Disturbance to Outer Soil Layers Depending on the Season of Timber Harvesting

DARIUSZ KULAK*, ARKADIUSZ STAŃCZYKIEWICZ AND GRZEGORZ SZEWCZYK

University of Agriculture in Krakow, Institute of Forest Utilization and Forest Technology, Department of Forest and Wood Utilization

Al. 29 Listopada 46 / 31-425 Krakow / Poland; tel./ phone: +48126625092 / fax: +48124124418 / e-mail: rlkulak@cyf-kr.edu.pl

Kulak, D., Stańczykiewicz, A. and Szewczyk, G. 2019. Disturbance to Outer Soil Layers Depending on the Season of Timber Harvesting. *Baltis Forestry* 25(2): 289–295.

Abstract

The paper concerns an analysis of differences in extent and characteristics of disturbances in outer soil layers, having occurred due to timber harvesting during the growing as well as winter seasons. The research areas were located in four upland mature stands – two beech and two fir ones. Felling works, conducted there in the above-mentioned seasons, were performed in the long timber system with skidding by means of a tractor of a skidder type. Performing works in winter, at thick snow cover, reduced the area of disturbed soil by 55% in fir stands and 30% in beech ones. Statistically significant differences were also recorded in respect of the depth of damages; in summer season they were more than twice as deep. Having analysed the quality of soil disturbances, it was established that the ones that emerged in winter were less harmful, being of rather minor and superficial nature. Compaction of soil was exclusively observed over surfaces where felling works were performed in the growing season. The conducted research confirmed that timber harvesting in winter is much less harmful to soil than it is in summer.

Keywords: timber harvesting, damage to soil, summer and winter season, ground disturbance, soil compaction

Introduction

Timber harvesting has a negative impact on forest ecosystems, including injuries to trees remaining in the stand, damage to regeneration, forest vegetal cover and soil (Gapšytė 2003, Sowa 1997). The extent of soil damage depends on many factors, such as: species and age of harvested trees, intensity of cutting, number and parameters of skidding tracks, landform, type and moisture content of soil, logging technologies and types of employed machines, season of the year (Reeves et al. 2012, Shrestha et al. 2008, Steponavičius and Zinkevičius 2010). The practice of timber harvesting in winter season, when the soil is frozen and covered with snow, has been applied in Polish forestry for many years, which is aimed, among others, at minimising an unfavourable impact of logging operations on the forest environment (Bluszkowska and Nurek 2010). There are a few published case studies providing an evidence that the extent of damage to outer soil layers caused by felling works performed in winter is smaller than the ones due to harvesting in the growing season (Stone 2002, Wayne 1988). Moreover, it was proved that the cohesion of soil caused by logging operations in summer was greater than that recorded in winter, in some cases even by 100% (Puettmann et al. 2008). As a consequence, the share of damaged trees (Cline et al. 1991) and vegetation in the lower forest layers (Berger et al. 2009) was also significantly higher. However, there is a scarce number of publications related to this topic and concerning research conducted in the Middle European conditions, employing work technologies and machines typical of this part of the continent. The issue, being the most frequently addressed in those few papers, regards damage to trees that are left in the stands after the harvest. According to Sowa and Stańczykiewicz (2002), who investigated early thinning treatments in fir stands, the share of damaged trees harvested in winter was lower when compared with growing season. Similar observations were made by Levkovskaya and Sarnatsky (2014), who noticed that mechanised timber harvesting performed in pine stands in spring caused more frequent, by 1.2 to 2 times, wounding of trunks and root systems of trees remaining in the stand when compared with those occurred during the works carried out in winter. Whereas, according to the results of the research conducted by Chmielewski and Porter (2012) in post-agricultural pine stands, the factor that determined the number of injured trees was the logging technology. Employing the method of the short-length-system caused greater damage to trees in winter (6.3 % injured specimens) than in summer (2.4 %), whereas the tree-length-system was less harmful in growing season (3.7 % for winter, and 4.0 % for summer). The studies carried out by Limbeck-Lilienau (2003) in 50- to 100-year-old spruce stands, where wood was harvested in the short-length-system, evidenced that the share of damaged trees depended on the employed types of harvesters. A wheeled machine injured less trees during winter harvest (4.5 % of extracted tress) when compared with logging in growing season (13.5 %). While a tracked one was less harmful in summer, when it caused damage to 13.5% of extracted trees, against 20% of specimens wounded during winter harvest. Taking into account that the research results present above are unambiguous, pursuing the studies on the impact of harvesting season on the extent of damage to the forest environment seems to be meaningful and well justified.

