Austro2007/FORMEC´07: Meeting the Needs of Tomorrows´ Forests – New Developments in Forest Engineering, October 7 – 11, 2007, Vienna and Heiligenkreuz – Austria

FOREST STAND DISRUPTION BY FULLY MECHANIZED LOGGING SYSTEMS IN SPRUCE STANDS

Radek Jirousek; Radomir Klvac; Stanislav Liska
Mendel University of Agriculture and Forestry in Brno; Czech Republic; klvac@mendelu.cz

Keywords: damage to stands, fully mechanized technology, control methods

Abstract: *Sustainable forestry supported by the PEFC and FSC certification systems needs to approach logging and skidding operations in an environment-friendly manner. The European Union does not have a unified method for the quantification of damage to forest stands after performed logging operations. The currently implemented individual control methods vary in their methodologies.*
A duly applied fully mechanized technology can reduce damage to stands. The upper limit of damage to standing trees achievable is 2 % of trees at maximum. The upper limit of soil disturbance can be derived from the root space of Norway spruce (Picea abies /L./ Karst) root system and reaches the rut depth of 10 cm.

1. Introduction

Sustainable forestry is one of the most significant priorities of the present forest management fully sustained by the PEFC and FSC certification systems. In connection to the issue of sustainable forestry it is necessary to think about the approach towards forest ecosystem as such, chiefly in commercial forests. This approach necessarily concerns also logging and hauling of wood. It is obvious that due to employment of logging and hauling machinery the forest ecosystems always suffer some degree of damage as a result of the interaction between the machine and standing trees or the soil surface.
Logging and hauling machinery cannot be assessed only with respect to achieved shift performance, labour productivity and energy intensity but also with regard to damages inflicted on the existing stand. The aim of an appropriately chosen logging and hauling machinery should therefore be the effort to minimize damages. Protection against occurrence of damage can be divided into active and passive.
Active protection can be understood as a complex of technical, production, technological and organizational measures which serve the reduction of damage occurrence to forest ecosystems. Passive protection tries to prevent damages by mere limitation or ban on production methods etc. (Simanov, 2001 in Michálek, 2002)

The utilization of fully mechanized logging technologies at concurrent correct observation of the technological procedure decreases the harm to forest ecosystem in comparison to traditional technologies. Ulrich et al. (1999) specifies the rate of damage values for harvester technology and for whole stem logging during improvement logging operations (see Table 1)

Share of processed wood mass by fully mechanized technology in contrast to motor-manual technology is much higher in many European countries than in the CR; e.g. in Sweden (approx. 98%), Ireland (95%) and in Finland (roughly 91%) (Karjalainen et al., 2001).

Table 1: Extent of damage during the application of different logging technologies and their variations

Short-length method (harvester technology)	Whole-stem logging technology (felling – chain saw, primary extraction – horse, skidding – general-purpose wheeled tractor)	Whole-stem logging technology (felling – chain saw, primary extraction – horse, skidding – wheel skidder)
2.02 %	7.28 %	22.12 %

With respect to the rising manpower costs and decreasing interest in the work in the forestry sector the volume of logging work ensured by means of harvester technology is now slightly on the rise in the CR. In spite of that, the volume of harvester technology in the CR does by far not reach the proportions of both Scandinavian countries and Ireland. In 2005, the volume of wood processed with the utilization of these methods amounted to the volume of 1.712 million m^3 out of the total logging capacity, which is 11% of the total volume of 15.51 million m^3 of logged wood (Anon. 2005).

There is no uniform standard within the framework of the EU forestry practice for the assessment of the forest stand condition after a performed logging operation. Several methods are used to determine the degree of harm to the stand and soil due to the machine passage the labouriousness, practical applicability, accuracy and speed of which differ. The objective of the paper is to evaluate disturbance of soil or damage to stand by logging and hauling machinery.

