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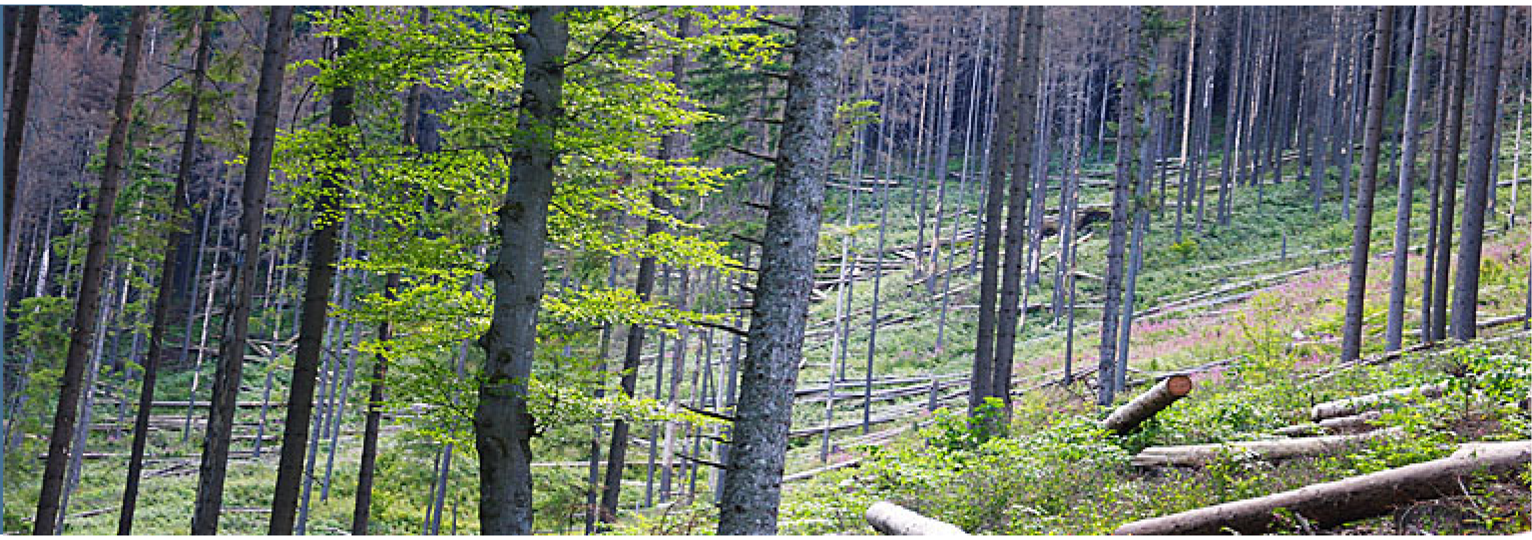

From Theory to Practice: Challenges for Forest Engineering

49th Symposium on Forest Mechanization
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Forest Engineering Network

From Theory to Practice: Challenges for Forest Engineering

Proceedings and Abstracts of the 49th Symposium on Forest Mechanization

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Preface

Ladies and Gentelmen,
Dear Colleagues,

On behalf of the Organising Committee and the authorities of Faculty of Forestry and Faculty of Production Engineering of Warsaw University of Life Sciences – SGGW I welcome you to Poland.

We are delighted to have you here to participate and share in the 49th International Symposium on Forestry Mechanization - FORMEC 2016. The Symposium "Forestry Mechanization" (from 1994 named with the acronym "FORMEC") was held for the first time in 1966. The original idea of the organizers of this scientific meeting was to give an opportunity to meet and discuss for scientists from Eastern and Central European countries. At the beginning the number of participants was rather small (20-30). The number of countries participating each year has grown steadily. In this year we have about 140 participants from 24 countries.

The theme of the 49th conference, https://www.formec.org/, which takes on 4–7 September 2016 in Warsaw, Poland, is: „From Theory to Practice: Challenges for Forest Engineering". Poland organises FORMEC for the fifth time (1970, 1979, 1988, 2000).

FORMEC is an international symposium which gathers leading professionals and scientists in the field of all aspects of forest engineering from all over the world. The aim of this meeting is to provide a forum to present and discuss recent research developments in the broad field of Forest Utilization and Forest Engineering and gives special room and attention to activities and future collaboration opportunities.

I wish you good luck and fruitful cooperation for joint thinking, joint productive work in the coming days. It is also my sincere hope that this symposium will be more than a mere networking opportunity for research cooperation, but that it will be also a platform for the sharing of our highest aspirations and for mutual encouragement and support.

Head of the Organising Committee
dr. Tadeusz Moskalik, prof. of WULS-SGGW

Chapter 1. Timber harvesting – productivity and efficiency

Comparison of standing timber sorting with bucking by harvesters

Jiří Dvořák[1]*, Pavel Natov[1], Jan Kašpar[1], Grzegorz Szewczyk[2], Mariusz Kormanek[2]

Abstract: Annually, harvester technology in the Czech Republic processes 29 % of annual wood yield, which represents 4.5 mil m^3. What remains an open issue is the possibility of electronic scaling and grading of timber from harvesters, which is motivated by two aims of timber suppliers (forest owners). The first aim is to achieve maximum possible yield and consequently maximum receipts for the produced timber. The second aim is to meet the requirements of customers who are in charge of timber sales. Deployment of harvester technology often shifts the preferences towards the latter aim, i.e. it results in submitting to customer requirements or, in a better case, in a compromise between the two possibilities, which may prove unprofitable particularly for forest owners. A comparison of planned production with the proposed grading of standing timber conducted prior to the actual launch of harvesting may guarantee efficient management. At present we can draw on assortment tables (e.g. Pařez and Michalec, 1987; Petráš et al., 1996) or indirectly on available commercial software applications, which are based on assortment tables and classify timber volume within six quality classes, mostly in relation to diameter at breast height, yield class, health status of the given stand, etc. Another possibility is to apply grading simulation based on data provided e.g. by measurement and control system of harvesters. Cut-to-length logging and consequent grading of spruce by harvesters remains the key application in forest management, as it takes up a major share of the of annual volume of timber production, i.e. approx. 73 % (MZe 2015). In extreme cases up to eight different spruce logs in six quality classes are produced by the harvester technology in a single production block, which may result in financial losses caused by misplacing individual assortments in the course of forwarding to roadside landings or giving preference to less valuable assortments during production to satisfy the demands of a particular customer. The quality of grading must be supported by correct methods of timber scaling in forest stands. The primary aim of this paper is to compare the differences in timber scaling by harvester production-recording software and manually within the stands. The second objective is to compare the volume of standing timber assortments with the corresponding volume of harvester-processed timber based on customer specifications. The resulting difference represents 1.5–4.7 % in electronic calculations of timber volume as compared with "Recommended Rules for the Measurement and Grading of Timber in the Czech Republic". The difference between standing timber grading and harvester-recorded grading ranges between 2.8 and 6.3 % in favour of customers in related quality classes.

Keywords: harvester technology, assortment, timber grading

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1. Introduction

Seen from our perspective, harvester technology has become the third production method in the long history which may be applied at the production stage of timber harvesting together with manual felling and motor-manual felling using chainsaw. This technology represents an important advance, as apart from the possibility of harvesting and handling of timber it offers a major added value, which is "individual" electronic timber scaling, performed along with delimbing and timber handling (Dvořák et al., 2011). This fact would be highly significant for forest management if outputs of the measurement and control system were respected by forest owners. However, the reality in Czech forest management is quite the opposite, with sporadic exceptions. Initial scaling and control scaling of produced assortments are done manually at roadside landings, as forest owners are suspicious of service providers as to the credibility of harvester data. The Czech Republic still lacks a unified control procedure which would provide a methodological system of control measurements and equipment calibration, as well as access to the systems to forest owners or representatives of independent organizations to allow them to check the settings of a number of parameters in the measurement and control system (e.g. settings for allowance, bark deductions, etc.).

This is due to ignorance of most forest managers with respect to harvester measurement and control systems, due to insufficient knowledge of these systems on the part of forest district managers in Forests of the Czech Republic, State Enterprise, which in turn limits the application of an already approved internal regulation into practice (LČR 2009) as well as the reluctance and inability of forest owners to apply legal mechanisms enabling the entering of third parties into measurement and control systems (e.g. by including this provision in contracts for work) of harvesters owned by other persons providing harvesting and forwarding services to forest owners.

The above-mentioned issue is a reality even at present, when the ratio of cut-to-length logging in the Czech Republic is estimated at almost 30 % (MZe 2015). The number of harvesters in the country also remains debatable. The Central Register of Motor Vehicles of the Czech Republic lists 81 vehicles (Natov et al., 2015), while statistics of the Ministry of Agriculture list a total of 494 machines (MZe, 2015). Considering the annual timber volume of 4.5 mil m^3 produced by the cut-to-length method, the actual number will probably be somewhere in the middle. The Central Register data are undeniably incomplete, as owners are not obliged to register the harvesters if they are not used on public and private roads. Numbers released by the Ministry of Agriculture, on the other hand, can be considered overrated with respect to the data collection method applied and the real usability of the owned harvesters.

The aim of the study is to point out differences amoung timber volume outputs obtained from harvesters, manual measurements and standing timber volume. Another objective is to compare the ratio of produced assortments volume with the volume according to assortment tables.

Conclusions of this report will serve as complementary material for "Recommended Rules for Electronic Scaling of Timber in the Czech Republic".

2. Methods

The primary task of the study is to verify the proposed methodology in a specific case study prior to launching system data processing from harvesters deployed in various production conditions. Owing to this, an analysis has been conducted at a single workplace so far. The procedure is outlined in the following points.

2.1. Specification of production conditions

Planned advance felling was analyzed in a forest stand 55B7b managed by the Military Forests and Farms, State Enterprise, the Hořovice division. Timber harvesting was done by John Deere 770D harvester with installed production-recording software TimberMatic 300, version CDM 2.3. Detailed technical parameters can be found on www.deere.com. The field conditions of the forest stand can be classified as terrain type 12, i.e. bearing terrain without obstacles, with slight slope inclination up to 15 %.

Only spruce was harvested in the stand. The surveying parameters of the forest stand are shown in Table 1.

2.2. Specification of cut-to-length logging in the forest stand

Cut-to-length logging is done according to customer specifications in six assortments (Tab. 2). The given production encompasses classes III, IV and V of the six classes according to which timber is classified in the Czech Republic (DPMTD, 2007). The last (seventh) assortment is classified as "waste" and represents harvesting residue which does not conform to the metric requirements of the produced assortments and is left cut-up in the stand. Round timber, aggregate and saw logs are intended for production of sawn timber (classified as quality class III). Mechanical wood pulp (work term "ROTO") is classified in quality class IV. Selection pulpwood and pulpwood, respective of their quality, are used for production of paper industry pulp or as a material for the production of compressed or glued boards (quality class V).

In John Deere harvesters the log parameters are entered in the production-planning software SilviA together with price matrices and "price types" (see chapter 2.3). The Timbermatic 300 system has an additional setting for entering every processed trunk and the assortments produced from it in the *.STM format (in harvesters using the StandForD 2010 system the files have *.HPR format). The data saving must be set up individually and is does not come pre-set by the harvester supplier. As standard, the measurement and control system saves only comprehensive information on production within a forest stand or a production block as files in *.PRD format (harvesters using the StandForD 2010 system the files have *.THP format) (Skogsforsk, 2010).

2.3. Specification of "price types" and method of volume calculation by the measurement and control system

Prior to launching production, the respective "price type" must be entered for each assortment, based on which the proposed grading and consequent calculations of assortment volume are done. At present, the Standard for Forest Data and Communication (StanForD) includes fourteen "price types" (Skogsforsk, 2012). For the purposes of calculations of the produced assortment volume the two following price types are used:

- **m3toDE**

The price type was included in the production-planning software following requirements from Germany. Volume calculations draw on the mid-diameter of the given assortment and nominal log length. The mid-diameter is rounded down to full centimetres and the volume is calculated from this value. The measurement procedure is prescribed by the Decree of the Federal Ministry for Food, Agriculture and Forests issued in 1969 (GERMANY, 1969). The assortment is classified based on the minimum top end diameter and entered nominal log length. The same method of volume calculation is required in the Czech Republic (DPMTD, 2007).

- **m3f**

The volume of whole-stem log or assortment is calculated from the real (non-rounded off) section diameter which is set at a 10 cm interval. The assortment is classified based on top end diameter. The diameter is measured in mm.

Table 1: Surveying parameters of the studied forest stand 55B7b according to the Forest Management Plan.

Tree species	**representation**	**mean tree volume**	**height**	**diameter at breast height**	**yield class**	**standing volume**
	(%)	(m^3)	(m)	(cm)	(-)	(m^3/ha)
spruce	90	0,72	25	29	30/2	385
larch	5	0,76	25	30	28/1	19
pine	3	0,71	23	31	26/2	10
birch	2	0,63	24	29	26/1	5

Table 2: Entered production and “price types” for calculating volume.

assortment	price type	min. top diameter (cm)	nominal log length (m)	specified quality (-)	quality class
round timber	m3toDE	20	4,00	1,2,3,4	III.
aggregate	m3toDE	12	4,00	1,2,3,4,5	III.
saw logs (KPZ)	m3toDE	17	4,00	6	III.
mechanical wood pulp	m3f	8	2,00	1,2,4	IV.
selection pulpwood	m3toDE	12,5	2,45	1,2,3,8	V.
pulpwood	m3f	5	2,00	1,2,3,4,7	V.
„waste“	m3f	3	0,01	1,2,3,4,5,6, 7,8	-

2.4. Method of calculating assortment volume in accordance with the Recommended Rules for the Measurement and Grading of Timber in the Czech Republic from 2008

Over bark volume calculations according to the “Recommended Rules for the Measurement and Grading of Timber in the Czech Republic 2008” (DPMTD, 2007) are done according to formula (1). The mid-diameter is measured in centimetres in the middle of the nominal log length. In mid-diameters over 20 cm the diameter is measured in two perpendicular directions from which the average is calculated. The decimal place values are rounded down.

$$V_{bk} = \frac{\pi}{4} * (d_{sk} - 2k)^2 * l * 10^{-4} \text{ (cm)} \qquad (1)$$

where:
V_{bk} log volume inside bark (m^3)
d_{bk} log mid-diameter measured over bark (cm)
l log length (m)
k bark thickness (cm)

Bark thickness of the spruce is calculated according to the formula (2):

$$2k = p_0 + p_1 * d_{sk}^{p_2} = \\ = 0{,}57723 + 0{,}006897 * d_{sk}^{1{,}3123} \text{ (cm)} \qquad (2)$$

where:
p_0, p_1, p_2 given coefficients based on specific woody species (-)
d_{sk} mid-diameter over bark (cm)

2.5. Method of calculating the volume of timber to the top of 7 cm. and the procedure of standing timber grading

One of the aims of the study is to compare the differences between timber volume from *.STM files with volume determined on standing timber prior to harvesting. The objective is to determine the deviation which, during standing timber auctions, may have a negative impact on work planning and economic results of the primary producer. To calculate standing timber volume in the Czech Republic, stakeholders use volume tables (ULT) which should calculate the entire volume of standing timber to the top of 7 cm over bark. For the purposes of this study we used simplified volume tables for determining the volume of standing timber to the top of 7 cm in hundredths of cubic meters inside bark, according to age classes, site classes and diameter at breast height without measuring height (Šimánek, 1987). The author assumes that the accuracy of this method is ±10 % of the actual volume.

In the course of volume calculations, diameters at breast height are stratified into diameter classes in 2 cm intervals, which is in turn important in timber grading. Percentage assortment tables draw on mean stem profiles. Assortment tables are designed to determine the ratio of volume of timber to the top of 7 cm in quality classes I to IV, which encompass timber in the form of round timber logs, quality class V (pulpwood) and quality class VI (firewood) (Pařez and Michalec, 1987). Quality classes V and VI have been joined together, as all harvester-produced timber in the given stand (including firewood) was delivered for the paper industry to produce pulp. The grading process takes into account the health status of the given stand, particularly rot at the lower parts of trees and top breakages, which degrade the quality of the assessed timber. The planned volume of assortments, or the ratio of individual assortments within the volume, is compared with the actual production.

3. Results

Six assortments of quality classes III and V were produced in the forest stand 55B7b. 802 out of the total 7,917 items produced were classified as “waste” and 65 items were not classified in the production-recording software (see Tab. 3). Pulpwood represented 59 % of produced assortments in the planned advance felling, which was the highest share. Assortment volume was also calculated in quality class III assortments, in selection pulpwood it was calculated according to the “m3toDE” price type, while in other logs according to the “m3fm” price type (see section 2.3).