This paper aimed to determine and compare parameters describing disturbances in outer layers of soil caused by timber harvesting in winter, at thick snow cover, and during the growing season. The scope of the research was limited to mature beech and fir stands, where logging operations were performed in motor-manual technology, employing tractors of a skidder type.

Material and Methods

Research area

The research was conducted in south-eastern Poland (Figure 1), in the territory enclosed within the following geographical coordinates: 49° 49' 86" N to 49° 47' 30" N and 22° 35' 74" E to 22° 41' 05" E, in four mature stands, managed under a shelterwood group system, the characteristics of which were given in Table 1.

Figure 1. Location of the research area, marked with a black circle, shown against the map of Poland (*Source*: www.google.maps.com)

Table 1. Major features of the investigated stands

Stand - symbol	Fir summer FS	Fir winter FW	Beech summer BS	Beech winter BW
Tree species composition	8 Fir 2 Pine	10 Fir	9 Beech 1 Pine	9 Beech 1 Oak
Site type	Fresh upland deciduous forest	Fresh upland deciduous forest	Fresh upland deciduous forest	Fresh upland deciduous forest
Age [years]	108	123	111	106
Mean diameter at breast height [cm]	50	59	49	51
Mean height [m]	31	32	30	30
Cutting intensity [$m^3 \times ha^{-1}$]	172	140	150	142
Quantity of removed trees [$pcs \times ha^{-1}$]	164	128	132	152
Soil type	Acid brown	Acid brown	Brown leached	Brown leached

In stands symbolised by FS (fir summer) and BS (beech summer), logging works were performed in August, while in those symbolised as FW (fir winter) and BW (beech winter) in February, at temperatures reaching down to –15 ^{0}C and snow cover of ca. 40 cm thick. The technology employed in all of the investigated stands was identical, including felling and delimbing with the use of a petrol chainsaw. Long wood was extracted from the stand to the skidding track, by means of a cable winch mounted on a skidder, the LKT 81 turbo model. The machine in question is a four-wheel skidder, weighing 7300 kg, equipped with a double-drum cable winch, with a pulling force of 80 kN, 60-meter cable, with a diameter of 14 mm and a winding speed of 1 $m \times s^{-1}$. The stems were then transported to landings by means of the semi-suspended skidding method. In each of the stands, four trial plots were established in locations representative for these stands. The trial plots were quadratic, with dimensions of 50 × 50 m, taking up an area of 0.25 ha. They were divided into 25 one-are measuring fields, being squares with sides equal to 10 m, the nodes of which were marked with wooden pickets. All of the trial plots were oriented in the same manner, with one of their sides parallel to the skidding track, not overlapping each other. A distance between the skidding tracks accounted for 100 m. With regard to the summer harvest, the measurements of the extent of soil damage were performed directly after the logging works had been finished. Whereas, for the winter harvest, the measurements were taken early in spring, as soon as the cover snow retreated. The disturbances in outer soil layer were recorded within the entire area of one-are trial plots using a steel measuring tape, with accuracy up to 0.5 cm. The measurements included the length of disturbances, their width and depth in relation to the primary ground level, established by means of a wooden levelling rod. Moreover, based on the observations of the soil surface around every of the 36 nodes in all of the 16 trial plots, a visual assessment of the soil damage was drawn, according to the classification system elaborated by Dyrness (1965) and modified by Giefing (1999):

1) undisturbed soil: forest litter prevailed, no traces of compaction, disturbance class R = 0,

2) minor damage to soil, enclosing three subclasses:

a) forest litter removed, mineral soil uncovered but undisturbed, disturbance class R = 1,

b) mineral soil mixed with forest litter, disturbance class R = 2,

c) mineral soil covering forest litter and post-harvest waste with a layer of ca. 5 cm thick, disturbance class R = 3,

3) major, deep damage to soil: outer soil layers removed, deeper layers uncovered, forest litter or post-harvest waste scarcely covering the soil surface, disturbance class R = 4,

4) compacted soil: clearly visible traces of compaction caused by a skidding vehicle or dragged wood, disturbance class R = 5.

