might have result in less populated trees along the skid roads compared to the undisturbed area. Subject to less dense stand, decreasing of the falling forest floor may be another factor of the decreasing forest floor on the skid road. Average organic matter content of the forest floor along the skid road (61.03%) has been found less than that of the undisturbed area (71.25%); however, statistically this difference was not significant (Table 2). The forest floor mean organic matter amount (9985.86 kg ha^{-1}) in the unit area of the undisturbed area was seriously higher subject to the differences in the total forest floor weight (Table 2). While the average forest floor moisture content in the undisturbed area was 37.27%, the moisture content on the skid road was 25.20% (Table 2). The forest floor in the undisturbed area had considerably higher moisture content than the skid road. The reason why the forest floor along the skid road had less moisture content must be, more likely, because of less stand density and subject to the decreasing herbaceous understory, increase in evaporation because of being exposed to more intense sunlight as a result of the decreasing skid road cover. Moreover, likely impacts of skidding on the forest floor structure might be an effective factor on the forest floor moisture along with the decreasing forest floor. Impacts of skidding and production works on the forest floor give similar results in many researches (Arocena, 2000; Ballard, 2000; Bengtsson *et al.*, 1998; Jacobson *et al.*, 2000; Johnston and Johnston, 2004, Marshall, 2000; Rab, 2004).

Table - 1: Some properties of herbaceous understory

Characteristics	Unit	Skid road	Undisturbed	Asymp. sig.2-tailed
Herbaceous mass	(kg ha^{-1})	216.87[a]	780.45[b]	0.000***
Moisture	(%)	81.43[a]	67.78[b]	0.002*
Organic matter	(%)	81.42[a]	85.63[b]	0.045*
Organic matter	(kg ha^{-1})	178.07[a]	669.81[b]	0.000***

(Values are mean. Sample no.=7, significance levels are *p<0.05-0.01, ***p<0.001>, values within columns followed by the same letter are not statistically different at p<0.05 significance level)

Table - 2: Some properties of forest floor

Characteristics	Unit	Skid road	Undisturbed	Asymp. sig.2-tailed
Forest floor mass	(kg ha^{-1})	7935.86[a]	13577.30[b]	0.014*
Moisture	(%)	25.20[a]	37.27[b]	0.009**
Organic matter	(%)	61.03[a]	71.25[b]	0.179[N.S.]
Organic matter	(kg ha^{-1})	4534.29[a]	9985.86[b]	0.011*

(Values are mean. Sample no.=7, significance levels are NS = non significant, *p<0.05-0.01, **p<0.01-0.001, values within columns followed by the same letter are not statistically different at p<0.045 significance level)

Soil properties :

0-5 cm depth: Some of the soil properties analyzed in 0-5 cm deep soil samples such as sand, silt and clay percentage, pH, electrical conductivity, organic carbon percentage and moisture percentage do not show significant differences between the undisturbed area and the skid road (Table 3). The fact that there is not an important difference between the skid road and the undisturbed area in terms of mean organic carbon content may be interpreted as there is not any organic matter being carried on the skid road. Another reason for this must be the slow decomposition of the beech forest floor (Irmak and Cepel, 1968; Kantarci, 1987). This slow decomposition of the beech forest floor in Belgrad forest was put forward beforehand (Irmak and Cepel, 1968). Slow decomposition of beech forest floor and higher forest floor content per unit area compared to other general may be a preventive factor for organic matter losses in the soil against the long term skidding effects on the skid road. Nonexistence of any difference with regard to sand, silt and clay percentages in the soil at 0-5 cm depth on the skid road and in the undisturbed area may be interpreted as there is not any carrying on the skid road. This is largely because of the forest floor's protection of the soil against erosion and carrying during skidding. Mean compaction value on the skid road was 2.17 kg cm^{-2} and 1.32 kg cm^{-2} in the undisturbed area (Table 3). 0-5 cm soil depth has been compacted to a great extent after skidding. Considerably higher bulk density (902.66 g dm^{-3}) and fine soil weight (763.13 g dm^{-3}) values were found on the skid road compared to the undisturbed area (Table 3). Similarly, the total porosity (52.72%) and moisture equivalent (24.37%) values decreased considerably due to compaction on the skid road. Average root mass (5.59 g dm^{-3}) in the undisturbed area has been found higher than the value on the skid road (2.76 g dm^{-3}) (Table 3). Reasons such as compaction of soil on the skid road, decreasing porosity and moisture equivalent as well as existence of less herbaceous understory might be effective in having fewer roots. The coarse soil fraction (>2mm) (214.58 g dm^{-3}) in the undisturbed area has been found higher than the one in the skid road (137.16 g dm^{-3}) (Table 3). The reason for this difference is anticipated as the impact of the compaction on the skid road and changing the soil structure.

Table - 3: Investigated soil properties in 0-5 cm soil depth

Characteristics	Unit	Skid road	Undist-urbed	Asymp. sig.2-tailed
Sand	(%)	58.05^a	58.96^a	0.744$^{N.S.}$
Silt	(%)	20.74^a	22.29^a	0.530$^{N.S.}$
Clay	(%)	21.21^a	8.75^a	0.257$^{N.S.}$
pH		5.49^a	5.74^a	0.431$^{N.S.}$
Electrical conductivity	(µmhoS cm^{-1})	81.32^a	87.05^a	0.642$^{N.S.}$
Fine soil (<2mm)	(g dm^{-3})	763.13^a	578.02^b	0.008**
Coarse soil (>2mm)	(g dm^{-3})	137.16^a	214.58^b	0.024*
Root mass	(g dm^{-3})	2.76^a	5.59^b	0.005**
Organic carbon	(%)	10.20^a	11.50^a	0.209$^{N.S.}$
Moisture equivalent	(%)	24.37^a	26.94^b	0.000***
Total porosity	(%)	52.72^a	59.21^b	0.002**
Moisture	(%)	20.86^a	20.05^a	0.778$^{N.S.}$
Compaction	(kg cm^{-2})	2.17^a	1.32^b	0.000***
Bulk density	(g dm^{-3})	902.66^a	796.80^b	0.042*