2. Material and methods

The McMahon's method extended by further criteria assessing also the damage to standing trees was applied for the evaluation of soil disturbance and stand damage.
This method serves the determination of the degree of soil disturbance. The concept of the method rests in ocular estimate of the soil disturbance in points of measurement. The points are situated in laid out lines perpendicular to the skidding lines. The spacing between the lines depends on the surface area of the stand and is calculated from the following relation

$$R = \frac{P}{n} * 10000 \quad (1)$$

where:

R - spacing between lines (m)
P - stand surface area (ha)
n - number of measurement points

Individual points are assigned a numerical code according to the extent of inflicted damage. Points are located on transects at all times 1m from each other. The points are always in the centre of plots with the diameter of 0.3m (707 sq cm). The number of points also depends on the required accuracy (or more precisely, on the maximum variation in %); see Table 2.

The method according to McMahon was modified for the purpose of determining its applicability and due to the necessity of identifying the rate of damage to standing trees. The modification consists in the expansion by 4 numerical codes which characterize the damage to standing trees (Table 3). These codes specify mechanical damage inflicted by the interaction between a machine or load and a standing tree. If there are more damages on one tree, each shall be registered individually and separately. These damages are registered on trees which are located in a 1m-wide stretch from the laid out assessment line.

Table 2: The number of measuring points necessary to achieve the required measuring accuracy (McMahon, 1995)

Error in %	**Number of measuring points**
1	10000
2	2500
3	1111
4	400

Table 3: Numerical codes characterizing the damage to trees (Ulrich et al., 2001)

Code 12	Minor damage to the tree up to 10 sq cm
Code 13	Damage to the tree up to 100 sq cm
Code 13+	Damage to the tree of more than 100 sq cm
Code 14	Trees without any damage

3. Results

3.1. Mathematic and statistic comparison of McMahon's method evaluation

The variables of damage are represented by individual codes of soil and standing tree damage, i.e. relative frequency of quantitative attributes with the values of variables 1 – 0 (yes – no). The variables in question have a probability character with binomial division and parameters of mean value $\mu = p$.
Dispersion is calculated on the basis of the following relation

$$\sigma = \frac{p*(1-p)}{n} \qquad (2)$$

where:
p is the probability of the phenomenon occurrence (code of damage)
n total number of experiment results

The accuracy of the result is defined by the interval of reliability for relative frequency p, which has the following estimation formula

$$P = p \pm z_\alpha * \sqrt{\frac{p*(1-p)}{n}} \qquad (3)$$

according to the location of values p and n,
where:
p is the probability of the phenomenon occurrence (code of damage)
n is the total number of experiment results.

or sufficiently high n and p within the interval of 30 % to 70 % the symbol P stands for the estimated interval of reliabilitFy and z_α represents the quantity of standardized normal division for the probability α. Necessary range of measurement is then calculated on the basis of the relation

$$n = p * (1 - p) * \frac{z_\alpha^2}{\Delta^2} \tag{4}$$

where:

Δ	is the estimated error
z_α	stands for the quantity of standardized normal division for probability α.
p	estimated interval of reliability.

For sufficiently high n and p within the interval below 30 % and above 70 % it is necessary to first use Fischer's transformation. Estimate φ_p = 2*arcsin $\sqrt{p}$ of the interval of reliability for the transformed variable φ_p can be determined as

$$\varphi_p = \varphi_p \pm \frac{z_\alpha}{\sqrt{n}} \tag{5}$$

where:

z_α	stands for the quantity of standardized normal division for probability α.
φ_p	estimate of interval of reliability for the transformed variable
n	number of experiment results

necessary measurement range calculated from this expression is equally determined from the expression

$$n = p * (1 - p) * \frac{z_\alpha^2}{\Delta^2} \tag{6}$$

where:

z_α	stands for the quantity of standardized normal division for probability α.
n	number of experiment results
p	estimated interval of reliability

Required numbers of measurements at probability of achievement of the required accuracy of 95 %, i.e. z_α =1.96 (=2) are listed in Table 2.

Table 4: Degree of soil surface disturbance

Soil surface disturbance											
Site	**Damage codes (%)**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Sufficient bearing capacity	89.7	1.8	1.2	0.0	0.0	0.1	0.0	0.0	2.4	0.2	0.1
Water-logged	**93.5**	**3.2**	**2.7**	**0.0**	**0.1**	**0.4**	**0.1**	**0.0**	**2.2**	**0.4**	**0.3**
Water-logged – inappropriate date	91.6	3.0	3.9	1.8	1.3	1.5	0.9	0.0	0.1	0.0	0.0

In total more than 60 measurements were taken in spruce stands in sites with a sufficient bearing capacity as well as in water-logged sites. Significantly different results were determined in water-logged sites where the date for the operation was chosen inappropriately and the damage to the stand was of relatively considerable nature (Table 4 and 5).