Statistical analyses of the data, size and depth of disturbances, obtained in the course of the research were performed with the use of the Statistica 9.1 software package (StatSoft PL 2009), employing the Shapiro-Wilk and Levene's tests, as well as Student's t-test. Statistical analyses were performed at the significance level $\alpha = 0.05$. Positional statistics of variates were also computed.

Results

The share of the area of disturbed soil, as a result of felling and skidding works performed in the investigated stands, was presented in Figure 2.

Temperatures below 0 °C and thick snow cover protected the soil against damage. Regarding both fir and beech stands, timber harvesting in winter caused smaller disturbances in the outer soil layers. Particularly legible difference between damage occurring in various seasons of the year was recorded in the fir stand, where felling and skidding were carried out during the growing season, resulting in twice as high share of the damaged soil.

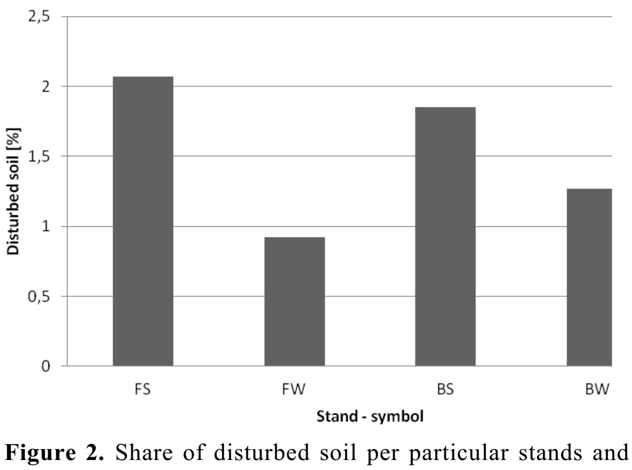

Figure 2. Share of disturbed soil per particular stands and seasons (FS, fir summer; FW, fir winter; BS, beech summer; BW, beech winter)

In the stand FS, over the trial plots with the total area of 1 ha, 159 disturbances in the outer soil layers were recorded, while in the stand FW there were 110 of them, 117 in the stand BS and 120 in the stand BW. Thus, the differences in the damage extent depending on the season of the year were not that large, which was particularly true for beech stands. Taking into account a significantly higher share of soil damaged due to timber harvesting in the growing season, clearly legible in Figure 2, it should be assumed that the extent of damage that occurred in this period was greater than the one that emerged in winter. Therefore, the analysis covered the size of particular disturbances recorded within one-are measuring fields in the investigated stands. Their basic positional statistics were presented in Figure 3.

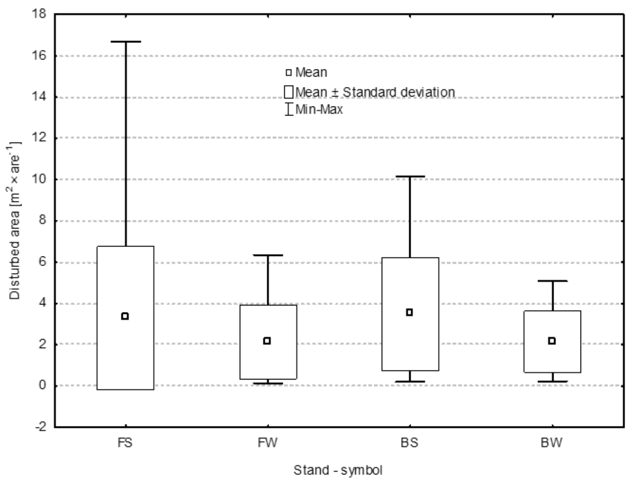

Figure 3. Descriptive statistics referring to the extent of soil disturbance within one-are trial plots (FS, fir summer; FW, fir winter; BS, beech summer; BW, beech winter)