The analysis calculates volume separately for each assortment. The total production volume derived from *. STM files according to the entered “price types” is 420.596 m^3. Calculations of timber volume according to the Recommended Rules for the Measurement and Grading of Timber in the Czech Republic from 2008 (hereinafter “recommended rules”) (DPMTD, 2007) determine the total timber volume at 414.434 m^3. The harvester production-recording software undervalues saw logs (round timber, aggregate, KPZ) by 0.4 to 0.9 % as well as selection pulpwood by 1 %. On the other hand, it overvalues quality class V assortments (mechanical wood pulp, pulpwood) by 8.8 % and 4.4 % respectively out of the total timber volume. The overall difference between production according to *. STM files and the recommended rules is 1.5 % (see Tab.4), which means that the production-recording software overvalues production volume. There is no legal norm in the Czech Republic which would stipulate the maximum allowable deviation from the recommended rules. The acceptable deviation is specified by an internal guideline or an agreement between the forest owner and service provider. For the largest forest owner in the country (Forests of the Czech Republic, State Enterprise) the permissible tolerance is 2 % (LČR, 2009). The commonly tolerated deviation is up to 5 % of the volume measured and calculated according to the recommended rules. The production-recording software automatically registers timber volume calculated in sections, which represents 433.88 m^3 in the studied volume, and the deviation from calculations according to the recommended rules would then be 4.7 % (Tab.4, column 2). Further results show calculations of standing timber volume prior to harvesting with the possibility of comparing it with electronic measurements by harvesters. Quantification of standing timber volume is an essential part of offers in the process of timber auctions. Electronic auctions are becoming increasingly attractive thanks to their "transparent" nature. Annually, Forests of the Czech Republic, State Enterprise, sell approximately 10 % of raw material in this way and are planning to increase the ratio to 20 % by 2019 (LČR, 2015). Standing timber offers in auctions require full callipering with consequent quantification of timber volume using forestry tables ULT (hereinafter ULT). Needless to say that timber volume is not a guaranteed quantity in auctions, unlike the number of trees. Yet the timber volume should be quantified as accurately as possible for timber recording. For our purposes we used simplified volume tables (Šimánek, 1987) (see section 2.5). Based on manually measured breast height diameter (1.3 m from the tree foot), relative site class 2 and the volume tables listed above, the volume of timber intended for felling was calculated at 659.38 m^3 (Tab.5). At this point it must be noted that the calculated volume differs strongly from the actual volume of the consequently harvested and measured timber. Similarly, the calculated volume deviates strongly from the requirements of the tables' authors, as the deviation should not exceed 10 %. This significant deviation can be accounted for by the application of simplified tables and by quantifying the volume of selected trees in advance felling, which is not a procedure commonly used in full callipering. In the course of our research we will continue to compare these methods of volume calculations to verify whether it is a system error or only an isolated case within the study.

If we disregard the differences in volume listed above and focus on a comparison of the "real" and "theoretical" timber grading, we can confirm minimum differences in classifying the log volume ratio into quality classes. Upon using the percentage assortment tables for the principal woody species in the Czech Republic (Pařez and Šimánek, 1987), 53.2 % of the timber volume calculated from volume tables can be classified into quality classes I - IV and 47.9 % of timber volume falls into quality classes V and VI. Logs of quality classes I – IV range within diameter classes 1–3, i.e. from 10 to 39 cm of mid-diameter depending on breast height diameter (Tab.6). In "real" grading we can see that 46.9 % of the total volume was classified as quality classes I – IV and 50.7 % as quality classes V – VI (Tab.7). The difference between the "theoretical" and "real" grading ranges from 3.4 to 6.9 %, which can be considered acceptable.

4. Discussion and conclusion

The conclusion of the conducted analysis presents different methods of calculating the processed timber volume with respect to the set "price type" in harvesters as well as the recommended rules for timber scaling and calculating standing timber volume prior to harvesting, which are reflected in differing results. At this point it must be noted that if we want to use harvester software outputs on the volume of processed timber both in the Czech Republic and Poland, it is necessary to set clear rules and control systems. This process starts with resetting the key factors, such as price type, bark thickness, allowance, cutting window and others, and encompasses calibration of the measurement systems.

Results obtained reveal differences in the outcome of two methods of calculating the same timber volume by the production-recording software (the presetting for each assortment can be selected from 14 formulas). The difference is primarily related to manual calculations based on Huber's formula which is required by the recommended rules. When calculating timber volume according to the preset price type, the difference in volume represents 1.5 % in favour of the harvester. It may be due to the fact that the harvester measures and calculates timber volume with the accuracy of three decimal places, while manual calculations involve rounding down to a whole number and volume is calculated with the accuracy of two decimal places. Different methods of bark deductions used by the harvester and in manual calculations account for the difference as well.

The second difference between the studied timber volume is 4.7 % in favour of the harvester (it calculates log volume in ten-centimetre sections). However, both of these differences of up to 5 % can be considered operationally acceptable (with the exception of requirements of Forests of the Czech Republic, State Enterprise, which request a difference of up to 2 %). A comparison with the results of standing timber volume calculations revealed a major difference of over 10 %. The author of volume tables considers this fact unaccountable and as such it will be subjected to further experimental measurements and analyses to investigate whether a system error had occurred.

Table 4: Comparison of assortment volume according to selected methods.

assortment	price type	number (pc)	mean volume of assortment i.b. according to set price type (m^3/pc)	mean volume of assortment i.b. calculation by sections (m^3/pc)
round timber	m3toDE	312	0,184	0,195
aggregate	m3toDE	980	0,096	0,102
saw logs (KPZ)	m3toDE	237	0,181	0,194
mechanical wood pulp	m3f	139	0,019	0,019
selection pulpwood	m3toDE	719	0,069	0,072
pulpwood	m3f	4 683	0,035	0,035
waste	m3f	802	0,005	0,005
unclassified	m3f	65	0,089	0,081
Total		**7 917**		

Table 5: Calculated volume according to volume tables for determining the timber to the top of 7 cm of standing trees.

interval of breast height diameter (cm)	diameter class (cm)	number of trees (pc)	volume per unit (m^3/stem)	overall volume (m^3)
0 – 90 *)	x	87	0	0
91 - 110	10	82	0.05	4.1
111 - 130	12	109	0.08	8.72
131 - 150	14	134	0.12	16.08
151 - 170	16	105	0.17	17.85
171 - 190	18	93	0.23	21.39
191 - 210	20	97	0.30	29.1
211 - 230	22	92	0.39	35.88
231 - 250	24	124	0.48	59.52
251 - 270	26	169	0.58	98.02
271 - 290	28	175	0.69	120.75
291 - 310	30	116	0.80	92.8
311 - 330	32	55	0.93	51.15
331 - 350	34	45	1.06	47.7
351 - 370	36	17	1.19	20.23
371 - 390	38	14	1.34	18.76
391 - 410	40	6	1.48	8.88
411 - 430	42	3	1.63	4.89
431 - 450	44	2	1.78	3.56
Total		**1525**		**659.38**

**) diameter class volume < 10 is not recorded in the tables*

Table 6: Classification of the produced timber into quality classes according to percentage assortment tables (Pařez and Michalec 1987).

diameter at breast height	quality class					
	I - IV.				V.	
	diameter class					
	3	2	1			
(cm)	(m^3)			(%)	(m^3)	(%)
10					4,1	0,6
12					8,7	1,3
14					16,1	2,4
16					17,9	2,7
18					21,4	3,2
20			8,8	1,3	20,3	3,1
22			15,3	2,3	20,6	3,1
24		13,1	16,9	4,6	29,5	4,5
26		42,4	12,2	8,3	43,4	6,6
28		73,1		11,1	47,7	7,2
30		58,1		8,8	34,7	5,3
32		33,0		5,0	18,1	2,7
34		31,6		4,8	16,1	2,4
36	3,3	10,3		2,1	6,6	1,0
38	7,3	5,6		2,0	5,8	0,9
40	4,3	1,9		0,9	2,7	0,4
42	2,6	0,9		0,5	1,4	0,2
44	2,0	0,6		0,4	1,0	0,2
Total	**19,6**	**270,6**	**53,2**	**52,1**	**316,0**	**47,9**

Table 7: Ratio of assortments in quality classes according to selected methods.

Grading method	Assortment ratio in quality classes		
	I. - IV. (round timber logs)	V. – VI. (stackwood)	not used or unclassified raw material
		(%)	
according to a measurement and control system	46,9	50,7	2,3
according to percentage assortment tables	53,2	47,9	-

The second aim of the analysis is to compare planned and actual timber grading. The results obtained reveal minimum differences in the volume ratio of individual assortments. Out of the total timber volume registered by the harvester software, 46.9 % is classified as quality class III round wood, 50.7 % as stacked timber of quality class V and 2.3 % is either not classified or constitutes waste which remains on the site or is consequently used for energy-producing purposes. When compared with planned grading, the volume ratio of assortments is 53.2 % and 47.9 % respectively in the order described above. Assortment tables do not take waste into account and only timber to the top of 7 cm is classified. The future task of grading simulations of the studied stands by a harvester simulator remains to determine whether it would be possible to achieve production of higher quality classes and thus better commercialize timber. It must be said beforehand that implementation of this objective in harvesting practice will probably always face two major obstacles: requirements of local purchasers of timber and the low volume of produced assortments of quality classes I or II whose production will be ineffective with respect to the consequent transport costs.

It may be concluded that the conducted analysis set the method of control timber measurements with respect to the "Recommended Rules for the Measurement and Grading of Timber in the Czech Republic" as well as the method of timber grading planning for forest owners. Both the methods could facilitate activities connected with planning grading and timber scaling if the rules for electronic scaling by harvesters are set and respected in forestry operations in the same way the Recommended Rules for the Measurement and Grading of Timber in the Czech Republic are respected.

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A new method for the loading of logs by portable winch and polyethylene chutes

H. Hulusi Acar

Abstract: In Turkey, approximately 50 million logs are being produced per year and they are loaded into the trucks. During the logging stage, the logs are transported over the forest roads with an average of one million roundtrips by trucks. In our country, mostly used traditional loading methods based on manpower. Only one portion loading operation is performed by machines that method can be relatively expensive and risky.

This study aimed to define a new combined loading system developed in which heavy logs are loaded into logging trucks by pulling them by a log-line powered by a portable winch within the chute system. This combined loading system can be a feasible solution for loading operations in economical cases. Moreover, it is believed that this loading system integrated with portable winch can be cost efficient and time saving solution, as well as ergonomic and safe method in the working fields.

Keywords: Log loading, Portable winch, Chute system

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1. Introduction

Timber harvesting activities are divided into three main stages including cutting, logging and transporting. The loading and unloading of the wood raw material removed from the forest stand to the road or ramp or stroge is one of the expensive and risky activities.

Forestry mechanization of production rate in developed countries is much higher than in our country. Topography is similar to Turkey's use of mechanization in the production activities in Austria is around 6-7% in our country is around 86% (Acar, 1998). But our country increases the cost of production of sufficient use of modern production machinery in forestry work is also caused a waste of time and value (Acar and Senturk, 2000).

Forestry General Directory's (FGD) annual wood production of about 15 million m^3 of industrial wood is carried out as 10 million stere of firewood. The annual wood production made by the private sector is around 3,5 million m^3 (poplar, etc.). The average annual wood raw material consumption in our country 23-24 million $m^{-3}yr^{-1}$ (Kaplan, 2007; Acar et al., 2008).

FGD 65% of the demand for industrial wood raw material market in Turkey at least 90% of income for the company are covered by forests is provided in this way. Approximately 60% of the industrial wood production FGD’s wood raw material production, which in turn generates 40% of timber production (DPT, 2001).

Forest management in Turkey, the annual average of US dollars 2 billion revolving fund is a big industry. The majority of this revolving fund revenues are derived from sales of wood raw material produced. Also constitute more than 30% of the budget goes to the production of wood raw material among the very expensive activities (OGM, 2006).

The production of primary forest products in the wood raw material forest management activities and transport studies represent the most expensive and most difficult stage. So that the entire forest given the importance of the subject obtained by the sale of wood obtained from forests close to the revolving fund of FGD is more emerging. Any kind of damage occurring during the transport of the wood because, due to the sales value of the wood with FGD lowers annual income.

In Turkey, the power structure and an expensive truck loading work in the forest, which occupies an important place in the production of wood working. Generally, this installer manpower or loading work carried out with the machine power is expensive and risky operation. Our country is produced at least 50 million timber per one year. These logs are made to perform the loading process approximately 1 million times to store the truck after being transported to the edge of the forest road in the forest.

The wood raw material is removed from the chamber to the edge of the forest road and heavy products in particular should be transferred to the storage timber attribute loaded soon. In this way both to prevent loss of quality of both products is not compromised modified work flow in the forest. Therefore they sometimes pausing to perform the loading work to avoid skidding works trucks waited for forest workers idle.

Failure to hold the truck as the installer is essential not to be kept. Not much wood production areas in a particular region, the installer is not used due to lack of economic and forced to go to work manually install. In such cases, the use of cranes can be profitable solution.

Technology development in forestry, especially for heavy timber loading is often not the case. Loading phase of timber trucks on forest roads in our country are usually performed using primitive techniques such as loading manually.

About forestry existing loading vehicles and methods in this study are given before. Then skidding to the edge of the forest roads brought heavy timber with the chute in the portable hand winch truck chassis to move aside to allow loading were examined.

2. Truck loading on the forest roads

Annual wood raw material and the expansion of the planned forest road construction and operable forest areas in Turkey, a substantial increase in the production of this increase, the transport business for sale or processing centers over cutting of forest products has become the most important problem of the operator. In terms of the continuity of the flow of the loading work required and the costs of transportation jobs in transportation has a great importance. Amount of expenditures for these jobs usually performed by hand in Turkey, covered about 40-50% of the total transport costs.

On the other hand, ensuring the necessary labor force is no longer a problem in some areas and disrupt the normal flow of this transport work.

A partial machine with a high volume of business and sales warehouse jobs in our country in recent years, although work should be seen in forests stowage or ramps, loading and unloading works in other businesses as well as storage is still done mostly by hand. Recently, the company's sales and the Caterpillar 920 stacker in warehouse stacked ramp located in the forest, Granab 9000 loader cranes and loading cranes Liebher 902 is seen that the loading work done by machines.

The next major phase of the transport of wood raw material phase extraction from the chamber; intermediate storage or loading trucks in the stack location, installed flow, warehouse or factory consists of the latest phase of the drain and return empty. This phase of the install phase four business takes longer than the other step (Acar, 1998). In addition, in recent store sales made forest products are also transported to the place of processing over long distances on the road again loaded with a variety of vehicles.

During loading it is possible to use in the warehouse loader vehicles procurement and efficiently. Because the amount of storage products are available to be loaded with more. However, the loading time in the woods - the amount of wood to be loaded loader etc. Although it is not profitable to keep that in certain continuous forest. Therefore simple, inexpensive, lightweight and portable structure in the hand winch loading of forest work practices will be beneficial from an economic and ergonomic.

Again hands to be run at least 3-4 people in the loading team, in terms of long and safety of the loading time "manual removal (loading) and occupational health and safety in the transport business" does not comply with the principles and so the machine is taken into account falling loading costs per unit load at work when, where the amount of load is less than or installer where the cost of transport to the loading point, the shape of the portable loading cranes will be an alternative.

Loading, in terms of the realization of delay-wood raw material transport has an important function. The effectiveness of this function, the cutting operations with loading and removal from the chamber depends on a good stacking and to ensure coordination between the main transport. For an loading activities efficiently, handling performs trucks and similar vehicles count on with loader capacity or lost time from standby prior to the loading of facilities loading teams to be balanced so as not to occur and need to be organized.

Sought to determine the degree of loading conditions in the loading machine mobility. For example, fixed or pallets to be loaded in the collection timber over a stack wheel; Having been stacked along roadsides or scattered at random in the use of timber wheel loader tires also have the ability to act quickly if there is appropriate.

3. New log loading method on the forest road

Used crane, used under study is PCW5000 brand is capable of shooting up to 100 m from the cable (Figure 1). When using dual traction rope can be doubled. PCW5000 (Table 1) price of cranes is around 3000 euros including taxes.

As the operating principle, one end of timber wrapped round the other end of the drum 3-4 rotates with the drum with waste wound the rope pulling operation of the motor as a result of timber shrinkage is carried out. To speed up the shot, adjust the motor to stop or reverse the negative cases at the end of the draft work-stopping device are available.

The chute system made of polyethylene material (Corrugated Chute SN4) in the study route has been created using artificial skidding. Polyethylene tubing is manufactured from low density materials, crushing, tearing and resistant to external influences such as shock. Type of chute used to form the synthetic route in the system relate to the material properties and dimensions are given in Table 2.

Plastic chutes (SN4 Corrugated Chute) is split in half longitudinally after obtaining full circle. It is then used to create the artificial route moved to the production area by two workers in the forest. Matched by the male-female heads of skidding direction of the artificial hill sloping terrain 3-5 on the road route forest mounted to each other with a smooth oval screw formed into the trucks. Thus, the insertion chutes of the timber during transport to the joints by pulling up is prevented (Figure 2a). Synthetic route is arranged if necessary qualities can be stabilized in different ways. This synthetic route in the chute system has a modular structure capable of assembly and disassembly has been carried out in a very short time like 1-2 hours.

Figure 1: Portable cranes and fixed state tree setup.

Table 1. PCW5000 Technical Features.

