The Effect of Wider Logging Trails on Rut Formations in the Harvesting of Peatland Forests

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Abstract

Peatlands are very problematic from the bearing capacity point of view. Therefore, logging activities on peatlands in Finland are mainly carried out during the coldest weeks in winter time. More intensive utilisation of peatland forests requires logging activities to be increasingly carried out during unfrozen conditions. Multiple passages of a harvester and a loaded forwarder used for the transportation of timber cause deep ruts on the forest floor. Wider logging trails have been presented as an interesting approach to increasing the number of forwarder passages along a single logging trail. It might be advantageous not to follow the same ruts on each pass but to choose a new parallel route, so that new ruts are formed alongside the previous ones. The study aimed at investigating whether it is beneficial to use wide trails in reducing rutting in forests growing on drained peatland. Field studies were conducted on a drained peatland in Alkkia experimental forest, located in Karvia in Western Finland. In the driving test, a forwarder was driven in the same forest site on logging trails with widths of 4.5 m, 6 m and 10 m. The results indicate that wider logging trails provide the forwarder driver with opportunities to reduce rutting in peatland forests.

Keywords: tree harvesting, trafficability, rut formation, soil bearing capacity

1. Introduction

The low bearing capacity of peatlands forms a severe obstacle for the prevailing harvesting machinery. Multiple passes of a harvester and a loaded forwarder used for the transportation of timber may cause deep ruts on the forest floor. Excessive machine sinkage has a direct bearing on the cost of machine operations and may lead to excessive site disturbance and soil damage (Tiernan et al. 2004, Zeleke et al. 2007, Ala-Ilomäki et al. 2011).

Currently, logging activities on peatlands are mainly carried out during the coldest periods in the winter. There are, however, local and annual differences in terms of the extent to which peatlands freeze. Warm autumn months and the isolative effects of snow cover and dry upper peat layers hinder the freezing process and make many areas impossible to access, even in the winter. The pronounced climatic change at high latitudes, predicted to occur as a result of global warming, is expected to prevent winter logging on peatland in these areas. More intensive utilisation of peatland forests requires logging activities to be increasingly carried out in unfrozen conditions.

Peatlands consists of a 10 to 20 cm thick top layer that includes roots of trees and shrubs, followed by layer of decomposed peat. From the bearing capacity point of view, the top layer, with its considerable tensile strength provided by the roots of trees and shrubs, is essential, with the supporting function of the decomposed peat being of secondary importance. If the bearing capacity of peat soil is weak, the first forest machine passes may break the vital root matrix, drastically reducing trafficability.

The mobility of forwarders in the summer logging of peatland forests has been studied rather extensively of late (O'Mahony et al. 2000, Tiernan et al. 2004, Zeleke et al. 2007, Ala-Ilomäki et al. 2011, Uusitalo and Ala-Ilomäki 2013). These studies show that the mobility of forwarders during the summer is critical. In many peatlands, the bearing capacity of peat soil is so weak that only a few forest machine passes along one logging trail will break the vital root matrix and may prevent forwarding operations (Nugent et al. 2003). Recent studies indicate that the most important characteristics affecting the bearing capacity of pine bogs are tree volume, the strength and moisture content of the uppermost layers of moss (Ala-Ilomäki et al. 2011, Uusitalo and Ala-Ilomäki 2013). In addition to that, logging residual is known to prevent excessive rutting although the role of logging residual has mostly been researched in mineral soils (McDonald and Seixas 1997, Eliasson and Wästerlund 2007, Gerasimov and Katarov 2010, Labelle and Jaeger 2012).

Wider logging trails have been presented as an interesting approach to increasing the number of forwarder passages along a single logging trail. Recent simulation studies have proved that doubling the number of forest passes along the most critical logging trail sections would in many cases markedly improve the possibility of successfully completing summer logging operations on peat soils (Uusitalo et al. 2010, Haavisto and Uusitalo 2010). It has also been shown that increasing the width of a logging trail from 4 m to 6 m does not drastically decrease the profitability of peatland forestry in the long term (Salomäki et al. 2012).