Felling works performed in the growing season resulted in an emergence of disturbances of greater area and variability (FS mean = 3.28 m^2, interval = 16.57 m^2, BS: 3.49 m^2 and 9.95 m^2, respectively) when compared with those recorded in winter (FW mean = 2.14 m^2, interval = 6.20 m^2, BW, 2.15 m^2 and 4.84 m^2, respectively). For establishing whether the period of performing logging works significantly affected the extent of damaged soil within the measuring fields, Student's t-test was conducted after the conditions of its applicability had been verified. This concerned an additivity and homogeneity of distributions, which was checked with the use of the Shapiro-Wilk and Levene's tests. The above-mentioned distributions were obtained through logarithmic transformation of data. With regard to the mean areas of disturbances recorded in fir (t = 1.98, p = 0.04) and beech stands (t = 3.28, p = 0.00), the period of harvest and the related weather conditions affected the extent of disturbed soil within the measuring fields.

Another important parameter in respect of the soil damage that could have been affected by the period of harvest, was the depth of disturbances presented in Figure 4.

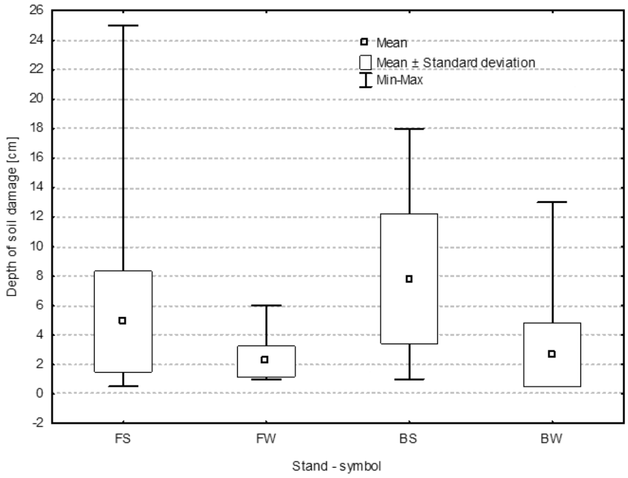

Figure 4. Descriptive statistics referring to the depth of soil disturbances (FS, fir summer; FW, fir winter; BS, beech summer; BW, beech winter)

The disturbances in soil layers that emerged in the course of the logging works performed in the growing season were deeper and their maximum values were significantly higher (FS, mean depth = 4.92 cm, maximum depth = 25 cm, BS: 7.82 cm and 18 cm, respectively) than those that occurred in winter (FW, mean depth = 2.20 cm, maximum depth = 6 cm, BW: 2.65 cm and 13 cm, respectively). Student's t-test revealed that the differences in disturbance depths were significant with regard to both ones: fir (t = 6.72, p = 0.00) and beech stands (t = 11.53 p = 0.00).

Classification of soil damage was performed in the nodes and was based on Dyrness' scale, which allowed confronting the disturbances encountered at the particular trial plots (Table 2).

Timber harvesting in winter resulted in an emergence of a smaller number of disturbances, which was evidenced by ca. 60% share of the class R = 0 (undisturbed soil), while logging works performed in the growing season displayed lower share of this class, accounting for ca. 40%. The most common form of disturbances, in reference to all of the analysed stands, was minor damage counted to classes R = 1, 2 and 3. The share of deeply damaged soil (R = 4), due to timber harvesting in the growing season, accounted for over 6 %, while in winter these values were lower, ranging from 1.5 % in the fir stand to nearly 3% in the beech stand. Significant differences in damage degree depending on the season of the year were recorded with regard to the share of compacted soil (R=5). At logging works performed in winter the soil damage of this class was not encountered at all, whereas skidding of timber when there was no snow cover increased the share of such disturbances, ranging between 7.6 % and 9 %.