Motor	Honda GXH-50cc
Maximum Pulling Power	Single rope: 1 tonne Double rope: 2 tonnes
Weight	16 kg
Motor	Four-stroke engine (Honda GXH-50cc)
Motor oil reservoir	0,25 Liter SAE 10W-30 API SJ Engine Oil
Petroleum reservoir	1,2 Liter
Petroleum type	Unleaded fuel
Petroleum consuming	340g/kwh
Maximum working range	1,5 Hours
Maximum pulling speed	85mm drum:18 mt/min (1080 mt/hr) 57mm drum: 12 mt/min (720 mt/hr)
Demansions	33cm x 38cm x 36cm
Used rope diameter	10mm – 16mm range
Suggested rope diameter	12mm-13mm range

Table 2. Characteristics of a polyethylene plastic chute forming artificial route.

Chute Features	
Chute shape	Half circle (U)
Chute material	SN4 Polyethylene
Chute diameter (mm)	500 mm
Chute thickness (mm)	4 mm
Chute length (mt)	7 mt
Chute weight (kg)	16 kg

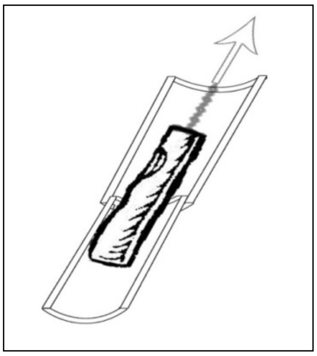
a)  b) 

Figure 2. Screws and chute position in the installation of chute route.

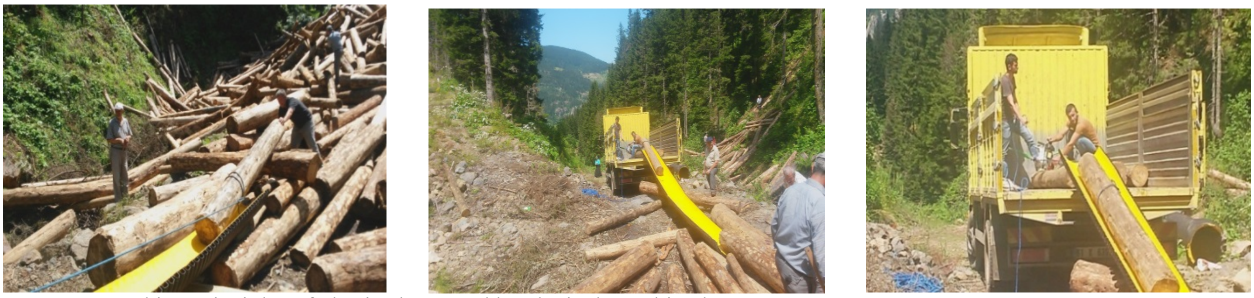


Figure 3. Working principles of plastic chutes and hand winch combined system.

The main components used in the controlled withdrawal system with manual winch truck chassis shifted upward in an artificial plastic timber transportation route created from polyethylene chute; chute route, 10 – 12 mm in diameter and portable hand winch rope can form listed.

In this method, plastic (polyethylene) the longitudinal slope of the artificial route consists of chute ranged between 20% and 25%. During loading of the transport direction of the connection ends of the plastic chutes positioned to be a rough oval hill together with screws were inserted into the right place to be installed by the truck chassis (Figure 2b).

Transport system, in the woods or on the edge of the forest road that was carried out in the form of a portable hand winch winding drum on the winch rope connected to the timber using engine power (Figure 3).

Repeated time measurement method to determine the yield of the time study hours required during loading (reset) technique was used (Acar, 2004). In controlled shooting time measurements in the chute, timber truck loading operation encountered during the experiment were performed. Here, the average value obtained in the absence of a sufficient number of measurements are made for various reasons only efficiency and speed calculation.

4. Conclusions

Our country; synthetic rope cranes movable with integrated chutes after the first time carried out using the system controlled truck loading applications pulling evaluated.

Hand winch with a chute in the chute combination of slope ranged between 20-25%. Each cycle pieces peeled spruce in a timber is being loaded onto trucks pulling a pick up time was measured as 67% of the total time of 161.8 seconds is the length of time. Average speed and efficiency nearly values obtained (Acar 2016).

Up the slope controlled shooting at an average speed of 1 km/h is particularly affected by the volume difference in friction chute route. Total transportation time on the right above the timber-controlled withdrawal period has occupied an important place (Acar 2016).

Some of the benefits of the preferred choices for the loading of the portable cranes are listed at belows.

* Portable winch and chutes can be moved easily by workers
* Setting is easy
* To be economic due to low fuel consumption
* High efficiency of the loading work in small scale
* To be ergonomic
* Because of the existing of distributer in our country, it can be easily obtained.

To facilitate the work in the timber loading done in forestry activities can be increased efficiency in the forestry sector, the reduction in the number and severity of occupational accidents, portable and development by evaluating the economic system, such as hand winch in terms of ensuring time savings in the realization of the work is required.

Portable winch in price could supply of forest workers, efficient and portable system that can be used for multiple purposes. This winch, and never run out of time to work for workers and so will eliminate the risk of interruption. Moreover, we also ensure timely completion of the employer's business plan without a hitch. This form is an ergonomic system as well as economic.

Considering the challenges of development work in the timber loading vehicles and methods in forestry, common and may be recycled to develop this kind of chute system and manual winch combination of work and has been important to put into practice.

Heavy timber products in the characteristic moved to the edge of forest roads should be transferred to the warehouse loading as soon as possible. In this way both to prevent loss of quality of both products is not compromised modified workflow in the forest. Failure to hold the truck as well as the installer should not be allowed to stand. High amounts of non-wood production areas, the installer is unable to get used to the lack of economic and forced manual loading business. In such cases, the use of cranes can be profitable solution.

Developed with this combined system, portable cranes practical, portable and loading of timber lost time from work, although not cheap, and it is thought to be reduced to a minimum the risk of accidents at work. Side of the road in the forest where no profitable or not the supply of heavy plow use, loading trucks and heavy industrial wood logs can be carried out easily with this system as developed.

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Log pulling-sliding head to be used during cable skidding by drummed tractor

H. Hulusi Acar

Abstract: Wood raw material production consists of a series phases among tree harvesting and reaches to the wood deport. The logs are usually 4-6 m in height consideration of the condition of forest roads and ease of ground based skidding. The logging activity is a process which is difficult, dangerous, and harmful to the environment and logs. Besides, it is difficult to loading the trucks, moving into storage and stowed away of the logs on the forest roads but much less harmful to the environment and logs. The logging activities are performed by the power of human, animal and machine. And this works carried out 90% of human power because of the terrain conditions and insufficient technology. So, light and heavy logs have generally been skidded on the ground by uncontrolled human power. Ground based skidding by human power can damage to environment, forest workers, work tools and skidded logs. The most important losses consisting of skidded logs are cracking, breaking, splitting and sprawl on the top parts of the logs. Injured parts on the top portions of logs skidded from forest to forest road have been cut. As a result, amount loss of 2% consists of each of the logs. This rate corresponds to the 300 000 m^3 of produced 300 million m^3 logs. The logs in our country are usually skidded by the human power from bottom of the tree to the forest road. This primitive skidding technique is caused important economic losses. The fiberglass caps which are compatible to top portions of the logs, adjustable and portable will eliminate these economic losses. Also, the caps have an important advantage such as less environmental damage.

Keywords: log skidding, log pulling-sliding head, forest tractor, logging

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1. Introduction

Approximately, half of the forests in Turkey are distributed at higher slopes and hilly areas. Therefore, ground based method is used at 90% level during removing of wood raw material from the forest stand.

Ground based skidding method cause injury to trees and seedlings in the transportation routes. This method also has led to physical and chemical degradation of forest soil and consequently, quality and quantity losses occur in economically transported forest products by hitting to existing trees and stones in environment (Laffan et.al.,2001; Ünver and Acar, 2009; Ünver and Acar, 2005).

Damages in skidded wood raw material are result from hitting to materials such that soil, stone and rocks. This damages may occur breaking the ends of the wood as fringing or stone stabbing as well as peeling or injury on the stem (Acar and Ünver, 2008).

The wood raw material is download the roadside to be delivered to the final consumer are assessed before being loaded onto trucks and it is checked that any damages such as fraying, cracking and breaking of wood products may be occured or not. Such damage occurs largely at the top of the wood part. Damaged parts located at the top of wood are cut and wood is made uniform cylinder that the wood is loaded into trucks. In practice, each end of the 5cm cutting of parts of both wood, has been accepted as normal, it is given name the cutting portion head.

It is reported that industrial wood quality and volume declined in order of 10% and 15-17% results from logging activities in a study carried out in forest in mountainous terrain of Trabzon and Artvin provinences (Gürtan,1975). In another study performed, it is expressed that quality losses of wood raw material during the harvesting activities may reduce 40% value of trees (Murphy vd, 1985).

Fjeld and Granhus (1998) reported that 12% root damages, 36% crown damages and 62% stem damages of residual trees were occured in norway spruce stand in which production intensity is m3 ha-1.

The aim of this study; to simplify the skidding operation above ground, their heads sprawl occurring in timber and timber made of fiberglass material to reduce the environmental damage to the head and emphasizing the importance of using adjustable caps. Thereby skidding resulting from the inevitable economic losses in the production of wood raw material and ergonomic and environmental impact will be minimized.

2. Pulling-sliding log heads (pslh) and its working techniques

The inner diameter of the timber hood made of fiber material 5 cm intervals (35-70 cm) were produced. Heads dimensions: Weight: 2-5 kg, lenght: 30 cm, Thickness: 8 mm.

Fiber heads have been developed to reduce environmental damages log cracks and breaks and allowing comfortable fitting of the obstacles to the advancement of transportation during skidding and easy to perform, ultimately to achieve an efficient skidding.

The fibers produced in the upper part of the timber heading (Figure 1) is mounted with a simple hook technique. Again pulling cable is wrapped as head of timber near the top (Figure 2).

Firstly, one worker takes fiber cover from head of log when the bride to tractor established at forest road then pulled logs are stocked at the edge of the forest road by tractors. Finally, the cable also removed by workers and tractor pull takes the position on the side of the road again.

Figure 1. The fiber heads designed and manufactured mold for logs.

Figure 2. Cable pulling to the forest road by fiber heads.

In cable pulling operations that combination with tractors, can be pulled several logs simultaneously. In skidding operation, the distance may vary, tractor cabling can be made from up to 150 meters. During tractor cabling, escort worker has to pull fiber head and cable down to log head. Neverthless, In the cabling work by fiber head cable is attached to the top of the logs.

3. Pulling-sliding log heads (pslh) and its importance

Transportation of logs from bottom to top over the natural ground has been performed by the MB-Trac 900 tractors with drum in which the average distance of 100-150 meters and as controlled as with cabling under the forest road or uncapped PSLH was carried out in two ways (Acar, 2013).

An analysis from a technical point of view, the downward performed uncontrolled skidding using PLSH the skidded logs, decreases possibility of hitting trees or stones, timber even faster moves and the remaining trees in the stand, was observed to decrease the damages on trees and soil. So, without fraying, breaking and splitting in logs incidents has not been caused to loss of volume by cutting head portion.

Labour productivity has been increased in overall due to reduced technical failures and logging damages during the carrying out contrrolled cable pulling from maximum 150 meter towards the forest road.

In Turkey, The importance of the study are better understood considering that as an avarage 15 million m3 timber (5 meter lenght) has been produced annualy and 2% of the this wood raw material which is 300 000 m3 becomes discarded by the cutting head portion (10 cm lenght). Developed fiber header, if used intensively by GDF (General Directorate of Turkish Forestry), the country with average savings of 120 million TL to the country's economy will be ensured efficient use of natural resources.

4. Results and conclusions

In general it is taken into account; PLSH has been found useful technical-economical-environmental and ergonomic aspects in particularly the cabling process from bottom to top by tractor. Besides, both damages being potential in stand and economical losses of logs have been minimized. Finally, loss of time that may occur are greatly prevented results from friction or sliding during the transportation activities (Acar, 2013).

In studies conducted from bottom to top by tumble tractors integrated with PLSH, cable pulling to have reached the conclusion that it is more efficient compared to the headless cable pulling in sloping terrain.

Particularly, during logging operations in sloping terrain, to get more efficiency of from the portable PLSH should be considered following points below.

• Log headers be designed for a research should be produced in the shape can comply with different diameters (For example: 30-50 cm, 50-70 cm, 70-90 cm etc.)

• Lighter, cheaper and less fragility polyethylene or semi steel material should have incentives to manufacture for producing PLSH.

• Communication network comprising at least two radios must be established, in order to provide occupational safety, in the case of long transportation distances.

• In cable pulling activities by tractors, it should be considered to improve the work efficiency of tractor after starting work when products accumulated ready for transportation.

• System header shape (egg), weight, durability, can be improved in terms of ease of mounting _ and research in this direction should be encouraged.

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Operational efficiency and cost of strip road construction in Tochigi prefecture, Japan

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Abstract: We conducted time studies of strip road construction at multiple sites in Tochigi prefecture to examine the differences in operational efficiencies and costs with respect to slope angle, soil type, and construction machinery. Study sites were located on gentle and middle slopes in Takahara Forest Owners' Co-operative, gentle and steep slopes in Takami Forestry Company, and two middle slopes in Nasu-machi Forest Owners' Co-operative. Productivity of earthwork was higher on gentle slope (32.0 m/h) than on middle slope (23.9 m/h) in Takahara Forest Owners' Co-operative. The soil on the steep slope in Takami Forestry Company was of the soft-rock type; treatment of this soil occupied 45% of the total construction time. The use of grapple buckets reduced the root movement and fix times by half. Productivities of felling operations increased significantly when feller buncher buckets were used instead of chainsaws. Thus, the use of feller buncher buckets effectively enhanced the productivity of strip road construction. Subsidies compensated the costs of strip road construction on almost all the study sites.

Keywords: strip road, construction machinery, slope angle, productivity, cost

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1. Introduction

For sustainable forest management and low-cost forestry operation, appropriate road networks must be established. However, forest road networks have not been well established in Japan, for example average road density of forest road, 13 m/ha and strip road, 4 m/ha (Forestry Agency, The Ministry of Agriculture, Forestry, and Fisheries of Japan, 2011). The Forestry Agency will accelerate the establishment of forest road networks combined with strip roads according to slope angle and operation systems (Table 1). In 2010, the Forestry Agency implemented the "Experimental Projects of Forest and Forestry Revitalization Plan", which includes aggregating small forests, establishing forest road networks, and promoting mechanization in order to conduct forestry operations efficiently on a large scale and reduce costs. We conducted time studies of strip road construction at multiple sites in Tochigi prefecture to examine the differences in operational efficiencies and costs with respect to slope angle, soil type, and construction machinery.

2. Material and Methods

Study sites were located on gentle and middle slopes in Takahara Forest Owners' Co-operative, gentle and steep slopes in Takami Forestry Company, and two middle slopes in Nasu-machi Forest Owners' Co-operative (Tables 2 and 3). Takahara Forest Owners' Co-operative used mini-backhoe with 0.16-m^3 bucket, Takami Forestry Company, and Nasu-machi Forest Owners' Co-operative used backhoe with 0.45-m^3 bucket. Furthermore, grapple buckets were equipped with backhoe on gentle slopes in Takami Forestry Company and middle slope 1 in Nasu-machi Forest Owners' Co-operative whereas a feller buncher buckets was equipped with backhoe on middle slope 2 in Nasu-machi Forest Owners' Co-operative (Figure 1). As soil type was soft rock on the steep slope in Takami Forestry Company, a forwarder was used to transport rocks to a disposal place.

Time studies were conducted for earthwork operations with backhoe. Some backhoes equipped with grapple buckets which could conduct bunching operations as well as earthwork operations whereas the backhoe equipped with feller bunching bucket which could conduct felling and bunching operations as well as earthwork operations. Therefore, time studies were also conducted for manual felling and grapple bunching operations in the investigated site where backhoes could not conduct these operations.

Table 1: Road density according to slope angles and operation systems.

	Slope [degree]	Operation System	Distance [m] from Forest road	Distance [m] from Strip road	Road density [m/ha] Forest road	Road density [m/ha] Strip road	Road density [m/ha] Total
Gentle	0-15	Ground based	150-200	30-75	35-50	65-200	100-250
Middle	15-30	Ground based	200-300	40-100	25-40	50-160	75-200
		Cable yarding	200-300	100-300	25-40	0-35	25-75
Steep	30-35	Ground based	300-500	50-125	15-25	45-125	60-150
		Cable yarding	300-500	150-500	15-25	0-25	15-50
Extreme	35-	Cable yarding	500-1,500		5-15		5-15

Table 2: Study sites.

		Slope [degree]	Age [year]	Stand density [stem/ha]	Stem volume [m^3/stem]
Takahara	Gentle	3.7	58	2,200	0.41
	Middle	19.7	57	2,200	0.42
Takami	Gentle	9.5	100	1,000	0.92
	Steep	34.0	43	800	0.52
Nasu	Middle1	22.4	43	1,900	0.30
	Middle2	27.4	52	2,600	0.22

Table 3: Strip roads.