Table 5: Degree of damage to trees

Damage to trees				
Site	**Damage codes (%)**			
	12	**13**	**13+**	**14**
Sufficient bearing capacity	1.9	0.9	0.1	97.1
Water-logged	**2.3**	**1.2**	**0.2**	**96.3**
Water-logged – inappropriate date	2.8	1.5	0.1	95.6

4. Conclusion

It is obvious that McMahon's method analyses the damage to stands in a complex manner with the original focus primarily on soil disturbance, risk of erosions etc. The supplemented codes characterizing damage to standing trees have turned this method into a versatile tool which also enables to determine the cause and extent of soil disturbance and damage to the existing stand. With regard to high number of points of measurement guaranteeing the required accuracy and difficult marking of measuring transects in younger stands and stands with high degree of stocking, the McMahon's method is more suitable for purposes of a very accurate determination of damage for expert opinions laying down the amount of compensation for the damage to forest property and for scientific application. The other methods, such as the German, Finnish or Swedish, are more appropriate for practical and flexible use due to their smaller time intensity and sufficient accuracy.

The McMahon's method varies from the Finnish, Swedish and German methods also in the interpretation of the examined variables. The rate of accuracy is directly proportional to the number of points of measurement. The accuracy of the German, Finnish and Swedish methods depends on the actual dispersion of the measured values of damage. The necessary number of plots defines the dispersion of values for the required accuracy. The higher the number of measured sample plots, the more accurate result can be assumed.

If machinery is used in water-logged sites, it is absolutely necessary to conform to the current moisture conditions in the soil and thus also to the soil bearing capacity. Lower damage to standing trees can be achieved by means of an appropriate employment of harvester technologies. Ulrich (1999) and Ryyanen (1992) appraise the preventable damage to standing trees at 2 % and between 0.9 % and 1.5 %, respectively.

Table 6: Soil surface disturbance due to operation of logging machinery. Assessment criteria

Damage class	Code	Type of disturbance	Description
SOIL DISTURBANCE:			
Soil without visible disturbance, maximum ground pressure – 50 kPa	1	humus not disturbed	Humus undisturbed in the plot, regeneration undisturbed, potentially only furrows after primary extraction of stems. Slash scattered in a layer of min. thickness
Minor damage due to dragging of the load	2	humus partly disturbed	a. Humus locally changed in its placement and composition, upper soil partially denuded after movement of stems from the stand, furrows clearly visible b. Humus and upper soil undergrowth parts of plants (bilberry etc.) are mixed on a larger area (approx. 50 %), soil structure modified very slightly
	3	humus and upper soil layer are mixed	Humus and upper soil layer are mixed; soil structure unchanged
Deep disturbance due to machine passage	4	Minor disturbance up to 5 cm deep	Disturbance of humus as well as soil in the wheel tracks due to compression. Change of soil structure is apparent, furrows after movement of stems during cable skidding. Accumulation of water in the ruts, creation of side ridges of soil with humus at the edge of the ruts.
	5	Major disturbance of the soil, ruts of up to 15 cm in the prevailing length	
	6	depth 15–30 cm	
	7	depth of over 30 cm	Considerable deformation of soil in the ruts, humus non-existent. Earth layered around the lines, unequal depth of ruts, tractor runs the risk of rutting, frequent presence of water in the ruts. Necessity of finding a new line or adjustment by means of a grader or piled up slash.
	8	layering of mineral soil and subsoil	Forest soil layering on the surface, the layers are not reinforced
Slash pile up	9	layer depth 10–30 cm	Forest soil is not visible, obstacles for transplants and outplanting
	10	layer depth of over 30 cm	
Impassable or inaccessible stands	11	rocks, stumps, stones, water-logged places	Local boulders and stumps (0.2 – 0.5 m^3) Soils partly muddy, passable only when frozen, gullies, hollows deeper than 1 m, locally weathered rocks. Slope angles of 30 % to 45 %. Non-productive spaces, water-logged soils, soils in slopes of angles higher than 45 %, occurrence of uninterrupted rocks, nurse crops.
DAMAGE TO TREES:			
Minor damage up to 10 sq cm	12	Scratches or bark peels within the specified range	Obvious mechanical damage, e.g. scratch or peeled off bark on buttresses or tree stems.
Bigger damage of more than 10 sq cm	13	Scratches or bark peels within the specified range	Specify the height of damage to the tree above the terrain in the form of a fraction.
	13+	Significant damage of over 100 sq cm	
Tree without any damage	14		There is no visually determinable mechanical damage on the buttresses or tree stems.