Wider logging trails enable the machine operator to choose a new route so that new ruts are formed alongside the previous ones. Ultimately, increased trail width could double the number of forwarder passages on each logging trail. This paper presents the results of a test whereby a forwarder was driven in the same forest site on logging trails with widths of 4.5 m, 6 m and 10 m. The study aimed at investigating whether it is beneficial to use wide trails in reducing rutting in forests growing on drained peatland.

2. Materials and methods

Field studies were conducted on a drained peatland in Alkkia experimental forest, located in Karvia in Western Finland. The study stand was drained for the first time in 1969 and the ditch network was cleaned in 1988. For the study, three straight logging trails, each roughly 350 m long, were marked prior to harvesting. The logging trails were laid out in parallel with 20 m spacing. The study trails were marked with coloured strips prior to harvest. All three study trails started with the 100 m long sections of 10 m wide trails, continued with 100 m long sections of 6 m wide trails and ended with 100 m long sections of 4.5 m wide trails (Fig. 1). There were 20 m long transition sections between the consecutive 100 m long sections. The borders of the study trails on the 6 m or 10 m wide sections were also marked with coloured strips prior to harvesting. The 4.5 m wide section was not marked, as it was considered the normal working method. Each 100 m long section included one study plot system-

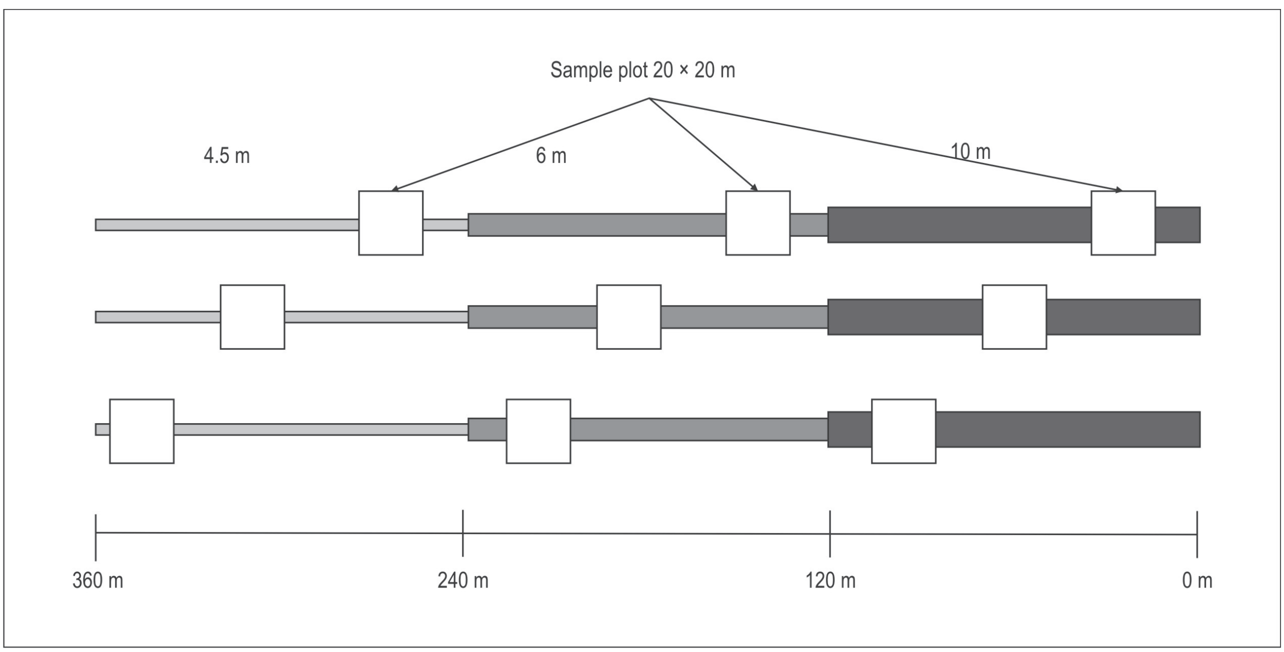

Fig. 1 Schematic layout of the study trails and sample plots within the study stands