Table 2. Damage to soil within the particular trial plots

Soil - name and R-class of the damage	Stand fir summer FS		Stand fir winter FW		Stand beech summer BS		Stand beech winter BW	
	Number of nodes	%	Number of nodes	%	Number of nodes	%	Number of nodes	%
Undisturbed soil (R = 0)	60	41.7	88	61.2	58	40.3	83	57.6
Minor soil damage (R = 1)	24	16.7	31	21.5	30	20.8	30	20.8
Minor soil damage (R = 2)	24	16.7	10	6.9	19	13.2	18	12.5
Minor soil damage (R = 3)	13	9.0	13	9.0	17	11.8	9	6.3
Deeply damaged soil (R = 4)	10	6.9	2	1.4	9	6.3	4	2.8
Compacted soil (R=5)	13	9.0	0	0.0	11	7.6	0	0.0
Total	144	100	144	100	144	100	144	100

Discussion and Conclusions

The motor-manual logging technology that employing semi-suspended skidding with the use of skidders is harmful to the forest environment, causing considerable damage to trees remaining in the stand, including specimens in regeneration layer, and finally forest soil (Giefing et al. 2012, Solgi and Najafi 2007). As far as the protection of forest ecosystems against negative impact of wood extraction with the use of skidders is concerned, an essential issue is to employ them only in older stands, maturing or mature ones. Based on results of the research conducted in stands belonging to a few age classes, starting from early thinned to mature ones, Suwała (2004) proved that semi-suspended skidding of long wood using skidders caused damage to trees and regeneration that was inversely proportional to the age of the stand. The research presented in this paper was carried out in stands of older age classes, under conditions that prompted the authors to assume insignificant harvest-related damage, including the soil damage as well. These assumptions appeared to be true. The investigated technology of logging works was not very harmful to forest soil; timber skidding performed in the growing season caused disturbances in soil layers only over 1.9-2.1 % of the entire research area. Harvesting of timber in winter allowed reducing the extent of damage by ca. 55 % in the fir stand and over 30 % in the beech stand, reaching the level of 0.9-1.3 % of the area of the felling site. Depths of ruts left by a skidder in summer (FS: ca. 5 cm, BS: nearly 8 cm) were more than twice as deep as those formed in winter (FW: slightly beyond 2 cm, BW: nearly 3 cm). The data published in the existing literature, referring mostly to timber harvesting in summer and autumn, indicates that motor-manual logging technologies employing cable skidders result in similar or higher degree of soil damage when compared with the experiment presented in this paper, in particular with regard to the variant of timber harvest in the growing season. Moreover, Suwała (2004) established that in pine stands, where clear-cutting was performed in openings, extracting wood by means of a cable winch mounted on a skidder caused damage to forest soil over 2.2 % of the area of the logging site. The author quoted above also noted that in younger stands, where tending treatments of early thinning nature were performed, employing the above-mentioned technology resulted in significantly greater damage to soil cover, exceeding 6 % of the area of the felling site. Soil damage observed by Jourgholami et al. (2014) in broad-leaved stands was only slightly smaller. In those stands, the share of compacted and disturbed soil, as a result of extracting wood using the Timberjack 450C skidder, constituted more than 5 % of the area of the felling site. Porter (1997), having investigated thinned stands, where late thinning treatment was performed engaging a skidder, estimated the share of damaged soil at 4.2 %. According to data quoted by Gapšytė (2003), referring to logging works under conditions identical to those described above, disturbances in soil layers emerged on 3.7% of the area of the felling site, though the studies included ruts left by wheels of vehicles on the skidding tracks. Apart from the ruts, furrows made by butt-ends of wood being dragged took up only 1.9 % of the area of the logging site. In the experiment discussed here, the tractor moved only on skidding tracks, outside the trial plots, therefore in these plots no ruts impressed by skidder wheels were recorded. Similar observations were made by Gil (2000), who claimed that the degree of harvest-related damage might be significantly reduced if wood was extracted by skidders moving on skidding tracks exclusively and the loads were pulled to the skidders with the use of cable winches.