		Road density [m/ha]	Width [m]	Gradient [%]	Cut height [m]
Takahara	Gentle	554.9	2.5	0.0	0.0
	Middle	808.5	2.5	29.6	0.0-1.2
Takami	Gentle	265.3	3.0	8.0	0.0
	Steep	139.9	3.5	9.6	2.2-2.6
Nasu	Middle1	221.2	3.5	8.4	1.6-2.5
	Middle2	259.6	3.5	11.4	1.2-2.2

Table 4: Machinery expenses [USD/h].

		Backhoe	Chainsaw	Grapple	Forwarder
Takahara	Gentle	25.08	2.37	17.69	-
	Middle	25.08	-	-	-
Takami	Gentle	54.85	-	-	-
	Steep	45.87	2.48	-	35.60
Nasu	Middle1	54.85	2.50	-	-
	Middle2	57.20	-	-	-

Costs were estimated using the labor expense (USD 25.50/h) and machinery expenses incurred for depreciation, maintenance, management, and fuel and oil (Table 4). Insurance costs were also estimated to be 20% of the direct expenses (Zenkoku Ringyo Kairyo Fukyu Kyokai 2001). In Japan, subsidized thinning operations also received subsidies for the establishment of strip roads. Standard unit costs for the establishment of strip roads were determined using the average slope angle (degrees) and the road width (Table 5). Then, subsidies were estimated using standard unit costs, length, assessment coefficients, and the subsidy rate of the Tochigi Prefectural Government (2010). A new subsidy system was initiated in 2011 (Tochigi Prefectural Government 2013). Standard unit costs for the establishment of strip roads were increased to enhance strip road constructions (Table 6).

Table 5: Standard unit cost (2010) [USD/m].

Slope	Width [m]		
[degree]	2.5	3.0	3.5
5	1.17	1.75	2.34
10	1.52	2.17	2.81
15	2.02	2.70	3.38
20	2.70	3.38	4.06
25	3.78	5.40	7.01
30	5.96	9.23	12.50
35	23.41	33.69	43.97

Table 6: Standard unit cost (2013) [USD/m].

	Slope	Width [m]		
	[degree]	2.5	3.0	3.5
Gentle	-15	6.15	7.06	8.77
Middle	-30	7.80	9.55	12.09
Steep	30-	10.52	19.12	23.79

3. Results

Productivity of earthwork was higher on gentle slope (32.0 m/h) than on middle slope (23.9 m/h) in Takahara Forest Owners' Co-operative (Table 7) because earthwork volumes on middle slope were larger than on gentle slope, roots dug on middle slope were fixed on road shoulder whereas those on gentle slope were just piled on road shoulder, and backhoe escaped logs and stones falling on middle slope.

Productivity of earthwork was the highest on gentle slope in Takami Forestry Company because stand density was lower subsequently the number of dug roots was lower and bigger machine could dig roots efficiently without digging soil around roots. The soil on the steep slope in Takami Forestry Company was of the soft-rock type; treatment of this soil occupied 45% of the total construction time.

Productivities of earthwork was higher on middle slope 1 in Nasu-machi Forest Owners' Co-operative (29.9 m/h) than on middle slope in Takahara Forest Owners' Co-operative (23.9 m/h) because of machine sizes and bucket types. According to machine sizes, the digging root time was shorter on middle slope 1 in Nasu-machi Forest Owners' Co-operative

(73 seconds) than on middle slope in Takahara Forest Owners' Co-operative (140 seconds). According to bucket types, the moving and fixing root time was shorter on middle slope 1 in Nasu-machi Forest Owners' Co-operative (13 seconds) than on middle slope in Takahara Forest Owners' Co-operative (26 seconds). Furthermore, the moving and fixing root time was shorter on gentle slope in Takami Forestry Company (8 seconds) than on gentle slope in Takahara Forest Owners' Co-operative (15 seconds). The use of grapple buckets reduced the root movement and fix times by half.

Productivity of earthwork was higher on middle slope 1 (29.9 m/h) than on middle slope 2 (21.2 m/h) in Nasu-machi Forest Owners' Co-operative because slope was steeper and logs were filled on the road surface to enhance on middle slope 2.

Productivities of felling operations with chainsaw were 5.0 m^3/h on gentle slope in Takahara Forest Owners' Co-operative, 13.0 m^3/h on steep slope in Takami Forestry Company, and 8.5 m^3/h on middle slope 1 in Nasu-machi Forest Owners' Co-operative whereas that with feller buncher buckets was 31.2 m^3/h on middle slope 2 in Nasu-machi Forest Owners' Co-operative (Table 7). Productivities of felling operations increased significantly when feller buncher buckets were used instead of chainsaws.

Productivities of bunching operations were 24.9 m^3/h on gentle slope in Takahara Forest Owners' Co-operative, 10.9 m^3/h on middle slope 1 in Nasu-machi Forest Owners' Co-operative whereas that was 43.3 m^3/h on middle slope 2 in Nasu-machi Forest Owners' Co-operative. Logs after chainsaw processing were bunched in Takahara Forest Owners' Co-operative whereas whole trees before processor processing were bunched in Nasu-machi Forest Owners' Co-operative. Grapple bucket was used for bunching whole trees left on the ground after chainsaw felling operations on middle slope 1 whereas feller buncher bucket was used for bunching whole trees directly just after felling operations by itself.

Productivity of earthwork including felling and bunching operations was higher on middle slope 2 (13.6 m/h) than on middle slope 1 (8.0 m/h) in Nasu-machi Forest Owners' Co-operative. Thus, the use of feller buncher buckets effectively enhanced the productivity of strip road construction.

Cost of earthwork was the lowest on gentle slope whereas that was the highest on steep slope in Takami Forestry Company because productivity was the lowest and a forwarder was used to transport rocks to a disposal place (Table 8).

Figure 1: Grapple bucket (Up) and feller buncher bucket (Down).

Table 7: Productivity.

		Earth work [m/h]	Felling [m/h]	Bunching [m/h]	Total [m/h]	Felling [m^3/h]	Bunching [m^3/h]
Takahara	Gentle	32.0	15.2	75.0	9.1	5.0	24.9
	Middle	23.9	-	-	-	-	-
Takami	Gentle	171.4	-	-	-	-	-
	Steep	3.9	28.9	-	-	13.0	-
Nasu	Middle1	29.9	19.4	24.7	8.0	8.5	10.9
	Middle2	21.2	65.6	91.2	13.6	31.2	43.3

Table 8: Costs and subsidies [USD/m].

		Costs				Subsidies	
		Earth work	Felling	Bunching	Total	2010	2013
Takahara	Gentle	2.34	3.12	0.88	6.34	1.30	6.85
	Middle	3.12	-	-	-	3.01	8.69
Takami	Gentle	0.64	-	-	-	2.41	7.86
	Steep	37.14	1.75	-	-	48.96	26.49
Nasu	Middle1	3.69	2.46	4.46	10.61	4.52	13.46
	Middle2	5.34	1.73	1.24	8.31	7.81	13.46

Cost of earthwork was the second lowest on gentle slope in Takahara Forest Owners' Co-operative because of higher productivity and lower machinery expense. Furthermore, cost of earthwork was lower on middle slope in Takahara Forest Owners' Co-operative than on middle slope 1 in Nasu-machi Forest Owners' Co-operative because of lower machinery expense. Moreover, cost of earthwork including felling and bunching operations was lower on gentle slope in Takahara Forest Owners' Co-operative than on middle slopes 1 and 2 in Nasu-machi Forest Owners' Co-operative because of lower machinery expense. Cost of earthwork was higher on middle slope 2 than on middle slope 1 whereas cost of earthwork including felling and bunching operations was lower on middle slope 2 than on middle slope 1 in Nasu-machi Forest Owners' Co-operative. Thus, the use of feller buncher buckets effectively reduced the total cost of strip road construction.

Subsidies in 2010 could not compensate the costs of earthwork in Takahara Forest Owners' Co-operative. As standard unit costs for the establishment of strip roads were increased to enhance strip road constructions in 2011, subsidies in 2013 could compensate the costs of earthwork in Takahara Forest Owners' Co-operative. Subsidies compensated the costs of strip road construction on the study sites excluding steep slope in Takami Forestry Company because of soil type.

4. Discussions

Hirabayashi et al. (2009) analyzed the relationships between productivity of earthwork and slope algles, stand densities, DBH. Then, they indicated slope angles were the most related to productivities. This is similar to results of Takahara Forest Owners' Co-operative in which slope angles were different, but stand densities and stem volumes were almost same. Yogi et al. (2008) reported the use of grapple buckets reduced construction times. This was similar to this study.

Katagiri (2013) reported productivity of felling operation using feller buncher bucket was 35.1 m^3/h with the stem volume of 0.22 m^3/stem which was similar to middle slope 2 in Nasu-machi Forest Owners' Co-operative. Katagiri (2013) also reported the productivity was 2 times higher than that by chainsaw. In this study, productivity of felling operation using feller buncher bucket was 2 and 6 times higher than that by chainsaw although stem volumes were different.

Yogi et al. (2010) reported productivity of earthwork including felling and bunching operations using backhoe with 0.28-m^3 bucket were 71.1, 50.5, and 33.3 m/day according to slope angles of 20, 25, and 30 degrees, respectively. As Yogi et al. (2010) estimated productivity with 5 hours per day, productivities in this study were estimated as 54.6, 40.0, and 68.0 m/day according to slope angles of 3.7, 22.4, and 27.4 degrees. The result of this study with slope angle of 27.4 degree was higher (68.0 m/day) because of machine size and grapple type using feller buncher bucket.

Katagiri (2013) reported productivities of earthwork including felling and bunching operations using grapple and feller buncher buckets were 106.5 and 114.4 m/day. As Katagiri (2013) estimated productivities with 6 hours per day, productivities using grapple and feller buncher buckets in this study were 48.0 and 81.6 m/day. Although results of this study were lower than Katagiri (2013), both studies indicated the use of feller buncher buckets effectively enhanced the productivity of strip road construction.

Katagiri (2013) reported costs of earthwork including felling and bunching operations using grapple and feller buncher buckets were 6.11 and 6.06 USD/m. Costs using grapple and feller buncher buckets in this study were 10.61 and 8.31 USD/m. Although results of this study were higher than Katagiri (2013), both studies indicated the use of feller buncher buckets effectively reduced the total cost of strip road construction.

Acknowledgement

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Implementation challenges for CTI in Norwegian wood supply

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Abstract: CTI (central tire inflation) or VTPC (variable tire pressure control) is a well-established technology for logging trucks in many forest regions. Norwegian wood supply is sourced primarily from non-industrial private forest owners over a road network with fragmented ownership. Truck transport is done by independent owners/operators while contracting and management is handled by jointly owned transport associations. In this context, successful implementation of CTI may require financing from multiple stakeholder groups.
This paper presents a pilot study on the possibilities for CTI use in Norway. In the first part of the study respondents from three stakeholder groups from coastal and interior regions were interviewed to map consensus on expected implementation effects and willingness to participate in a common financing model. In the second part of the study a method was tested for selecting focus areas for CTI-introduction based on wood supply and forest road data. Results also highlight the additional potential of CTI to gain access to mountainous parts of the study area with steeper road grades.

Keywords: introduction area, bearing capacity, transport distance, gradeability

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1. Introduction

After development of central tire inflation (CTI) for military services during the 1940s and 50s, the technology was adapted to industrial contexts during the 1960s and 70s. The development and use of CTI on logging trucks began during the 1980s and 90s in North America and similar testing began in the Nordic countries after year 2000 (Bradley 2010). Since then implementation in parts of Sweden has increased (Hell 2011, Rådström 2014), particularly in areas of sedimentary parent materials with low bearing capacity (Ramén 2014). Numerous earlier studies have examined the effect of CTI on the traction of logging trucks in mountainous terrain (Bulley & Blair 2001).

Payment for logging truck transport services is similar throughout the Nordic countries, using a tariff formula with a fixed price per cubic meter plus a distance-dependent price per cubic meter and km. In Norway, these tariffs vary considerably between areas because of the varying GVW allowed on different segments of the road network. Although transport from forest to mill has traditionally been paid by the mill customer, suppliers may also bear the extra costs of the transport service when their forest roads do not fulfill agreed standards. The effects of CTI on both bearing capacity and gradeability are therefore of interest for Norwegian wood supply and warrant a closer examination of its application there.

This paper describes a pilot study examining the possibilities for introducing CTI in Norwegian wood supply. The study had two parts; evaluating user views of CTI and finding an area suitable for CTI introduction.

2. Material and Methods

The study of stakeholder views of CTI was based on quantifying response within two themes; the expected effects of CTI and different alternatives for financing CTI-investments. Ten respondents were interviewed; 5 from the mid-coast region and 5 from the interior valley region. The distribution of respondents per region was as follows: forest owners association (2), truck operator/owner (1), transport administrator (1) and forest industry (1). Each respondent was given the same general introduction to CTI technology for conventional logging trucks (56-60 t, 7-axle self-loading truck and trailer combinations with dual tires and tandem-drive). After this they were asked to evaluate 19 formulations on a written questionnaire with a 5-point Likert scale (1=disagree, 5=agree).

The second part of the study tested a method for locating an area with sufficient volumes of suitable conditions for a possible introduction of CTI in Oppland county of southeastern Norway. The approach was based on joining delivery data to forest road conditions. The delivery data concerned one year's pulpwood deliveries (2014) including date of delivery, landing GPS coordinates, volume, species, distance to delivery point and maximum GVW allowed on the delivery route. The forest road data consisted of a 3-category field classification of road characteristics (2012-2014) including wearing course thickness, road width, shoulder width, ditch function, bearing capacity as well as measurements of the maximum road grade in both unloaded and loaded directions. Bearing capacity (BC) was classified also on the basis of the current frequency of rutting (0=no rutting, 1=shorter sections of rutting, 3=continuous rutting over the entire segment). The joining of the respective landings and road segment positions was done with GPS coordinates in Q-GIS with the nearest neighbor join function (NN-join).

After getting an overview of geographical distribution of potential delivery volumes over CTI-relevant road conditions, supporting cost models were made for the estimating the effect of CTI on typical road maintenance costs and transport costs.

3. Results

3.1. Stakeholder acceptance

High median scores (4 or higher) in the stakeholder interviews gave an indication of existing consensus on CTI effects and financing alternatives (Table 1). Clear consensus exist on the expected points such as increased traction on steep grades (5) and bearing capacity during thaw/rain (5), followed by reduced need for road maintenance (4,5) and storage time at landing during thaw/rain (4).

Concerning the stakeholder group that should cover the costs for CTI, no consensus was seen for any particular group, but it was clear that a mutual or distributed financing alternative was preferred (5). Regarding exactly which costs should be covered, no high scores were found, with only a neutral score for a complete coverage of installment and running costs (3) and a lower score for adjusted tariffs (2,5).

Table 1: Stakeholder agreement (1-5) with claims regarding the expected effects of CTI and potential alternatives for financing and service payment.

Theme	Claim [unit]	Median score [1-5]
Expected effects of CTI	Increased traction on steep grades	5
	Increased bearing capacity during thaw/rain	5
	Reduced need for road maintenance	4.5
	Reduced storage time at landing during thaw/rain	4
	Reduced rutting year-round	3.5
	More even delivery rate during thaw/rain	3.5
	Reduce truck vibrations and increase operator comfort	3.0
	Reduced storage time at terminal/mill	2.0
	Reduce wear on trucks and increase truck life	2.0
	Reduce annual utilization hours	2.0
	Reduce diesel consumption	1.0
CTI should be financed by	Supply organization	2.5
	transporter	2
	Mill customer	1
	Mutual financing model	5
Financing should cover	Complete installment and running costs	3
	Coverage of transporters costs via adjusted tariff	2.5
	Partial installment and running costs	1.5

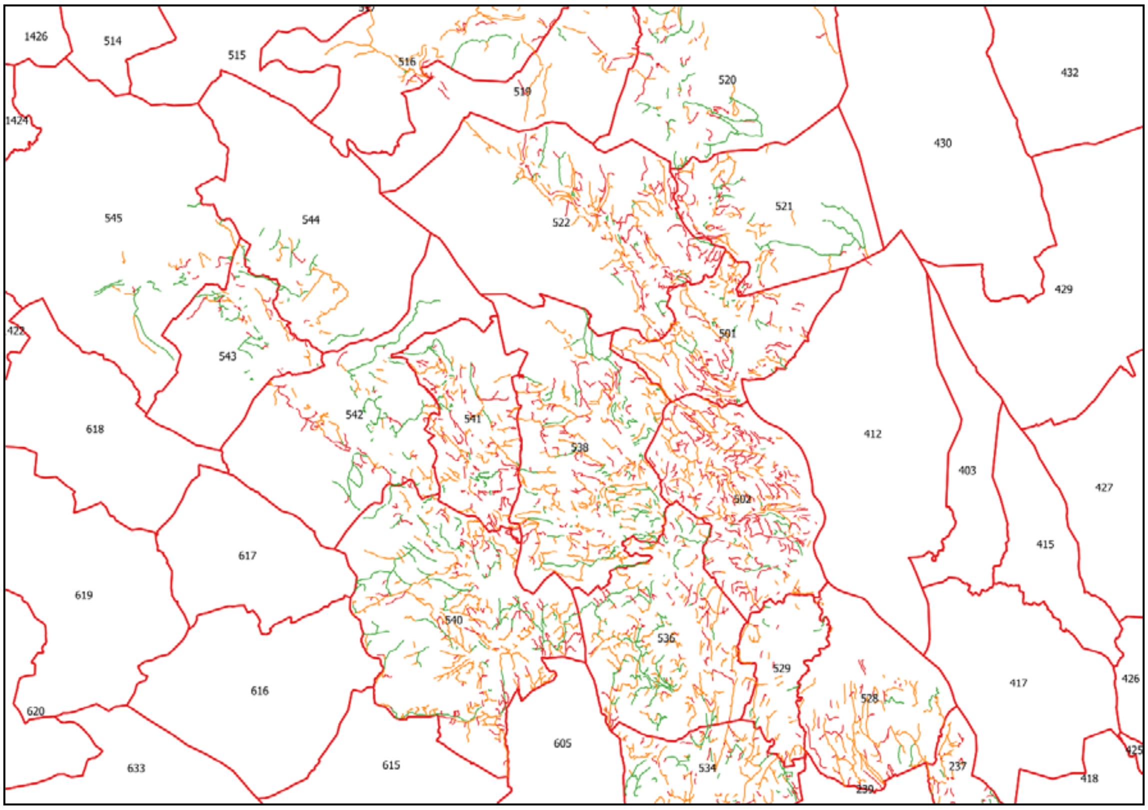

Figure 1: Geographical overview of forest road bearing capacity classes 1 (green), 2 (orange) and 3 (red) in the municipalities in Oppland county (red borders with black numbers).