Table 1 Technical data for the machines used in the study

Equipment	Ponsse Fox harvester	Ponsse Buffalo forwarder
Number of wheels	8	8
Tyres	710/45-26.5	800/40-26.5
Tracks/chains	Clark Terra TL85 (front) wheel chains (rear)	Clark Terra TL85 (rear) wheel chains (front)
Net mass without tracks or chains, kg	18,200	18,900
Nominal Ground Pressure (NGP), kPa (machines equipped with tracks or chains)	41 (front) 43 (rear)	46 (front) 43 (rear), without load
Number of wheels	8	8

atically laid out along the test trails. The study plots, 20 m in length and 20 m in width, were placed parallel to the study trails. Along the centre line of the sample plot, five sample lines, perpendicular to the centre line, were marked on the ground at 4 m intervals, the first sample line starting 2 m and the last sample line 18 m from the beginning of the plot.

Harvesting and test drives were carried out in September 2011. The site was harvested with an 8-wheeled Ponsse Fox harvester that had a boom reach of 10 m and was equipped with tracks on the front bogie and chains on the rear bogie. The technical details of the harvester are provided in Table 1. The harvester was operated by an experienced operator. Normal thinning procedures were followed. All the trees removed from the logging trail and the trees adjacent to the trail were processed above the trail, resulting in logging residue accumulation on the logging trail. Trees located more than roughly 3 meters from border of the trail were processed outside the logging trail. Along the 6 m wide trail sections, the amount of removed trees in areas outside the logging trails was reduced, so that the volume of the remaining trees per hectare would equal that along the 4.5 m wide trail sections. No thinning outside the logging trails was accomplished along the sections with 10 m wide trails. Along the 6 m wide and 10 m wide trail sections, all trees were processed above the trail. It was estimated that brash mat along the 6 m wide trail section was distributed quite evenly along the whole 6 m wide area and along 10 m wide section quite evenly along 7 m wide area. These values were later used in making theoretical calculations on the mass of logging residuals per hectare. While harvesting, the automatic measurement and bucking optimization system stored the profiles of the removed stems in the STM format.

After harvesting, the depth of the ruts caused by the harvester in each sample line was measured with a horizontal laser levelling device and a laser levelling rod equipped with a laser beam detector. The device was first placed at a random location along the trail to obtain a reference height, which was then carved on the surface of a nearby tree. The reference level of the ground outside the wheel ruts was first measured to the left and the right of the sample line. The laser levelling rod used for measuring the height was pushed lightly against the ground to compact any loose surface layer vegetation and the relative level to the reference mark was calculated by reading the level of the laser beam detector attached to the surface of the laser levelling rod. The depth of ruts on both sides of the centre line was measured by placing the laser levelling rod at the bottom of the rut, reading the relative height of the bottom and calculating the depth of the ruts by comparing these values to the closest reference level of the ground. Rut depth after harvesting (Rut_{harv}) is the mean of the rut depths of both tracks caused by the harvester.