The analysis of post-harvest soil condition performed in the nodes of network of quadratic trial plots and based on Dyrness' scale, confirmed that performing logging works in winter, when the ground is frozen and covered with a thick snow cover, resulted in reducing their negative impact on the forest environment. Due to timber harvesting in summer the share of undisturbed soil (R = 0) was significantly lower, though the share of deeply damaged soil (R = 4) was visibly higher. In both of the discussed seasons, the share of soil with minor damage (R = 1, 2, 3) stayed at the similar level. Compaction of soil (R = 5) was recorded only over the areas where logging works were performed in the growing season. In comparison with the research results reported by Dudek and Sosnowski (2011) for mountain mature stands in southern Poland, the studies presented in this paper revealed a different harmfulness degree of the technology under scrutiny. The authors quoted above established that skidding of timber with the use of the LKT 80 tractor in summer resulted with a higher share of undisturbed soil (R = 0), accounting for nearly 80 %. They also noted lower shares of disturbed soil, within the classes R = 2, 3, 4, and the higher shares of compacted soil (R = 5 ÷ 12 %). This greater compaction of soil was most likely due to a different technology of skidding, in which a skidder moved inside the stand when approaching the extracted logs. Whereas, in the studies discussed herein, logs were dragged to the skidding track with the use of a cable winch, and then loaded on a skidder. In other studies conducted by Glazar and Maciejewska (2009), who investigated late thinning treatments performed in pine stands with semi-suspended skidding of timber by means of a farm tractor, no damage (R = 0) was encountered over 75 % of the area of the felling site. Over nearly 25 % of the examined area minor soil damage (R = 1, 2, 3) was detected, severe and deep damage to soil occurred merely over 1 % of the area of the felling site, while soil compaction (R = 5) was not recorded at all. Thus, soil damage described by the above quoted authors was smaller when compared with the one discussed in this paper, though this may be due to two reasons. Firstly, the studies described here were carried out in upland stands, where terrain conditions were more difficult when compared with more accessible lowland stands. Secondly, the skidding mean employed in logging described by Glazar and Maciejewska was a regular farm tractor with smaller weight and a cable winch with a lower pulling force than those of a skidder. Another comparative studies concerning the difference in degree of damage caused by harvesting in winter and summer were conducted in 100- to 120-year-old boreal pine stands in Russia by Mikheev (1950). The quoted author stated that semi-suspended skidding of timber performed in winter with the use of a tractor did not affect the soil and forest vegetation noticeably. Whereas, logging works carried out in summer caused soil disturbance over nearly 20% of the area of the felling site. This mostly concerned shifting of the outer soil layer with forest litter and smaller plants, which corresponded with the damage class R = 3, according to the scale employed in this paper. Wheel ruts with an average depth of 10-20 cm, complying with the damage class R = 5, were less numerous. The latter type of damage, soil compaction, i.e. an increase in soil cohesion, was sporadically encountered in winter, not only due to protection of soil provided by a thick snow cover, but also because of freezing of the outer soil layers. The depth of frozen ground is mostly dependent on the thickness of snow cover, number of days when the temperature drops below 0 °C, moisture content and soil structure (Saarilahti 2002). Studies on properties of soil damaged due to timber skidding performed in winter using the EcoTrac skidder proved that the soil cohesion was greater when the ground was not frozen (Šušnjar et al. 2006). The very same investigations revealed that removing snow cover from unfrozen ground during timber skidding at temperatures below 0 °C was favourable since it allowed the outer soil layers to freeze, protecting them against compacting. With regard to the research presented in this paper, the temperature, at which logging works were performed in winter, accounted for ca. -15 ^{0}C, which caused only minor soil disturbance.

The research discussed here confirmed that timber harvesting in winter may significantly reduce the degree of damage to the outer soil layers. In respect of both ones, the total share of the felling site area, where soil disturbances were recorded and the depth of furrows made by butt-ends of long wood being dragged were smaller at skidding in winter. Employing Dyrness' scale for estimating the damage degree prompted the authors to draw the conclusion that timber harvesting under such conditions is also less likely to disturb the soil layers and consequently, less harmful to forest ecosystems. Therefore, logging operations should be preferably performed in winter, to reduce the harvest-related damage. However, regarding the nowadays reality of market economy, it is simply impossible to reduce the entire period of logging works to few months within a vegetation dormant season, because of the necessity to maintain the uninterrupted rhythm of wood deliveries to its buyers (D'Amours et al. 2008). Though, such an approach can be adopted in stands embraced by particular care of foresters due to its protective and landscape-related values.