3.2. Suitable areas for CTI introduction

For the second part of the study, joining spring, summer and fall deliveries with the road segment data showed that approx. 25, 55 and 20 % of delivery volumes came out on roads with bearing class 1 (high), 2 (medium) and 3 (low), respectively. Four municipalities of 27 (no 502, 521, 541 below) had the highest proportions of deliveries linked to road segments with class 3 (Figures 1 and 2).

Six of 27 municipalities had high proportions of volumes linked with forest roads with high adverse loaded grades (Figure 2). These were clustered in two parallel valleys (519/521/522 and 541/542/543) and one intermediate area (538). The three municipalities with low bearing capacity formed a perimeter encompassing most of the municipalities with steep roads.

3.3. CTI costs and potential road maintenance savings

A simple truck cost calculation model was used to quantify the extra cost of CTI. The calculations assume an installment cost of 250 000 NOK per truck with annual maintenance costs of 25 000 NOK per year. Given the initial installation cost, the extra cost of CTI per transported m^3 increased with decreasing yearly production (m^3/yr) and increasing transport distance, yielding an extra cost of approx. 1.5 NOK/m^3 at 50 km and 2.5 NOK/m^3 at 150 km (Figure 3, left). Accumulating the annual delivery volumes over roads of bearing capacity class 3 over increasing transport distances within the relevant municipalities yielded the result shown in figure 3 (right). Given a required annual transport volume of 30 000 to 50 000 m^3 for a conventional logging truck, figure 3 shows that these volumes are available without exceeding a distance of 80 km to pulpwood terminals. The maximum cost for CTI under these conditions is lower than 2 NOK/m^3. These volumes (transport distances < 80 km) were sourced primarily from a single valley (municipalities 501, 502, 519, 521, 522) where the rail corridor offers numerous terminals. The distance from the terminals to the neighboring parallel valley (541, 542 or 543) exceeded the 80 km limit.

Data on forest road maintenance costs was collected from a local road association in a municipality with a high proportion of deliveries over bearing capacity class 3 (municipality 521). In this case the actual road maintenance costs over a two year period averaged 30 NOK per transported m^3. Given that 75 % of road maintenance costs typically consist of gravel and grading (Bjerketvedt & Nyeggen 2007) and CTI typically results in a 20 % reduction in road wear (Bradley 2010) this offers a theoretical reduction in road maintenance of 15 %. For the given case study (15 % reduction of 30 NOK/m^3) this corresponds to a road maintenance savings of 4.5 NOK/transported m^3, more than twice the extra costs of CTI.

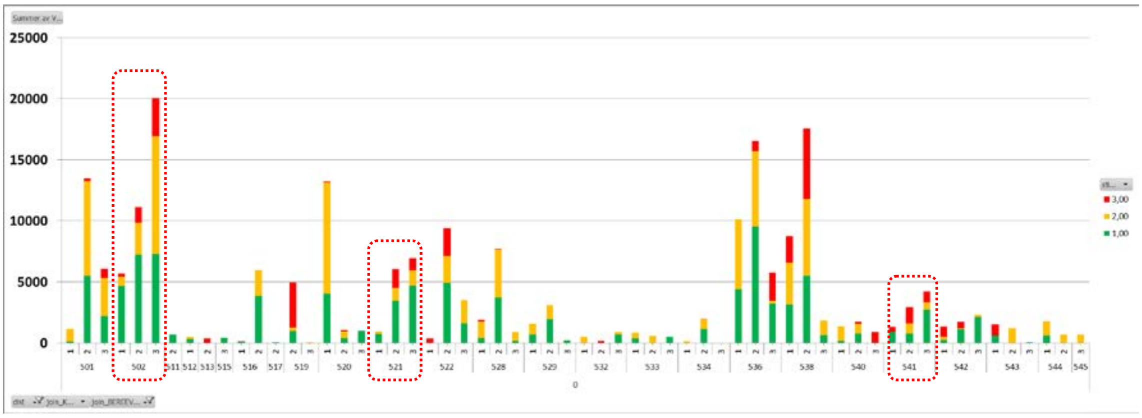

Figure 2: Distribution of spring, summer and fall delivery volumes (m^3/year) per municipality (501-545) and forest road bearing capacity class (1-3 on X-axis). The colors indicate the distribution of volume per class of adverse loaded grade (green= 0-5 %, yellow= 5-10 %, red > 10 %).

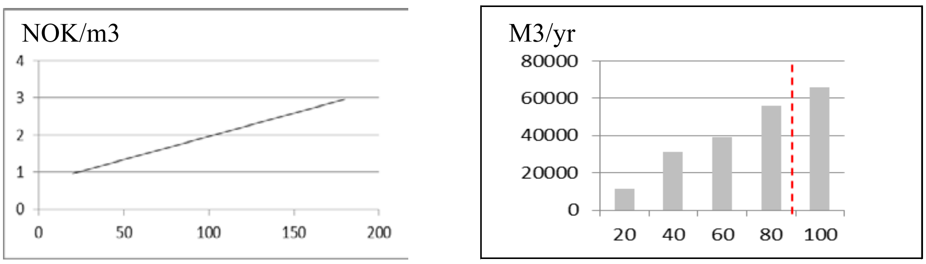

Figure 3: The cost of CTI (NOK/m^3 on y-axis) with increasing transport distances (km) on the left. The annual delivery volumes over roads of bearing capacity class 3 (m^3/year on y-axis) available within a maximum transport distance (km) on the right.

The final question within the pilot study was the expected effects of CTI on the availability of areas with steep adverse grades in winter. For this, straight line gradeability formulas were used from Skaar (1977) and Hjort (2012) together with a selection of winter traction and rolling coefficients (Söderlund & Wickström 1963, Nilsson 1970, Wenger 1984). Given a typical GVW of 56 t with 18.4 t on the tandem drive, typical coefficients (traction = 0.33, rolling resistance = 0.0022) yielded a maximum loaded winter grade of 9 %. Given an 18 % increase in traction with CTI (Amlin & Bradley 1992) the grade increased to 11 %. Applying the 9 % limit for adverse loaded grades on the joined road segments indicates that 33 % of the winter deliveries would require a reduced trailer load without CTI. The use of CTI (11 % adverse grade) reduced this volume to 19 %.

4. Discussion

The first part of the study notes that many of the effects of CTI quotes from previous studies were directly credible for the interviewed stakeholders. The remaining issue concerns the financing of the initial CTI investment and later payment for CTI services. Experiences from the introduction of CTI in Sweden showed a transition from 1) initial investment subsidies (paid by the transport service buyer) for the first vehicles to 2) later service payment solutions with adjusted tariffs. In the Swedish case, the accounting of transport services can be handled via a central forest sector information system (SDC) with contract-specific tariffs, enabling adjustment for CTI-specific tariffs. The architecture of the Norwegian system (SkogData) is similar the Swedish and provides the same possibilities. Wood pricing in Norway, however, has historically been set for delivery to roadside, with transport costs being paid by the mill customer. An increasing proportion of supply agreements have been set with terminal or mill-side prices with transport costs then being paid by the supply organization (in most cases the forest owner's association). This offers the potential to simplify transactions for redistributing eventual CTI costs between relevant stakeholders, such as the owners of marginal forest roads. While the interview results showed a consensus for a distributed financing model (score=5 in Table 2), the respondent scores for financing via single stakeholder groups showed the least pressure on the mill customer (score=1), with a slightly higher pressure on the transporter (score=2) and the supply organization (2,5).

The general consensus on CTI effects include both increased availability and reduced road maintenance costs. These advantages accrue to either the individual forest owner (reduced road maintenance) or the forest owner's association (improved wood availability to fulfill delivery contracts). Assuming a 50/50 distribution of pulpwood and sawlogs, a straightforward use of CTI-tariffs would channel 50 % of the extra costs to the forest owner's association (where pulpwood is priced for delivery to terminal) and 50 % to local sawmills (where sawlogs are priced for delivery to roadside). As noted earlier, limiting the additional cost of CTI to the indicated levels
(1.5-2 NOK/m^3) also assumes that CTI-trucks are used year-round on short-haul deliveries, which would reduce the flexibility of fleet management by transport associations. The realism of these assumptions varies between seasons and years and must be examined further with the relevant stakeholders. A straightforward solution for implementation of CTI-specific tariffs is to pass on the additional costs to individual forest owners whose road networks require this technology. This could be handled through the internal pricing mechanisms of the forest owners association.

The second part of the study estimated sufficient CTI-relevant volumes to run a CTI-truck year-round within the indicated perimeter of clustered municipalities, without exceeding a cost of 2 NOK/m^3. This cost compared favorably with a 4 NOK/m^3 estimated saving of road maintenance costs. The estimated savings of road maintenance, however, relies on three assumptions; first, that the road maintenance cost for the selected case (30 NOK/m^3) is representative, second, that all maintenance needs result from logging transport and third, that the year-round reduction of rutting with CTI is really 20 %. A more conservative estimate assuming 20 NOK per transported m^3 with an estimated savings of only 15 % would reduce the net savings to only 1 NOK/m^3. In this case, increased wood availability for the supply organization becomes a more relevant aspect for CTI-financing.

The effect of CTI on winter traction was also relevant in the case area. The latest years have seen an increase of maximum allowed GVW from 50 and 56 to 60 tons. While most of the older forest roads are designed with a maximum grade of 10 % (for 50 t trucks), these may not be as easily available for winter transport for heavier truck configurations. However, an 18 % increased traction for driven tandems with CTI (Amlin & Bradley 1992), almost compensates for the 20 % increase in GVW, maintaining cost savings expected of 60 t trucks (2 NOK/m^3 and 0.05 NOK/m^3/km). On the other hand, the proportion of loads actually delivered with a GVW over 50 t was still under 50 % at the time of the case study because of bottlenecks in the connecting municipal and county roads.

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New delimbing tool for harwood trees: feedback on new ribbed knives after one year experience

Emmanuel Cacot[1]*, Jean-Christophe Fauroux[2], David Peuch[1], Alain Bouvet[1], Mahmoud Chakroun[1]

Abstract: Looking at mechanized cut-to-length harvesting in broadleaved stands in France, an increase of the workforce was observed between 2008 and 2014 both in terms of companies (62 to 73: +18%) and harvesters (from 72 to 105: +46%). During the same period, machine productivity rose from 14,000 m^3 to 15,000 m^3 per year (+7%), for a full-time equivalent harvester. Despite this, interviewed drivers consider that the current harvesters are not yet adapted enough to hardwoods' typical branchiness and crookiness… Moreover productivities are judged as low compared to the performances of the same machines in softwood stands, which holds back the adoption of fully-mechanized practices in broadleaved stands. On the other hand, the decrease of manual workforce (-400 lumberjacks/year) and the national mobilization policy (+12 Mm^3/year by 2025) both call for answers to this mechanization challenge.
Several solutions were imagined, developed and tested in ECOMEF project (Eco-design of a mechanized tool for hardwood harvesting). One focuses on the shape of the delimbing knives modified by the integration of ribs in the cutting area. First, the energy required by different sorts of blades to cut hardwood branches was quantified in laboratory by IFMA. Usual knives were compared to different shapes of ribbed knives (length, thickness, width of ribs) to determine the best performing solution. Based on these results, 2 harvesters working over 90% of their time in broadleaved stands (chestnut, oak, hornbeam, birch…) were equipped with 1 fix and 2 mobile ribbed knives per head: John Deere 1270E with 752 HD head and tracked excavator Case CX 210 with Kesla 25 RH head. A global survey (productivity, wear of the knives, opinion of drivers) was carried out by FCBA during over one year. Some time-studies were also recorded for specific trees, with numerous and big branches, to focus on the efficiency of this new knives in comparison with the normal ones. With the ribbed knives, the 2 harvesters were in average 21% more productive during delimbing process. The global productivity is less impacted by this novelty but the drivers were very satisfied by the robustness of the knives.
Work is still underway to further optimize the shape of knives and integrate other innovations from the ECOMEF project.

Keywords: broadleaved stands, hardwood mechanization, delimbing process

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1. Introduction

Looking at mechanized cut-to-length harvesting in broadleaved stands in France, an increase of the workforce was observed between 2008 and 2014 both in terms of companies (62 to 73: +18%) and harvesters (from 72 to 105: +46%) (Cacot and al., 2015 1). During the same period, machine productivity rose from 14,000 m^3 to 15,000 m^3 per year (+7%), for a full-time equivalent harvester. Despite this, interviewed drivers consider that the current harvesters are not yet adapted enough to hardwoods' typical branchiness and crookiness… Moreover productivities are judged as low compared to the performances of the same machines in softwood stands, which holds back the adoption of fully-mechanized practices in broadleaved stands. On the other hand, the decrease of manual workforce (-400 lumberjacks/year) and the national mobilization policy (+12 Mm^3/year by 2025) both call for answers to this mechanization challenge (Cacot and al., 2015 2).

The project ECOMEF (Eco-design of a mechanized tool for hardwood harvesting) aimed to develop a specific head for mechanized harvesting in hardwoods. For this, following a methodology for innovation (Chakroun and al., 2014), several problems encountered with existing materials developed for conifers, were listed and prioritized. Thus the 3 main problems are in order of importance: delimbing (because of big branches, hard wood, acute angle with the trunk), feeding process with crooked trees and grabbing trees in clumps. Following the methodology of innovation, many concepts have been imagined to solve these problems. The most promising were designed, tested in laboratory with monofunctional demonstrators then, for the main relevant, tested on logging sites. Based on this approach, ribbed knives for delimbing were developed.

2. Design and test of ribbed blades in laboratory

2.1. Design new shapes for delimbing knives

The knives currently available on the market have the shape of curved blades made of hardened steel and soldered to a curved pivoting arm. The delimbing process consists in translating the knife along the trunk surface with a given speed (typically 1-7m/s). Then, branches are cut by impacting against the cutting edge of the blade, located close to the trunk surface. Improving the delimbing operation could be obtained with innovative knives. The existing patents prove that innovative blade shapes could be provided. Moreover, the testing of existing blades showed that blade thickness had to be reduced for better cutting (Dargnat and al., 2014).

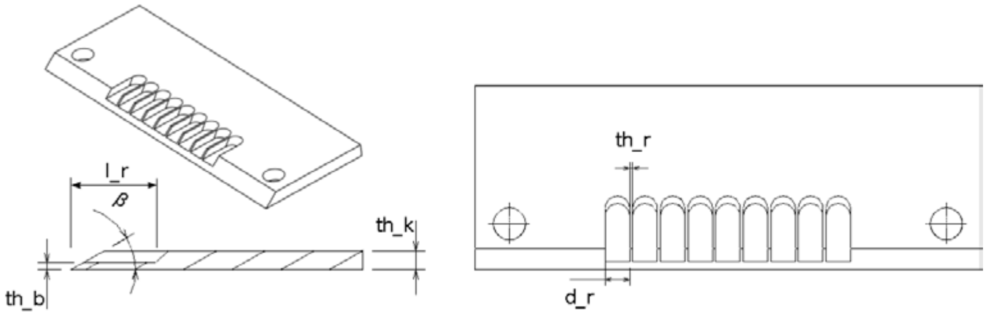

Figure 1: Geometry of the innovative ribbed knife with its geometric parameters.