Test drives were carried out with an 8-wheeled Ponsse Buffalo forwarder (Table 1). Since the soil was very soft due to a long period of rain, the tests were carried out with no load. All three test trails were first driven once along the ruts caused by the harvester. The rut depth was then measured exactly as it was after the harvester pass. Rut depth after one forwarder pass ($Rut_{\mathrm{forw\_one}}$) is therefore the mean of the rut depths of both tracks caused by one harvester pass and one forwarder pass. Next, the forwarder drove along the test trails three more times, except on the third test trail, which was driven only twice more. These results were treated equally regardless of the number of passes. While driving these two to three additional times, the forwarder operator was allowed to utilise the whole width of the trail and choose new parallel routes, so that new ruts were formed alongside the previous ones along the 6 m-wide and

Table 2 Means of the ruts measured in the study

Study trail	Nominal width	Rut_{width_tot}	Rut_{harv}	Rut_{forw_one}	Rut_{forw_sev}	Rut_{incr_forw} (Rut_{forw_sev} – Rut_{harv})	V_{plot}	$V_{harvested}$	Dry mass of logging residues
		Mean							
	m	cm					m^3		kg/ha
1	4.5	341	8.4	11.4	14.1	5.7	188	73	15 700
2	4.5	337	9.3	17.2	22.4	13.1	192	53	12 300
3	4.5	361	16.0	17.2	21.3	5.3	177	54	11 500
All	**4.5**	**346**	**11.2**	**15.3**	**19.3**	**8.0**	**185**	**60**	**13 200**
1	6	436	14.5	19.1	18.4	3.9	172	81	12 800
2	6	386	9.2	10.8	13.2	4.0	202	92	14 900
3	6	448	14.4	15.0	18.5	4.1	141	62	10 600
All	**6**	**423**	**12.7**	**15.0**	**16.7**	**4.0**	**172**	**78**	**12 800**
1	10	433	18.0	19.1	21.2	3.2	202	90	12 300*
2	10	625	14.3	22.4	18.5	4.2	173	86	10 700*
3	10	625	18.0	19.5	23.2	5.2	171	84	11 700*
All	**10**	**561**	**16.7**	**20.3**	**21.0**	**4.2**	**182**	**87**	**11 600***

*It was estimated that along 10 m wide trails the logging residues distributed quite evenly across a 7 m wide area.

Rut_{width_tot} = Total width of ruts; Rut_{harv} = Rut depth caused by harvester; Rut_{forw_one} = Rut depth after one forwarder pass; Rut_{forw_sev} = Rut depth of several forwarder passes

10 m wide sections. Along the 6 m wide trail sections, both the depth of the first (original) ruts on both sides of the trail (Rut_{first_left}, Rut_{first_right}) and the depth of the second (new) ruts (Rut_{second_left}, Rut_{second_right}) on both sides of the trail were measured. In two of three sample plots along the 10 m wide sections, even third ruts were formed (Rut_{third_left}, Rut_{third_right}). The rut depth of several passes (Rut_{forw_sev}) is the maximum of the means of the first, second and third ruts:

$$Rut_{forw\_sev} = Max\ (Mean\ (Rut_{first\_left}, Rut_{first\_right}), \\ Mean\ (Rut_{second\_left}, Rut_{second\_right}), \\ Mean\ (Rut_{third\_left}, Rut_{third\_right})) \qquad (1)$$

Along the 4.5 m wide trails, no second ruts were formed, which means that Rut_{forw_sev} is equal to the mean of the first ruts ($Mean\ (Rut_{first1}, Rut_{first2}$). The increase in rut depths after harvesting (Rut_{incr_forw}) is calculated by subtracting Rut_{forw_sev} from Rut_{harv}. The total width of all ruts was also measured along all sample lines. The total width of ruts (Rut_{width_tot}) is the distance from the left border of the rut on the far left to the right border of the rut on the far right.

After the test drives, all the remaining trees on the study plots were measured for diameter at breast height (DBH). The volume of trees on the plot (V_{plot}) is the sum of all the harvested ($V_{harvested}$) and remaining trees. The DBH of the remaining trees was converted to cubic metres by using taper equations by Laasasenaho (1982). The DBH, height and volume of each harvested tree was derived by using the harvester stem profile data (STM format) that gives the diameter of the stem profile in 10 cm intervals. Cubing of trees was derived by summing up 10 cm long sections. Estimates of dry mass of logging residuals were calculated using biomass equations by Repola (2009).