References

Berger, A. L., Puettmann, K. J., Host, G. E. 2004. Harvesting impacts on soil and understory vegetation: the influence of season of harvest and within-site disturbance patterns on clear-cut aspen stands in Minnesota. *Canadian Journal of Forest Research* 34(10): 2159–2168.

Bluszkowska, U. and Nurek, T. 2010. Badanie sezonowości prac leśnych. [Studying seasonality of forestry works]. *Technika Rolnicza Ogrodnicza Leśna* 5: 22–24.

Chmielewski, S. and Porter, B. 2012. Waloryzacja wybranych metod pozyskiwania i zrywki drewna w sosnowych drzewostanach przedrębnych. [Assessment of selected wood harvesting and logging methods in thinned pine forest stands]. *Technika Rolnicza Ogrodnicza Leśna* 3: 23–25 (in Polish).

Cline, M. L., Hoffman, B. F., Cyr M. and Bragg, W. 1991. Stand damage following whole-tree partial cutting in northern forests. *Northern Journal of Applied Forestry* 8(2): 72–76.

D'Amours, S., Rönnqvist, M. and Weintraub, A. 2008. Using Operational Research for Supply Chain Planning in the Forest Products Industry. *INFOR: Information Systems and Operational Research* 46 (4): 265–281.

Dudek, T. and Sosnowski, J. 2011. Ocena środowiskooszczędności wybranych technologii zrywki drewna w lasach górskich [Evaluation of the environmental impact of selected timber extraction technologies used in mountain forests]. *Sylwan* 155 (6): 413–420 (in Polish).

Dyrness, C. T. 1965. Soil surface condition following tractor and high-lead logging in the Oregon Cascades. *Journal of Forestry* 63(4): 272–275.

Gapšytė, A. 2003. Assessing damage to trees and soil in thinning of pine stands. *Baltic Forestry* 9 (1): 69–74.

Giefing, D. F. 1999. Wpływ pozyskania drewna w czyszczeniach późnych drzewostanów sosnowych na środowisko. Część 2. Gleby. [The impact of logging during the cutting old pine stands on the environment. Part 2. Soils]. *Sylwan* 6: 91–100 (in Polish).

Giefing, D.F., Bembenek, M., Gackowski, M., Grzywiński, W., Karaszewski, Z., Klentak, I., Kosak, J., Mederski, P.S. and Siewert, S. 2012. Ocena procesów technologicznych pozyskiwania drewna w trzebieżach późnych drzewostanów sosnowych. Metodologia badań [Evaluation of thinning operations in older stands. Research methods]. *Nauka Przyroda Technologie* 6, 3, #59. (in Polish with English abstract) Available online at: https://www.npt.up-poznan.net/volume6/issue3/abstract-59.html

Gil, W. 2000. Naziemna zrywka drewna skiderami w ujęciu kodeksu praktyk pozyskaniowych. [Ground skidding of wood from the point of view of the logging practice code]. *Sylwan* 1: 59–73 (in Polish).

Glazar, K. and Maciejewska, M. 2009. Ecological aspects of wood harvesting and skidding in pine stands with use different technologies. *Acta Scientarum Polonorum, Silvarum Colendarum Ratio et Industria Lignaria* 8 (3): 5–14.

Jourgholami, M., Majnounain, B. and Abari, M. E. 2014. Effects of tree-length timber skidding on soil compaction in the skid trail in Hyrcanian forests. *Forest Systems 23*(2): 288–293.

Levkovskaya, M. V. and Sarnatsky, V. 2014. Ecological and Economical Aspects of Felling with Use of Multi-operational Felling Machines and Machinery. In: V. Golonko and A. Imada (Eds.). Neural Networks and Artificial Intelligence. Springer International Publishing, New York, p. 5–8.

Limbeck-Lilienau, B. 2003. Residual stand damage caused by mechanized harvesting systems. In: T. Steinmüller, and K. Stampfer (Eds.). Proceedings of the Austro 2003 meeting: High Tech Forest Operations for Mountainous Terrain. CD ROM, p. 1–11.