Using this idea, it was decided to try to decrease the cutting force needed to cut a branch by using a blade as thin as possible. By doing that, the contact surface between the knife and the branch is minimized during the cut. It helps to decrease the friction and also increases the stress on the wood fibers that get torn by the blade cutting edge. Obviously, a very thin blade has also to be strong enough to resist to the cutting loads and more generally to all the shocks that occur during forestry operations. In order to avoid any bending of the cutting edge, additional ribs, used as stiffeners, were positioned regularly along the cutting face. Figure 1 shows the new blade design and the associated dimensional parameters:

- β, the sharpness angle,
- th_b, the blade thickness,
- l_r, the rib depth,
- th_k, the knife thickness,
- d_r, the distance between ribs,
- th_r, the rib thickness.

2.2. Tests of various ribbed knives with a delimbing test bench

The effects of the geometric parameters of the knife on the cutting force during the cut of the branch have been tested. For this, a test bench was built in order to compare many types of delimbing blades on various types of branches (Fig. 2). It includes a blade support gliding on guiding rails and actuated by a hydraulic cylinder. The branch is maintained by two supports and the blade parameters (cutting force and displacement) are measured by two sensors.

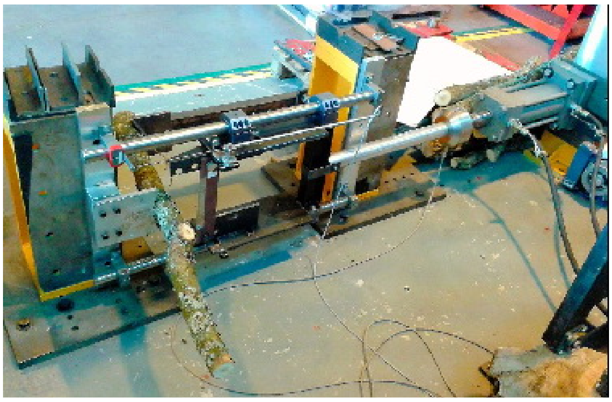

Figure 2: Delimbing test bench.

A first preliminary work was performed to evaluate the delimbing performance of existing smooth blades. These tests highlighted a positive effect of the new ribbed blades on cutting force, compared to usual smooth blades (see table 1).

The influence of different geometric parameters on the cutting forces was also experimented. A low sharpness angle (β close to 15°) decreased the cutting force but the blades were damaged due to a lack of mechanical strength. 30° seemed to be a good compromise. In a same way, low thickness blade (th_b < 1mm) was not enough resistant and judged not adapted to operating conditions. The effect of the depth of ribs was not clearly established and complementary tests should be performed. A low distance between ribs (8 mm) significantly increased the cutting forces, and a good compromise between mechanical strength and cutting forces was established at 16 mm.

Table 1: List of the 9 tested configurations on the bench and maximal cutting force (branch diameter 80mm, β = 30°, l_r = 40mm, d_r = 16mm).

Knife name th_k - th_b - th_r	Knife thickness th_k (mm)	Blade thickness th_b (mm)	Rib thickness th_r (mm)	Maximal cutting force (kN)
1. Smooth 8 mm	8	/	/	30.0
2. Ribbed 8-3-2	8	3	2	26.9
3. Smooth 10	10	/	/	32.9
4. Ribbed 10-3-1	10	3	1	26.3
5. Ribbed 10-3-2	10	3	2	25.6
6. Ribbed 10-5-2	10	5	2	27.4
7. Smooth 12	12	/	/	32.4
8. Ribbed 12-5-2	12	5	2	25.9
9. Ribbed 12-7-2	12	7	2	30.2

Complementary finite element simulations were performed on a curved knife model to optimize its geometry and find the maximal load admissible for different knife configurations. The aim was to compare these loads to forces at the impact of the branch and during the branch-cutting. The simulations permitted to extract nine configurations to test on the test bench (Table 1). For all these configurations, the sharpness angle β was set to 30°, the ribs depth l_r to 40 mm and the distance between ribs d_r to 16 mm.

The analysis of the cutting during the tests allow to draw the following conclusions:

- The blades of thickness th_b = 3 mm were not sufficiently rigid and plastic deformations occurred during delimbing:
    - A bending of ribbed knife 8-3-2 occurred for a 75 mm branch diameter (which corresponded to an axial load of 30 kN).
    - A bending of ribbed knife 10-3-2 occurred for a 100 mm branch diameter (which corresponded to an axial load of 48 kN).
- The thickening of the ribs from 1 mm to 2 mm increased slightly the cutting forces, that was 26.3 kN for Ribbed 10-3-1 and 25.6 kN for Ribbed 10-3-2.
- For a given knife thickness, the thinner the blade, the lower the max. cutting forces.
- For a given thickness of the cutting blade, the thickness of the knife and thus the height of the ribs had a little effect on the maximal cutting forces.

2.3. First short field tests

After the promising FEM models and experimental results on the test bench, a prototype ribbed top-knife was produced for tests on a Kesla 25RH harvesting head. The tests allowed to evaluate the material strength in real conditions, the values of delimbing forces and the gains of productivity. The experiments were organized in a coppice with clumps of chestnut trees. Five prototype knives were tested, defined by their th_k-th_b-th_r-l_r parameters, each one on fifty trees, and the results are summarized in Table 2. All the innovative ribbed knives brought productivity gains from 8% to 40%. Long ribs were also tested with success.

Table 2: Productivity gains for the 5 tested ribbed knives with respect to a classical knife.

Knife type th_k-th_b-th_r-l_r	**Productivity gain**
12-5-2-43	8%
10-3-2-43	23%
12-7-2-43	40%
12-5-2-94	32%
12-7-2-94	32%

3. Tests of ribbed knives in real conditions

3.1. Material and method

Based on the previous results obtained in laboratory, two harvesters (Figure 3) have been equipped with the best ribbed knives (12-7-2). The rib depths (l_r) had to be adapted for each knife of the 2 heads taking into account the gap between them.

These two harvesters were selected for different reasons:

- they worked most of their time in broadleaved stands (over 90% of their time) in 2 regions (Centre and Aquitaine) with different types of stands (regular forests / coppices), species (mainly oak / mainly chestnut tree) and logging operations (thinning / clear cut);
- they represented the various kinds of harvester (purpose-made harvester / tracked excavator used as harvester) equipped with two different harvesting heads well-represented in France in hardwood mechanized operations;
- the drivers were very well-experimented with over 15-year experience mainly in broadleaved stands.

Figure 3: A prototype ribbed knife replacing a mobile classical knife on a Kesla 25 RH harvesting head.

The Kesla 25RH head were equipped with 3 ribbed knives: 1 fix and the 2 upper mobile ones (Figure 4). The ribbed blades were bolted to the original threaded mobile knives. For the JD H752 harvesting head, the manufacturing of ribbed knives was more difficult because of the shape of the knives (triangular) and the small gap between the two mobile knives (little space to insert a ribbed blade on the bottom knife). As a result, 4 different versions of ribbed knives were manufactured and tested for this head before finding the good one. Finally, ribbed blades have been bolted to the original threaded mobile knives, like for Kesla, but we were not able to manufacture a ribbed bottom knife. So for the JD H752, we did not have a full ribbed delimbing ring but only a partial one (the fix and the upper mobile knives).

These tests have been carried out during over one year, from November 2014 to March 2016. So we could ask to the drivers their global feeling and feedback on the ribbed knives: what do they think about them, what are the difficulties/facilities they have to face, how are the ribbed knives after one year in real productive conditions in forest… Moreover, some trees have been characterized (diameter, branching, crookiness...) before being cut and processed. These trees have been deliberately chosen according their potential difficulties to be processed (big branches, forks, crooked trees). All the cutting and processing operations were monitored in detail, individually (time study for each monitored tree), according to the AFOCEL protocol, which is compatible with the AIR3-CT94-2097 (PMH5). Where possible, two different samples were characterized on the same logging site, and processed separately in order to compare the original knives and the ribbed ones. With this detailed protocol, a total of 768 trees have been identified, characterized and monitored individually during their harvesting process.

Figure 4: Tracked excavator Case CX 210 + harvesting head Kesla 25 RH II (left), purpose-made harvester John Deere 1170E + harvesting head H752 (right).

Table 3: Number of monitored trees during their process according to their species and size.

		Oak		Other species (chestnut tree, birch, aspen…)		Total
		⌀ < 25cm	**⌀ > 25cm**	**⌀ < 25cm**	**⌀ > 25cm**	
CASE CX 210 + Kesla 25 RH II	Normal knives	-	-	50	-	50
	Ribbed knives	25	4	249	44	322
John Deere 1170E + H752	Normal knives	16	37	165	28	246
	Ribbed knives	32	20	95	3	150
Total		**73**	**61**	**559**	**75**	**768**

3.2. Analysis and results

- **Feedback from drivers**

The first, and important, feedback is the good result of these new ribbed knives in delimbing process, but any specific measures were realized to characterize precisely this aspect. The branches are correctly delimbed, close to the trunk, with a sharper cut even with big branches (10-15cm of diameter) in comparison with normal knives. The processed logs are in accordance with the specifications.

Figure 5: Example of different logs processed in chestnut trees with the ribbed knives (JD H752): logs for pickets (left), pulplogs (middle) and sawlogs (right).

After one year of experience, the drivers pointed out also the good robustness of the ribbed blades and the good resistance of sharpening.

Figure 6: State of the ribbed knives (Kesla 25RH) after one-year utilization in broadleaved stands.

- **Results on productivity**

The drivers observed by themselves a gain of productivity but not for all the logging sites, depending on the species, the global shape of the trees (stand with a majority of straight trees or reverse with crooked trees) and the logging operations (clear cut and thinning). The time studies carried out by FCBA highlight a small gain of the global productivity with ribbed knives in clear cuts, but not statically significant. Indeed, whatever the shape of the knives, they have only influence on delimbing process and too much other parameters than branchiness are involved in the harvesters' productivity in broadleaved stands (see figure below with the effect of clear cuts and thinnings).

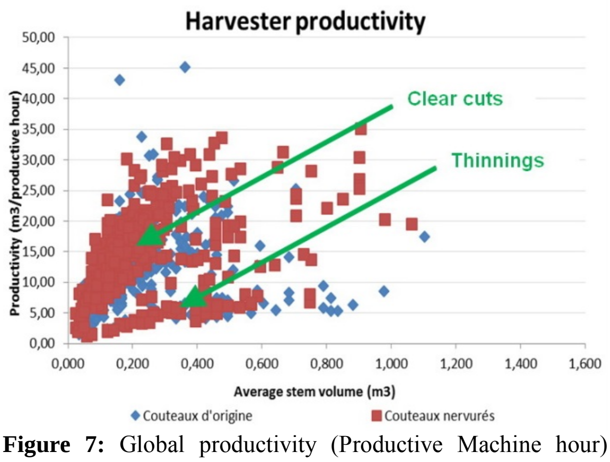

Figure 7: Global productivity (Productive Machine hour) of the 2 harvesters equipped with normal knives (blue dots) and ribbed knives (red dots).

Then the analysis and comparisons were based only on the process times (delimbing branches and cutting logs), in order to better understand the effect of the knives. These process times represent about 50% of the global productive working time machine for the 2 harvesters in broadleaved stands (Fig. 8).

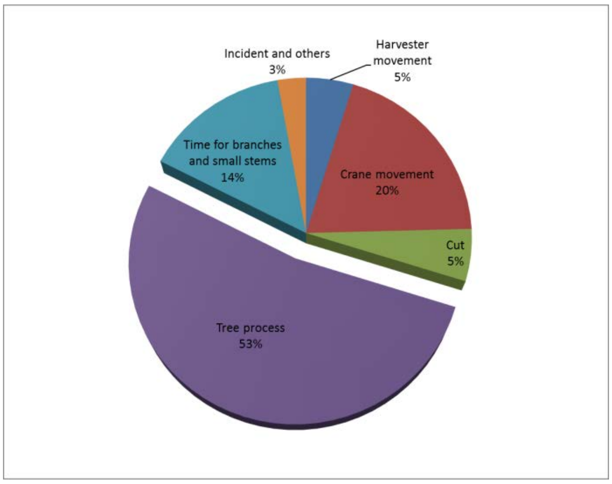

Figure 8: Distribution of work phases of the 2 harvesters in broadleaved stands.

Sub-samples, from the 768 recorded trees, were used in order to have equivalent average stem volume for trees processed with normal knives in the one hand and ribbed knives in the other. The differences are statistically significant (analysis of variance). Thanks to the ribbed knives, the gain of productivity during tree process is over 20% in general (table 4 and figure 9).

In a second step, the productivities between normal and ribbed knives were compared taking into account the shape of the trees: branchiness, forks, crooked trees (see paragraph 3.1). The average grade on the shape of the trees is 0.5 (tree with little difficulty for processing) to 3.5 (tree with many difficulties). From 0.5 to 1.5, the rib knives provide real gains in productivity during processing, about 37% compared to normal knives, with statistically significant differences (ANOVA). For trees with a shape grade over 1.75, no statistically significant difference was observed between the 2 types of knives: sometimes ribbed knives have better results, sometimes the normal knives. The number of trees with a shape grade greater than 1.75 are however few and it is difficult to have clear conclusions.

If we draw a parallel with species, ribbed knives bring gains during processing mainly in chestnut (for trees > 0.1 m^3), aspen and birch trees (for trees > 0.2 m^3, below these trees have only small branches and ribbed knives do not differentiate to normal knives). These species present generally some difficulties during processing but relatively moderate (medium-sized branches, few crooked trees…). Their grades are in fact between 0.5 and 1.5, where the ribbed knives provide the most gain. By contrast, the oak trees present more defaults (large branches, crooked trees) with shape grades over 1.75. For oaks, recorded trees, fewer than for other species, ribbed knives bring no gain.

Table 4: Comparison of sub-samples with the same average stem volume for the 2 harvesters with original and ribbed knives.

		Case CX 210 + harvesting head Kesla 25 RH II		John Deere 1170E + harvesting head H752	
		Original knives	**Ribbed knives**	**Original knives**	**Ribbed knives**
Average stem volume (m^3)		0.151	0.150	0.286	0.284
Number of monitored trees		50	225	246	93
Productivity during tree process (m^3/PMH)	Min	11.0	10.2	3.9	7.7
	Max	54.2	69.4	82.8	94.6
	Moy	27.2	32.9	25.8	31.4
Gain on productivity			**+21%**		**+21.7%**

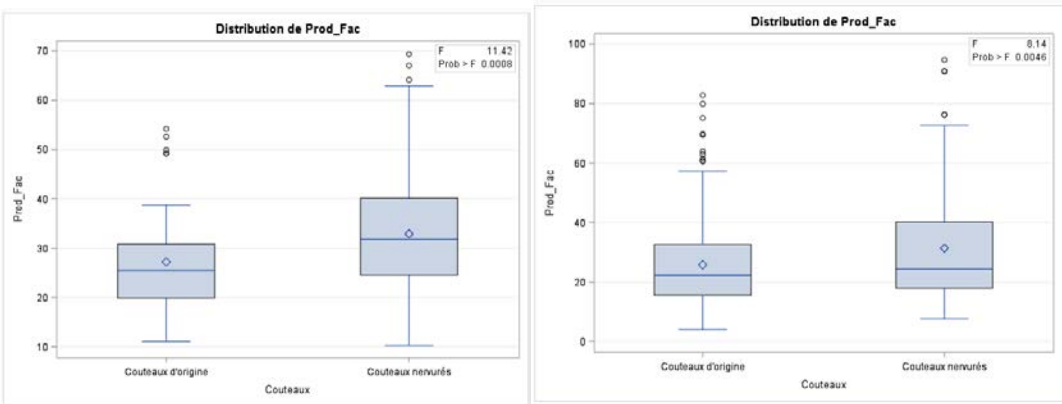

Figure 9: Distribution of productivity for Case CX 210 + Kesla 25 RH II (left) and John Deere 1170E + H752 (right). “Couteaux d’origine” = original knives; “Couteaux nervurés” = ribbed knives.

3.3. Discussion

A lot of parameters impacts the productivity of machines and finally, despite the number of monitored trees, we have not been able to analyze further the data as we did not have enough data for each category (for example, oaks with the same average volume, the same shape grade, in the same stand, monitored with the same machine with the normal knives and the ribbed ones).

Moreover, for the John Deere harvester, we had to change regularly the ribbed knives before finding the good technical solution. And, even with the last version of the ribbed knives, the delimbing ring (1 fix knife + 2 upper mobile ones) was not completely ribbed, as we could not include a ribbed blade on the second upper mobile knife. So the ribbed system monitored for this harvester is not optimal. As a result, the driver of this John Deere harvester was less enthusiastic by the ribbed knives than the other driver of Case.

4. Conclusion

With an average gain over 20% when processing trees (this phase represents about 50% of productive working time of harvesters in hardwoods), the ribbed knives provide a definite plus compared to standard knives. Discussions with harvesting head manufacturers have shown that this path of progress, on the shape of knives, had never been prospected. This concept has been patented by the industrial partner of the project ECOMEF. These knives can equip any head as an option without any particular modification.