3. Results

Rut depths are significant. The mean of rut depths after one harvester pass (Rut_{harv}) varies between 8.4 cm and 18.0 cm and the mean of rut depths after one harvester pass and one forwarder pass (Rut_{forw_one}) between 10.8 and 22.4 cm (Table 2). Increasing the logging trail width from 4.5 m to 6 m increased the total width of the ruts by 77 cm (from 346 cm to 423 cm), and increasing the trail width from 4.5 to 10 m by 215 cm (from 346 cm to 561 cm). Wider logging trails resulted in a decreased rut depth. The increase in rut depths after harvesting (Rut_{incr_forw}) is clearly lower on 6 m wide (4.0 cm) and 10 m wide (4.2 cm) test trails than on 4.5 m wide trails (8.0 cm). Characteristics of the test trail sections were similar in terms of growing stock (V_{plot}) and mass of logging debris, but the means of the ruts on different test trail sections indicate that the strength of the soil increased from the start to the end of the trails. The first 100 m long sections, with 10 m wide trails, clearly had the deepest ruts after harvesting, the 100 m long sections with 6 m wide trails were the second deepest, and the third 100 m long sections with 4.5 m wide trails had the shallowest ruts (Table 2).

4. Discussion

The test arrangements were affected by very wet conditions. The autumn of the test period was very rainy, making the peaty soil very humid and soft. Therefore, the forwarder drove the tests with no load. Overall, the mean rut depth after harvesting was considerably deeper than in earlier tests carried out in Finland in August. Uusitalo and Ala-Ilomäki (2013) measured mean rut depths at 7.0 to 13.5, the mean of all study plots (with a brash mat) being 10.1 cm in circumstances with smaller growing stock. In the study by Uusitalo et al. (2012), rut depths after harvesting varied from 2.0 to 17.1 cm, the mean of all study plots being 9.0 cm.

Pre-planning of the test trail sections failed to some extent. The soil properties clearly changed along the 350 m long test trails. It would have been wise to change the order of the 4.5 m, 6 m and 10 m wide sections within the three trails. No visible differences in trial conditions were found prior to the tests, since the properties of the soil were not adequately measured. However, the sections were similar in terms of growing stock, which is the variable most often used for describing trafficability in peatland forests. The study material comprises only one forest and the operations were carried out with only one harvester and one forwarder. Pine bogs in Finland vary to some extent in terms of growing stock and thickness of the peat layer. The study stand was quite typical in terms of growing stock. Thickness of the peat layer was not measures accurately but few random measurements indicated that the thickness of the peat layer was more than four meters. Moreover, the machines were rather poorly equipped for peatland operations. Equipping the machines with special soft soil tracks on both front and rear bogies would probably have decreased rutting.

Despite the many shortcomings of the test, the results of the study can be considered promising. The widening of the trail from 4.5 m to 6 m was clearly beneficial from the point of view of the maximum rut depth. Allowing the forwarder driver to choose a new parallel route, so that new ruts were formed alongside the previous ones, resulted in 5 cm lower maximum rut depths on average after three to four forwarder passes. However, this study does not reveal the extent to which wider logging trails increase the maximum number of passages allowed on one trail. The increase in trial width from 4.5 m to 10 m also markedly decreased the maximum rut depths, yet the increase from 6 m to 10 m did not result in a further decrease in rut depth. Trails wider than 6 m bring additional variables that have an effect on the results into play. Increasing brash accumulation on the trail also raises the question of how the trees should be processed. In this trial, no extra instructions were given to the harvester operator as to how to accumulate the brash mat. If the brash mat on the 10 m wide trail was forced to accumulate on a narrow belt, it would most probably have reduced rutting. Widening the trail to 10 m will, however, reduce the economic output of the forest in the long run (Salomäki et al. 2012).