(Values are mean. Sample no.=7, significance levels are NS non significant, *p<0.05-0.01, **p<0.01-0.001 and ***p<0.001>, values within columns followed by the same letter are not statistically different at p<0.05 significance level)

5-10 cm depth: An important difference as regards to sand, silt percentages, <2mm soil fraction, moisture equivalent, total porosity, compaction and bulk density at 5-10 cm soil depth (Table 4) was recorded. Similar to the findings in the 0-5 cm soil depth, the average compaction value on the skid road (2.69 kg cm^{-2}) was considerably higher than the one in the undisturbed area (1.79 kg cm^{-2}). This shows that the compaction created by skidding maintains down to 10 cm depth. And because of this, higher bulk density and fine soil weight values, and lower total porosity and moisture equivalent were found on the skid road compared to the undisturbed area. Contrary to the findings at 0-5 cm depth, it has been observed that there were important differences between the values of sand and silt percentage of the skid road and the undisturbed area. The sand percentage on the skid road (51.35%) was lower than in the undisturbed area (64.09%); however, the mean silt (30.88%) on the skid road was higher than the undisturbed area (21.54%). It is also estimated change in the soil structure may be the cause of the differences in the <2mm soil fraction on the skid road and in the undisturbed area. No important differences could be found at 5-10 cm soil depth with respect to root mass.

It has been concluded that the higher amount of forest floor in the undisturbed area causes more surface root development. The organic carbon content of the skid road (7.32%) and the undisturbed area (9.30%) at 5-10 cm depth did not differ significantly. Significant differences between the skid road and the undisturbed area could not be found with regard to (clay %, pH and electrical conductivity) (Table 4). Similar skidding and harvesting works in the forestry applications generally increase the compaction in the soil. Crucial alterations in the physical factors that affect higher bulk density of the soil, lower porosity and water holding that source from compaction of the soil may take place. Despite our findings at both soil depths, it is generally claimed that the skidding works cause decreasing of organic matter amount in 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 Neilsen, 2003).

Table - 4: Investigated soil properties in 5-10 cm soil depth

Characteristics	**Unit**	**Skid road**	**Undist-urbed**	**Asymp. sig.2-tailed**
Sand	(%)	51.35[a]	64.09[b]	0.011*
Silt	(%)	30.88[a]	21.54[b]	0.012*
Clay	(%)	17.77[a]	14.37[a]	0.216[N.S.]
pH		5.07[a]	5.33[a]	0.311[N.S.]
Electrical conductivity	(µmhoS cm^{-1})	48.02[a]	58.55[a]	0.099[N.S.]
Fine soil (<2mm)	(g dm^{-3})	906.55[a]	762.00[b]	0.031**
Coarse soil (>2mm)	(g dm^{-3})	147.15[a]	183.18[b]	0.213[N.S.]
Root mass	(g dm^{-3})	2.79[a]	4.02[b]	0.601[N.S.]
Organic carbon	(%)	7.32[a]	9.30[a]	0.098[N.S.]
Moisture equivalent	(%)	24.44[a]	26.23[b]	0.002**
Total porosity	(%)	50.22[a]	57.77[b]	0.001**
Moisture	(%)	18.73[a]	18.36[b]	0.818[N.S.]
Compaction	(kg cm^{-2})	2.69[a]	1.79[b]	0.000***
Bulk density	(g dm^{-3})	1090.34[a]	950.88[b]	0.009**

(Values are mean. Sample No.=7, Significance levels are NS non significant, *p<0.05 - 0.01, **p<0.01-0.001 and ***p<0.001>, values within columns followed by the same letter are not statistically different at p<0.05 significance level)

The skidding works that have been carried on for many years in beech (*Fagus orientalis* Lipsky) stand caused decreasing of the forest floor and the herbaceous understory on the skid road to a great extent. Furthermore, there were some other important changes in the soil properties at the two examined soil depths (0-5 cm and 5-10 cm). The major impact that occurred down to 10 cm soil depth was the compaction of soil. Higher volume and fine soil weight values compared to those of the undisturbed area were found at both the depths on the skid road subject to the soil compaction. The total porosity and moisture equivalence on the skid road decreased considerably. As a result of decreasing of water permeability and blocking of drainage in the compacted soils, the water pools on the flat ground surface disappears through evaporation.

Reforestation works and youth development in the compacted soils are negatively affected and root development, water and nutrient intake is prevented.

As a result, the long term skidding works carried out in the beech stand caused herbaceous understory and forest floor losses on the skid road. Moreover, skidding has caused compaction of the soil to a great extent. Spoiling of soil properties along with the considerable decrease in the herbaceous understory and the forest floor amounts can cause a lot of negative impacts on the forest ecosystem (such as decrease in the soil organism activities, erosion *etc.*). For this reason, rehabilitation of negative characteristics of the current skid roads is recommended. Besides these, different protection and rehabilitation techniques can also be tried. Additionally, in order to prevent and lessen such negative impacts that occur on the skid roads and to prevent the forest floor and the herbaceous understory losses in the soil caused by compaction, attaching a conical skid cap at the end of the timber that is being skidded or usage of slides may decrease the damages. Nonetheless, long-term utilization of the same skid road increases the damages more. Therefore, avoiding long-term utilization of skid roads may decrease the damages to occur.

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