The rut depth of 10 cm, as defined by the Finnish method for soil disturbance determination, can be regarded as a critical value of soil disturbance also in the context of the Czech Republic. This limit of disturbance is based on the biological and growth characteristics of Norway spruce which is the most frequently represented tree species in the CR. Ulrich (2006) remarks that the root space under spruce stands in central Europe is only few centimeters high (8–20 cm).

This is the reason why higher tolerated rut depth would necessarily lead to damages on the root system. The overview of damage specified in Table 6 can also serve as a basis for the critical value determination. Apart from soil disturbance, also individual types of damage to trees are listed.

5. Acknowledgements

This paper was elaborated with the contribution of a Research plan of the Faculty of Forestry and Wood Technology at Mendel University of Agriculture and Forestry in Brno "Forest and wood, …" MSM 6215648902 and the National Agency for Agricultural Research (NAZV) project of the Ministry of Agriculture of the CR – "Model of a multicriteria evaluation of environment-friendly skidding technologies" QH71159.

6. References

ANON.,2006. Zpráva o stavu lesa a lesního hospodářství České republiky v roce 2005, (Green report of the Czech Republic) Ministerstvo zemědělství, Praha. ISBN 80-7804-550-3. 135 pp. In Czech.

BJÖRHEDEN, R., FRÖDING, A., 1986. A new routine for checking the biological quality of thinning in practice. The Swedish University of Agricultural Sciences, Department of Operational Efficiency, Research Notes 48. 14 pp.

KARJALAINEN, T., ZIMMER, B., BERG, S., WELLING, J., SCHWAIGER, H., FINÉR, L. AND CORTIJO, P., 2001. Energy, carbon and other material flows in the Life Cycle Assessment of forestry and forest products. Achievements of the Working Group 1 of the COST Action E9. European Forest Institute, Finland. ISBN 952-9844-92-1, ISSN 1455-6936. 68 pp.

MC MAHON, S., 1995. A survey method for assessing site disturbance. New Zealand Logging Industry Research Organisation. Project Report 54.Rotorua. 16pp.

MICHÁLEK, T, 2002. Rozbor škod na lesních porostech způsobených těžební činností a posouzení metod pro jejich zhodnocení. Diplomová práce. (Damage on forest stand evaluation caused by logging technologies. Diploma thesis). Ústav lesnické a dřevařské techniky LDF MZLU v Brně. 49 pp. In Czech.

SIMANOV. V., 2002. Těžba a soustřeďování dříví (přednášky – osnova). (Harvesting and logging – lecture notes). Ústav lesnické a dřevařské techniky LDF MZLU v Brně. In Czech.

RYYANEN, S., 1992. Agricultural tractor and harvester in thinning of pine stands. Tyotehoseuran-Metsatiedote. 1992, No.3, 6 pp.; 8 ref.

ULRICH, R., NERUDA, J., VALENTA, J., CHYBA, M., INGERLOVÁ, J., 2001. Kontrolní metody po probírkách provedených harvesterovou technologií, které jsou vhodné pro lesnickou praxi. Vyjádření škod na půdě a porostu. Studie. MZLU v Brně. (Harvesting system Evaluation methods suitable for forest praxes. Soil and stand damages). In Czech

ULRICH, R., NERUDA, J., VOJÁČEK, A., INGERLOVÁ, J., 1999. Zjišťování škod ve smrkových probírkových porostech po harvesterech a vyvážecích traktorech. Studie. MZLU v Brně. (Damage investigation in spruce stands caused by harvester and forwarder.). In Czech.