Work is still underway to further improve the concept with a new generation of ribbed knives, working on the shape of the blade and on the support arm. The 2 testing harvesters will be able finally to be equipped with a full ribbed delimbing ring. Other time studies are provided. We are going also to monitor the ribbed knives in softwood. The drivers have already used them in such stands (black and maritime pines, Douglas firs) with good results but without quantified time studies led by FCBA.

However, the ribbed knives do not appear as a miracle solution for delimbing. They know limits, over conventional knives, when the branches become too big, especially for oak. Other concepts are imagined in ECOMEF project to go further in hardwood mechanization, either to facilitate delimbing or treat other difficulties in this mechanization.

5. Acknowledgements

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Time of arrival variations for short-sea shipping of roundwood and chips within the Baltic Sea

Dag Fjeld[1]*, Bruce Talbot[2]

Abstract: Supply structures for Nordic forest industries often include import volumes which can be critical for during certain seasons. Around the Baltic Sea, these volumes are delivered with small bulk vessels (under 10 000 DWT). Even though the cargo sizes for roundwood shipments are small in relation to other bulk products, reliable deliveries are important for an efficient supply system.

This paper presents a recent example of cargo-level variation in voyage and arrival times for selected roundwood and chip flows in the Baltic Sea area. These simple statistics can be useful for stock- and contingency planning when securing wood supply from multiple sources. Data was made available from the Vesselplan system for a subset of import flows to Sweden for ports of lading in Russia, Estonia, and Latvia to ports of discharge in the south, southeast and north of Sweden.

Vessel/cargo size varied from just under 2000 to over 6000 metric tons. The average voyage times between port combinations varied between 26 and 66 hours, and varied considerably within each combination. 85% of the cargoes arrived within 5 hours of the latest estimated time of arrival. The results showed a typical right-skewed distribution with a higher frequency of late arrivals than early arrivals. The smallest deviations were seen for south Sweden where cargoes came predominantly from Latvia. The longest delays were noted for southeast and northeast Sweden where a higher proportion of cargoes came from Estonia and Russia.

Keywords: wood supply sourcing, shipping, reliability

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1. Introduction

The Nordic wood supply import has varied considerably over the last 15 years. For Sweden these volumes decreased from 13 million m^3 in 2000 to just under 8 million m^3 in 2009, rebounding thereafter to approximately 11 million m^3 in 2013. Although these volumes are marginal for many mills, predictable deliveries are important for reliable wood supply.

For sources in the Baltic Sea region, these volumes are delivered with small bulk vessels (under 10 000 DWT). Although typical cargo sizes for roundwood shipments are small in relation to other bulk products, one vessel carries the same volume as 100 trucks or 3-4 trains. An overview of the current level of precision is therefore a good starting point for both improved planning and research purposes.

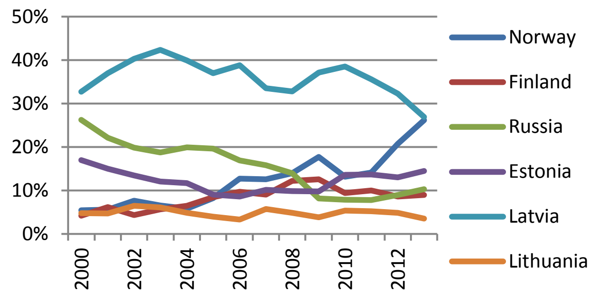

Figure 1: The distribution of main sources for Swedish roundwood and chip import 2000-2013 (Skogsstyrelsen 2015).

1.1. Import sourcing

An overview of import sourcing from 2000 to 2013 (Skogsstyrelsen 2015) shows the main volumes from Latvia, Estonia and Russia, with Russian volumes later being surpassed by Estonian and Norwegian volumes after 2008. Given that Norwegian volumes were delivered primarily by rail, this leaves the same three sources as the dominant sources for shipping of import volumes.

The goal of the study was therefore to quantify the cargo-level arrival precision for short-sea shipping of roundwood and chip deliveries from the three main sources to Sweden.

2. Material and Methods

Data was made available from Vesselplan (www.vesselplan.com) for 335 roundwood and chip shipments during 2013. The Vesselplan system provides an online platform for storing, exchanging and updating wood flow plans and delivery information for all members companies based on a common cargo identification. The flows selected were from Latvian (4), Estonian (2) and Russian (8) ports of lading (PoL) to ports of dischange (PoD) in south (11), southeast (16) and north Sweden (17). The distribution of cargoes is shown in Table 1.

The variables examined included aggregate voyage time (including delays before leaving PoL, voyage time and delays before discharging at PoD) as well as the estimated and actual times of arrival (ToA) at the port of discharge. Data on all cargoes was anonymous without specification of seller, vessel or customer.

3. Results

Vessel cargo sizes were divided into classes of under 2000 mt (class 1), 2000-4000 mt (class 2) and over 4000 mt (class 3). Class 2 cargoes dominated for the PoDs in the south (11, 16) while class 3 dominated in the north (17). Class 3 cargoes were most frequent during january-march (Q1), declining through april-june (Q2) to the lowest proportion during july-september (Q3), thereafter increasing through october-december (Q4).

Table 1: Number of cargoes per selected flow from Port of Lading to Port of Discharge.

Port of lading	S SWE (11)	SE SWE (16)	N SWE (17)
	No. of cargoes to Port of Discharge		
LV (4)	38	76	76
EST (2)	11	46	29
RU (8)	0	32	27

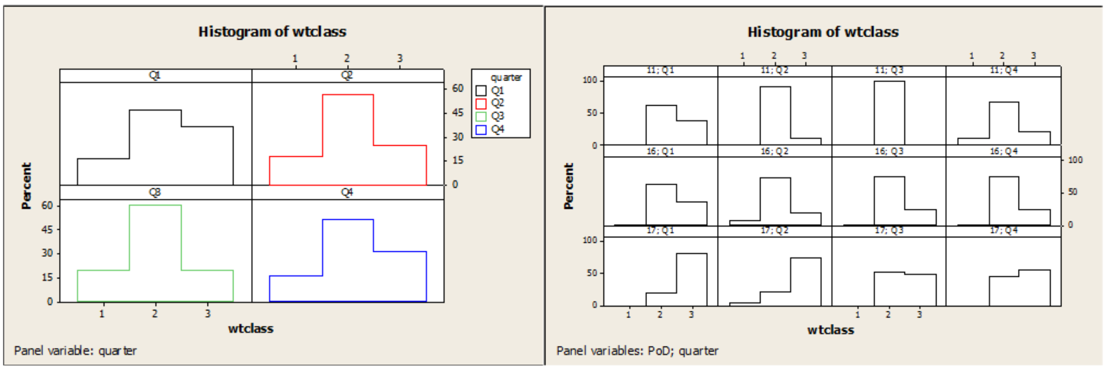

Figure 2: The distribution of vessel cargo weight classes (wtclass) per quarter (Q1-Q4) on left and per port of discharge (PoD 11, 16, 17) on right.

Table 2: Average voyage times from Port of Lading (PoL) to Port of Discharge (PoD).

(PoL)	S SWE (11)	SE SWE (16)	N SWE (17)
	Avg. voyage times to PoD (hrs)		
LV (4)	33	26	56
EST (2)	40	34	54
RU (8)	n/a	n/a	66

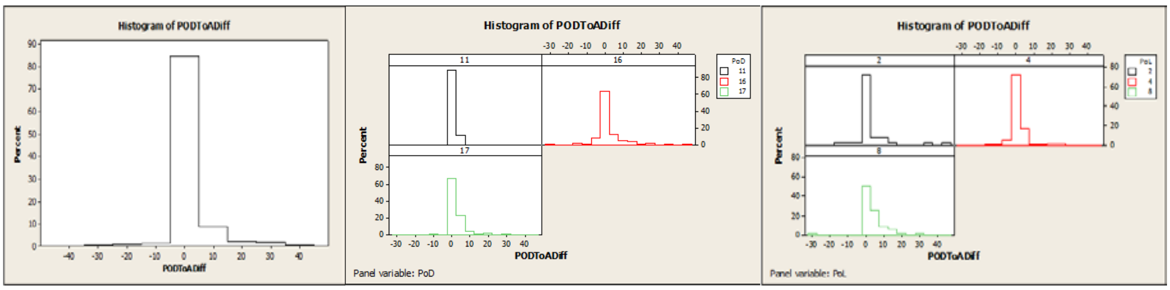

Figure 3: The distribution of deviations between estimated and actual times of arrival at port of discharge (PoD_ToA_Diff in hours). The figure on the left includes all observations. The figures in the middle and on the right are the distributions per PoD and PoL, respectively.

The average time between loading and discharging was just over 60 hours. This time consisted of 59% voyage time, 36% delays before leaving PoL and 5% delays before discharging at the PoD. The average time between PoL-PoD combinations ranged between 26 and 66 hours as shown in Table 2.

Overall, 85% of cargoes arrived within 5 hours of their estimated time of arrival. The deviations between estimated and actual time of arrival (ToA) show the expected right-skewed distribution with a higher frequency of late arrivals than early arrivals (Figure 3). The smallest ToA deviations were for PoDs in southern Sweden (11) where cargoes come predominantly from PoLs in Latvia (4). The largest deviations were for PoDs in the southeast and north where a higher proportion of cargoes come from Estonia (2) and Russia (8). The percent of on-time arrivals was highest for cargoes from Latvia (4) and Estonia (2) and lowest from Russia (8).

4. Discussion

The follow-up of delivery data via Vesselplan served as a useful source for quantifying risks for short-sea shipping of roundwood and chips between the various PoL-PoD combinations. While experienced shippers have an intuitive understanding of these, such quantitative measures are useful for further OR work with short-sea shipping.

The overall distributions of deviations between latest estimated and actual time of arrival showed a relatively high proportion of on-time arrivals (85% within 5 hours of estimated ToA). Figure 3 visualizes the longer delays associated with northern shipping routes such as RU (8) to N SWE (17). Surprisingly, the study did not quantify any increase in delays during the winter. This is presumably due to the mid-winter ice conditions during study period (Figure 4) where both the Gulf of Finland (PoL 8) and Gulf of Bothnia (PoD 17) had drift ice conditions (red) with limited amounts of fast ice (grey). This, in combination with the more frequent use of larger ice-classed vessels to ports in north Sweden (Figure 2) limited the adverse effects of winter conditions.

Import statistics since 2000 show a gradual increase in the number of countries exporting roundwood or chips to Sweden until 2004-2007. Since then, volumes have become increasing consolidated to fewer sources. The initial period was also associated with more frequent use of general purpose bulk vessels (min-bulkers or coasters). With later reduced import volumes and consolidation of sources, there has been an increasing use of specialty wood-shuttles, with wider and shallower hull profiles enabling larger deck loads and easier access to more marginal ports. Given the larger vessel cargo sizes for the northern PoL-PoD flows (Figure 2), this trend for specialized vessels is most relevant for the shorter southern routes.

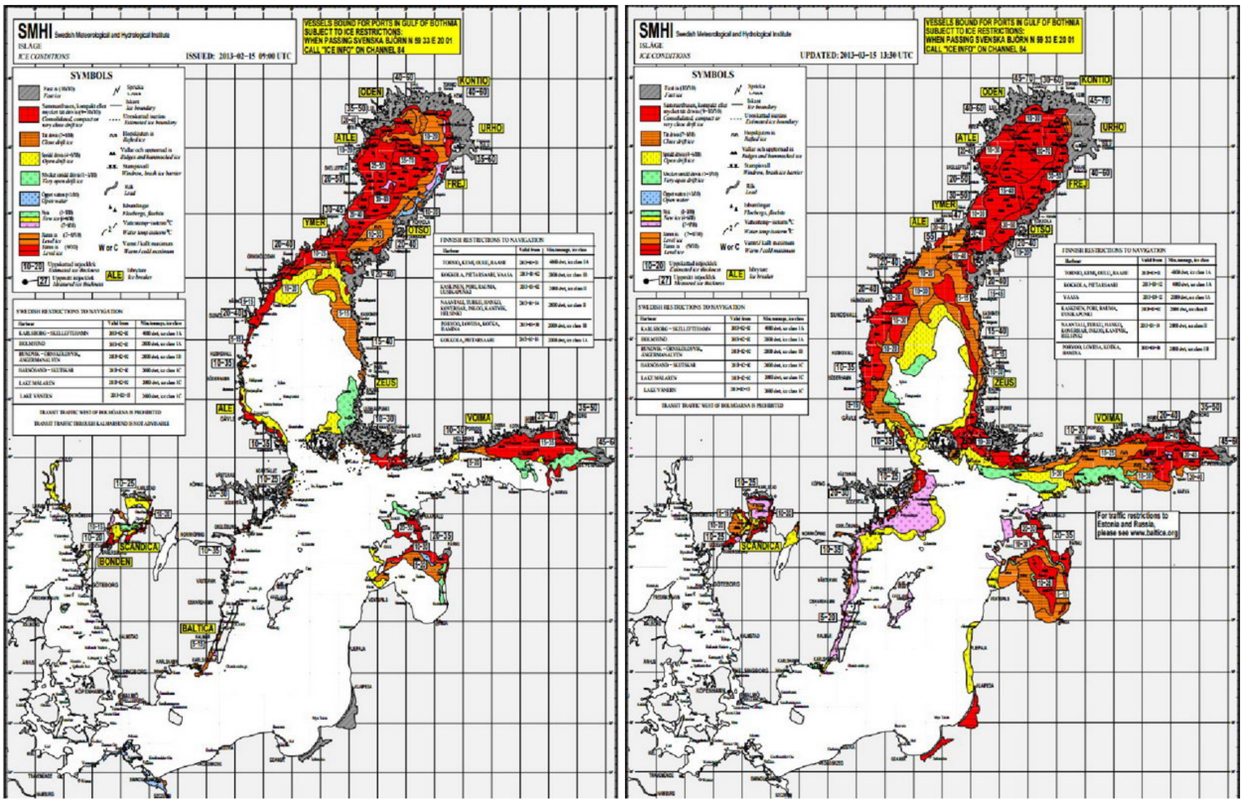

Figure 4: Mid-winter ice conditions in the Baltic Sea during the study period (Mid-Feb on the left, Mid-march on the right, SMHI 2013).

5. Acknowledgements

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Evaluating the debarking efficiency of modified harvesting heads on European tree species

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Abstract: Debarking can help maintain forest health and lower the spread of spruce bark beetle as it reduces the export of nutrients, which are mostly located in tree bark.
Existing purpose-built debarking harvesting heads are successfully used in Eucalyptus plantations. However, to maintain flexibility and lower investment cost, modifications were made to commonly used harvesting heads mounted on single-grip harvesters to assess their debarking efficiency under Central European conditions.
Different field tests, with varying tree species, summer and wintertime, diameters and age classes are established in Lower Saxony and in Bavaria, Germany. All tests are performed using the cut-to-length method. To quantify debarking ability originating from head modifications, measurements are performed with a photo-optical evaluation software.
First results demonstrate considerable differences in debarking efficiency between vegetation season and tree species. More specifically, when used within the growing season, innovative head modifications provided an efficient method of achieving in-stand debarking of over 80%.

Keywords: Debarking harvesting head, debarking efficiency, photo optical measurements, mechanized operations

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1. Introduction

Until the late 1980's bark had no value as fuel for heat and power plants or as substitute for other channels of distribution, thus making in-stand debarking very common in German forestry. It was furthermore necessary to reduce the weight of the logs by removing the bark to fit the contemporary technological standards and loading cranes (Sohns 2012). Without the presence of bark, stem drying rate was increased and a weight reduction of 30% depending on species and bark thickness was achieved (Sohns 2012). Over the past few decades, tree bark became a demanded resource for sawmill co-generated power plants and other distribution channels (e.g. bark mulch) and was therefore increasingly exported out of the forest. The trend towards constructing larger capacity sawmills equipped with their own debarking facilities, have since re-introduced a demand for in-stand debarking (Leidner 2015). Nowadays, in-stand debarking only plays a minor role when considering forest health and spruce bark beetle (Ips typographus) prevention (Ebner and Scherer 2012).

Unlike in Germany, whole stem or log debarking is a common treatment, especially in so-called "tree farms" located in South Africa or Brazil. The characteristics of Eucalyptus and the designated use for the pulp and paper industry necessitates in-stand debarking. Craft mills in South Africa usually set the allowable threshold of bark percentage remaining on stems at 0.8-1.0% (van der Merwe et al. 2015). Since the difficulty of removing bark from Eucalyptus trees considerably increases as the wood dries, the development towards highly mechanized felling and debarking systems has been accelerated in these conditions. Currently the most widely used harvesting method in the "tree farms" is cut-to-length using a single-grip harvester and forwarder (Nutto et al. 2015) similar to operations in Germany.