Mikheev, S.D. (Михеев, С.Д.) 1950. Vliianie traktornoi treliovki na usloviia lesovozobnovleniia. [The influence of tractor skidding on conditions for forest regeneration]. *Lesnoie khoziaiistvo* (2): ...-...? (in Russian).

Porter, B. 1997. Techniczne, ekonomiczne i przyrodnicze aspekty zrywki drewna w sosnowych drzewostanach przedrębnych [Technical, economic and environmental aspects of logging in thinned pine stands]. Wyd. Fundacja Rozwój SGGW, Warszawa. 80 pp. (in Polish).

Puettmann, K.J., D'Amato, A.W., Arikian, M. and Zasada J.C. 2008. Spatial impacts of soil disturbance and residual overstory on density and growth of regenerating aspen. *Forest Ecology and Management* 256 (12): 2110–2120.

Reeves, D., Reeves, M., Abbot, A., Page-Dumroese, D. and Coleman M. 2012. A detrimental soil disturbance prediction model for ground-based timber harvesting. *Canadian Journal of Forest Research* 45 (5):821–830.

Saarilahti, M. 2002. Dynamic Terrain Classification – Modelling of the seasonal variation of the trafficability on forest sites. Appendix Report No. 1. Project Deliverable D2 (Work Package No. 1) on: Soil Interaction Model / Development of a Protocol for Ecoefficient Wood Harvesting on Sensitive Sites (EcoWood). Quality of Life and Management of Living Resources Contract No. QLK5-1999-00991 (1999-2002). 22 pp.

Shrestha, S.P., Lanford, B.L., Rummer, R. and Dubois, M. 2008. Soil disturbances from horse/mule logging operations coupled with machines in the Southern United States. *International Journal of Forest Engineering* 19 (1): 17–23.

Solgi, A. and Najafi, A. 2007. Investigating of residual tree damage during ground-based skidding. *Pakistan Journal of Biological Sciences* 10 (10): 1755–1758.

Sowa, J.M. 1997. Podstawy metodyczne modelu szacowania szkód pozyskaniowych w środowisku leśnym [Methodical basis of the model for estimating harvest damage in the forest environment]. In: A. Grzywacz (Ed.). Kongres Leśników Polskich. 24-26 kwietnia 1997. Materiały i Dokumenty. Tom II. Warszawa, p. 132–138 (in Polish).

Sowa, J.M. and Stańczykiewicz, A. 2002. Związki rozmiaru szkód pozyskaniowych w trzebieżach wczesnych z okresem przeprowadzania cięć [Relationships between the extent of harvest damage in early thinning and the period of cutting]. In: T. Lukač and J. Koreņ (Eds.). Logistika technickej vżroby dreva v Karpatoch: Mater. Międzynar. Konf. Nauk, Zvolen, 9.-10. septembra 2002. Vydavate¾stvo TU, Zvolen, pp. 229–236 (*in Polish*).

StatSoft PL 2009. Statistica advanced analytics software package. Version 9.1. *URL*: https://www.statsoft.pl

Steponavičius, D. and Zinkevičius, R. 2010. The Study of the Logging Methods Prevailed in Lithuania and other Countries of Central Europe. *EJPAU* 13(1): #01. Available online at: http://www.ejpau.media.pl/volume13/issue1/art-01.html

Stone, D.M. 2002. Logging options to minimize soil disturbance in the Northern Lake States. *Northern Journal of Applied Forestry* 19 (3): 115–121.

Šušnjar, M., Horvat, D. and Šešelj, J. 2006. Soil compaction in timber skidding in winter conditions. *Croatian Journal of Forest Engineering* 27(1): 3–15.

Suwała, M. 2004. Uszkodzenia gleby w drzewostanach sosnowych przy pozyskiwaniu drewna w praktyce leśnej [Soil disturbances during wood harvesting in pine stands in forestry practice]. *Sylwan* 1: 87–101 (*in Polish*).

Wayne, M.C. 1988. Soil Disturbance by logging in New England – review and management recommendations. *Northern Journal of Applied Forestry* 5 (1): 30–34.