The test driver gave very positive feedback on driving along wider trails. He felt that wider trails gave him more opportunity to plan his driving, allowing him to fully benefit from the bearing capacity of the trail and thus reduce rutting. The test was carried out in very difficult conditions, with inadequately equipped machines and only in one forest. Therefore, the test should be repeated with larger study material. It is also important that the key soil properties are measured.

5. References

Ala-Ilomäki, J., Högnäs, T., Lamminen, S., Sirén, M., 2011: Equipping a conventional wheeled forwarder for peatland operations. International Journal of Forest Engineering 22(1): 7–13.

Eliasson, L., Wästerlund, I., 2007: Effects of slash reinforcement of strip roads on rutting and soil compaction on a moist fine-grained soil. Forest Ecology and Management 252(1-3): 118–123.

Gerasimov, Y., Katarov, V., 2010: Effect of bogie track and slash reinforcement on sinkage and soil compaction in soft soils. Croatian Journal of Forest Engineering 31(1): 35–45.

Haavisto, M., Uusitalo, J., 2010: Turvemaan ensiharvennusten maastovaurioita minimoiva reitinoptimointi LOGTRACK-simulattorilla. The Finnish Forest Research Institute. Unpublished manuscript 19 p.

Laasasenaho, J., 1982: Taper curve and volume functions for pine, spruce and birch. Communicationes Instituti Forestalis Fenniae 108, 74 p.

Labelle, E.R., Jaeger, D., 2012: Quantifying the use of brush mats in reducing forwarder peak loads and surface contact pressures. Croatian Journal of Forest Engineering 33(2): 249–274.

McDonald, T., Seixas F., 1997: Effect of slash of forwarder soil compaction. Journal of Forest Engineering 8(2): 15–26.

Nugent, C., Kanali, C., Owende, P.M.O., Nieuwenhuis, M., Ward, S., 2003: Characteristic site disturbance due to harvesting and extraction machinery traffic on sensitive forest sites with peat soils. Forest Ecology and Management 180(1-3): 85–98.

O'Mahony, M.J., Ueberschaer, A., Owende, P.M.O., Ward, S.M., 2000: Bearing capacity of forest access roads built of peat soils. Journal of Terramechanics 37(3): 127–138.

Repola, J., 2009: Biomass equations for Scots pine and Norway spruce in Finland. Silva Fennica 43(4): 625–647.

Salomäki, M., Niemistö, P., Uusitalo, J., 2012: Ensiharvennuksen toteutusvaihtoehdot ja niiden vaikutukset männikön tuotokseen ja kasvatuksen kannattavuuteen ojitetuilla turvemailla – simulointitutkimus. Metsätieteen aikakauskirja 3/2012, 163–178.

Tiernan, D., Zeleke, G., Owende P.M.O., Kanali, C.L., Lyons, J., Ward, S.M., 2004: Effects of working conditions on forwarder productivity in cut-to-length timber harvesting on sensitive sites in Ireland. Biosystems Engineering 87(2): 167–177.

Uusitalo, J., Ala-Ilomäki, J., 2013: The significance of above-ground biomass, moisture content and mechanical properties of peat layer on the bearing capacity of ditched pine bogs. Silva Fennica 47(3): 1–18.

Uusitalo, J., Haavisto, M., Niemistö, L., Kataja, J., 2010: Assessing the effect of harvesting method on soil disturbances with a spatial harvesting simulator. Proceedings FORMEC 2010 Conference, July 11–14, 2010, Padova, Italy, 5 p.

Uusitalo, J., Kaakkurivaara, T., Haavisto, M., 2012: Utilizing airborne laser scanning technology in predicting bearing capacity of peatland forest. Croatian Journal of Forest Engineering 33(2): 329–337.

Zeleke, G., Owende, P.M.O., Kanali, C.L., Ward, S.M., 2007: Predicting the pressure-sinkage characteristics of two forest sites in Ireland using in situ soil mechanical properties. Biosystems Engineering 97(2): 267–281.

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