In-stand debarking of harvested trees can provide multiple benefits;

i) increased drying rate lowers the weight of wood that needs to be transported from the landings to the mills and can therefore reduce costs in the logistic chain.
ii) in certified forests, chemical treatments of logs is prohibited thus requiring a quick turnaround from the time of harvesting to transportation of products to the mill in order to lower the risk of spruce bark beetle infestation. Debarking can depressurize the time schedule in the logistic chain as debarked logs do not provide breeding grounds for spruce bark beetles and can be stored for a longer time period in the forest.
iii) since a high nutrient content originates from tree bark (Weis and Göttlein, 2002), methods of maintaining bark within forest stands during mechanized timber harvesting operations could provide good opportunities to conserve soil fertility.
iiii) as nutrients are highly located in bark, debarking can also lower the ash content and fine dust emission when burned as firewood (Windl 2015).

In this study, debarking rollers and other modifications, designed for Eucalyptus harvesting heads, are adjusted on commonly used harvesting heads and tested under Central European conditions. In cooperation with the Kuratorium für Waldarbeit und Forsttechnik eV. (KWF) we:

- evaluate time and monetary profits/losses of harvesting heads with debarking capabilities compared to conventional harvesting heads (KWF).
- assess the influence of vegetation season, tree species and tree form on the debarking percentage after technical modifications (PhD).
- quantify the debarking percentage via the development and use of automated measurement systems (PhD).
- develop best management guidelines to help improve the quality and efficiency of stem debarking when using harvesting heads with debarking capabilities.

To evaluate the percentage and quality of bark removal referred to the modifications, measurement systems are developed in the project.

2. Material and Methods

Different field tests, with varying tree species, diameters and age classes are established in two States located within German, Lower Saxony and Bavaria. These tests are repeated in both summer and winter seasons to evaluate the influence of associated sap flows on debarking quality. In total 1000 m³ of wood was harvested and processed with the debarking harvesting head prototype in the first two runs. A sample of 249 logs of spruce (*Picea abies*) and pine (*Pinus sylvestris*) were examined in the first summer (2015) and 350 in winter (2015) tests (Fig. 1) to assess the debarking percentage.

Initial testing was performed with a standard H480C-John Deere harvesting head mounted on a John Deere 1470 single-grip harvester and further tests with Ponsse and LogMax harvesting heads are planned. Feed rollers are changed at the beginning of the trials with custom built rollers and the corresponding roller-pressure is lowered to reduce wood damage. The felling process is similar to conventional cut to length harvesting operations (Fig. 2). But in addition the tree needs to be moved over the full length, 2 times through the harvesting head to debark.

To measure the debarking percentage, trees are felled and processed with the modified harvesting head, placing all logs originating from one tree on one small pile in the stand, so they can be marked with number plates and afterwards be retraced. The logs are then transported with a forwarder to roadside landings, unloaded and placed in parallel on the forest road with a minimum of 1-2m spacing, depending on the diameter, so pictures of each log can be taken easily without overlays. The length, top, mid and bottom diameter of every log is gathered and recorded together with the attending log number.

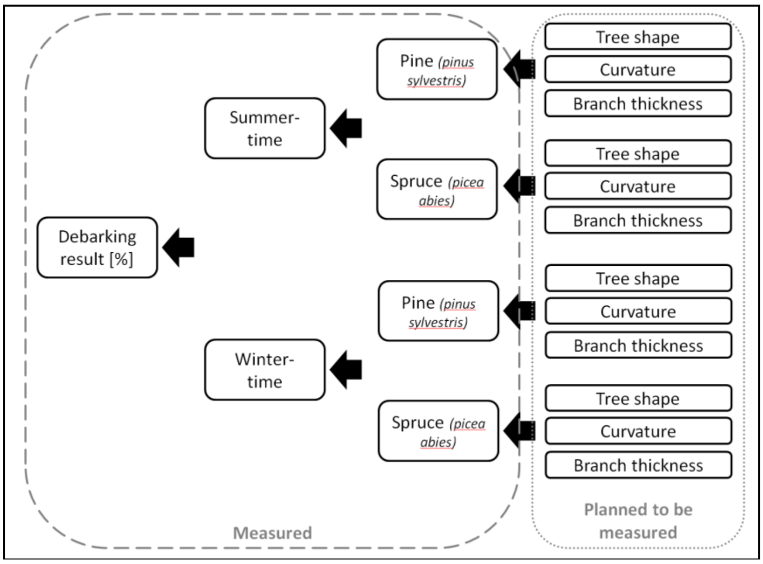

Figure 1: Influencing factors that are planned to be taken into account.

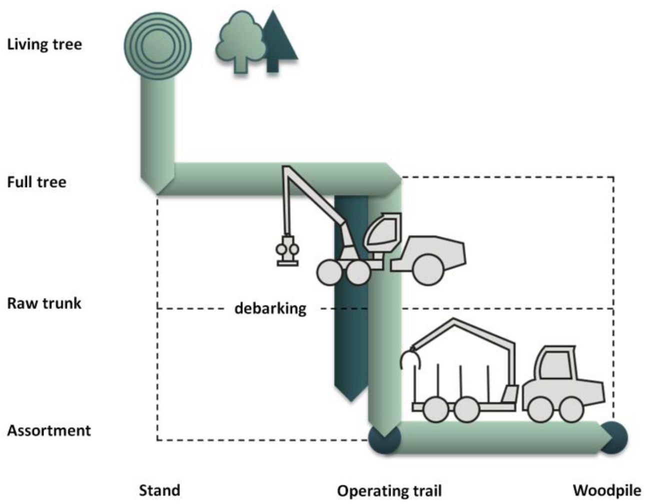

Figure 2: Procedure graph of the wood harvesting (modified after Erler, TU Dresden).

This is necessary to reconstruct the whole tree afterwards in the database. In a final step, pictures are taken from each log. The pictures are taken with a conventional reflex camera so a failure throughout distortion needs to be taken into account. To eliminate this failure and for higher accuracy, a second photo-optical system is currently being tested. The Trimble V10 is a calibrated 360° measurement tool that can take multiple pictures in a short amount of time, which are assembled on a computer afterwards so that both sides of the stem are recorded on one picture. As the cameras are calibrated, curvature, branch thickness, length and diameter measurements can be performed in the office. This directly lowers the dependency on weather as the time in field is shortened. Tree shape evaluations still have to be performed on the standing trees (pre-inventory) directly in the forest. The calculation of the debarking percentage will be performed through attendant software.

The photo-optical software to assess the debarking efficiency is developed within the project and uses digital pictures of the processed logs to define different polygons and to calculate the stem surface considering the curvature. As the polygons are categorized in different categories (wood, bark, covered, not measureable, etc.) the percentage of each polygon type in relation to the total surface can be calculated (Fig. 3). Polygon identification is currently performed manually but steps to convert the method to an automated system is in progress.

3. Preliminary Results and Discussion

First tests showed that; i) there are considerable differences in the debarking efficiency between vegetation seasons. Within summer time, the modified harvesting head prototype was able to reach high debarking results that were in average 87% for both pine and spruce. During winter-time the average debarking rate decreased to about 50%. In addition, variation of debarking percentages was more pronounced especially for pine, which might be related to the higher sample size. Enlarging the sample size for both species and vegetation seasons will clarify this assumption (Fig 4). ii) hardwood and softwood trees responded similarly on debarking. To prove that, additional tree species such as douglas fir (Pseudotsuga menziesii), beech (Fagus sylvatica) and oak (Quercus spec.) were tested but not in a representative amount and therefore not presented here. iii) the debarking percentage seems to be affected by the diameter of the stem being processed.

Figure 3: Projection of a spruce stem with defined bark polygons in the photo-optical evaluation software (stemsurf).

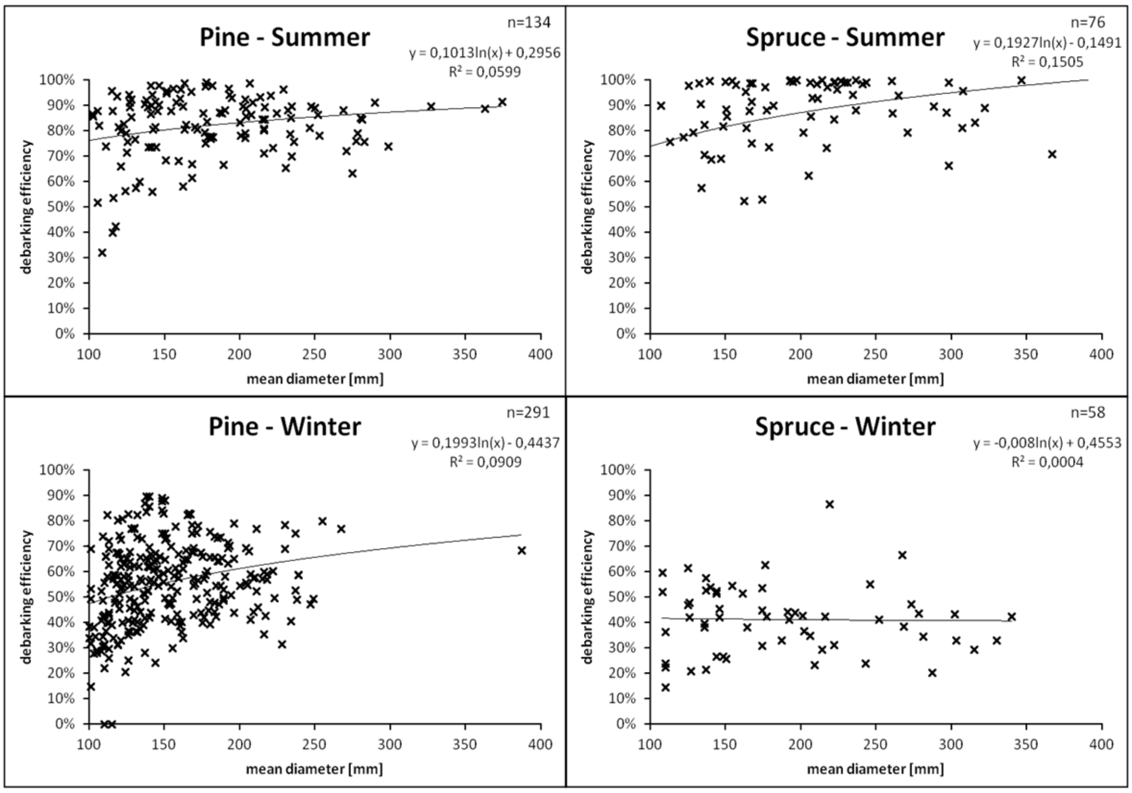

Figure 4: Overview of the debarking efficiency depending on log mean diameter, measured in the first winter and summer test for pine and spruce.

As the diameter falls below a certain value the feed rollers begin to slip and the debarking efficiency decreases. The bottom stems, originating from the base of a tree, exhibit a lower debarking percentage as the harvesting head is not able to debark the part of the tree where it attaches to while felling. To approve these assumptions the sample size needs to be enlarged. iv) curviness and large branches seem to have an effect on wood damage and debarking percentage. With commonly used harvesting heads debarking percentages, in summertime, of 25-30% where achievable by changing the roller-pressure (Braun 2015; Hohenadl 2015). Therefore, to attain a more efficient debarking, modifications on the head are absolutely necessary.

4. Future work

Upcoming work will be divided in three main components. Priority will first be given to develop and continue to refine automated measurement systems to assess debarking efficiency. Other measurement systems are still under investigation (e.g. Light detection and ranging (LiDAR)), to assess if they might improve the database. Secondly, a benchmark of debarking efficiency will be obtained by state-of-the-art mill instruments and compared to all measurement systems used in the current study. Lastly, a more detailed understanding of factors affecting debarking efficiency (diameter, tree form, branch thickness, etc.) will be sought via controlled testing and good practice guidelines for quality and cost-efficient debarking will be developed.

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The effect of independent variables of time equations at the logging with harvesters

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Abstract: For the planning of the harvesting process multivariate power time-functions have been set up for hardwood and softwood species and for different types of species, which can be used by practical experts in the field. Using these equations the cycle time, specific time requirements and performance of harvesting can be calculated. Norm tables (including time, performance, costs) have been set up for hardwood and softwood stands, indicating the harvesting time (min/m^3), volume of logged timber in one operating hour (m^3/h) and specific costs of harvesting (Ft/m^3) related to 1 m^3 produced timber, by applying different values for the independent variables.

From the independent variables of the time-functions (stem bending, branchiness, tree forks, number of assortments, stem volume, distance of changeovers) it is the number of assortments which affects the value of the cycle time most significantly in the case of both hardwood and softwood stands. The specific time requirement is mostly influenced by the number of assortments, stem volume and changeover distance, while performance is mostly affected by stem bending, branchiness and the presence of tree forks.

From among the independent variables it is the number of assortments that affect mostly the percentual change of the cycle time in both hardwood and softwood stands. The percentual change of the specific time requirement is mostly influenced by the number of assortments, stem volume and distance of changeovers. The performance is also determined most significantly by stem volume and the number of assortments.

The presence of bends in the harvested stems influences the cycle time and specific time requirement to a lesser extent (in terms of order and percentual change) than the branchiness of the stems, in hardwood stands. Respecting performance, branchiness influences the most significantly percentual changes, while it is the stem bending, which is the mostly determinant in terms of order.

Keywords: harvester, time equations, independent variables

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1. Introduction

In Hungary highly mechanized logging technologies are used more and more often, for example the CTL (Cut To Lenght) work system when felling, skidding, delimbing, assorting, chopping, bunching and reviewing are done with a harvester and skidding and forwarding are done with a forwarder. Forwarding works next to harvesters can of course be done with other lead machines (forwarding trailer) or horses as well. The growing spread of harvesters in the last few years justifies the setting up of time equations and norm tables which can be used by professionals. Because of that and other reasons at our institute we have been collecting time and work condition data of harvesters working in domestic forests for almost 10 years now.

2. Material and Methodes

2.1 Data collection for multivariate power equations

To be able to evaluate the work of harvesters (worktime structure, performance) measurements are needed to be done in stands. The data collection in the field was done with the method of continuous time measurement. The data collection was done using a stopwatch, field data minute-book and measuring tape. At the end of each procedure section/procedure period the elapsed time from the beginning of the measurement was recorded (Gólya, 2003). During the record the following „procedure-elements" were separated:

- Seeking out the tree (S): the time in which the operator puts the harvester head on the stem of the tree using the manipulator arm;
- Felling, processing (F): the time including felling, skidding, delimbing, chopping and bunching per assortment;
- Change-over (C): locomotion movement;
- Only felling (OF): time for felling a very thin or bad quality (e. g. totally rotten) tree, which does not provide timber;
- Arranging branch material (AB): arranging branch material which acts as a confounding factor for some reason;
- Arranging timber (AT): arranging timber which acts as a confounding factor for some reason;
- Resting (R): the time for satisfying human needs;
- Troubleshooting (TH): the time for troubleshooting technical hitches that happen during work;
- Maintenance (M): the time for satisfying mechanical needs (e. g. changing chains, refueling);
- Waiting (W): other time lost (e. g. phonecalls).

Besides time tree species and the volume of processed timber per cycle (number of processed assortments) were recorded as well just like the distance of change-overs (with estimation). In order to define the performance of the machine we defined an average size assortment for each timber assortment type. Depending on the time of the measurement and the number of assortments the top diameter of 50-150 pieces of logs were recorded per each assortment type. By knowing the lenght the volume of average size assortments can be determined by using the Excel scaling programme adapted to the evaluation programme (made by the author based on the scaling book). Every harvested log got a so called hardship score during the measurement (forstINNO, 2007). This is made up of three subscores:

- crookedness (1-3);
- limbiness (1-4);
- forkedness (1-3).

The determination of hardship subscores was done with subjective methods but it was based on categories set up and defined previously. The subscores for characterizing individual trees were determined by the visual survey of each stem.

2.2 Multivariate power equations for harvester loggings

The data series collected in the field are suitable for creating *multivariate power equati*ons based on regression-analysis. By using the equations the norm tables are easy to set up. Several data series were created from the results of the field measurements. (Table 1.). The data series were done for each tree species which contained one dependent variable – performance (P, m^3/min) or specific time demand (t_{sp}, min/m^3), or cycle time (t_c, min/cycle) – and contained several independent variables. This is for example the assortment number (N, pcs/tree) and timber volume (V_t, m^3/tree), as well as the scores of crookedness (CS), limbiness (LS), forkedness (FS) or the summarized hardship score (HS) derived from these. From the independent variables mentioned above only the time of 'Seeking out the tree' and 'Felling, processing' got collected (these two process elements determine a cycle) with the data belonging to them (SF data series group). Furthermore another data series group got established marked SFC because in that case besides 'Seeking out the tree' and 'Felling, processing' the process element of 'Change-over' and its connected data got collected as well. In this case cycles were determined by change-overs. Based on summarizing and averaging the data between change-overs we got the dependent variables (P, tsp, tc) as well as the independent variables (s, m; N_t, pcs/cycle; Q, m^3/cycle; CS_a; LS_a; FS_a; and HS_a).

63 SF and SFC data series were established respectively. From the data collected in the field and calculated during the processing work time-equations were created with the help of regression-analysis (exponential functions with three, four, five, six variables) in hte following form:

SF data series (five and three variables):

$$t_c = c \times CS^{\alpha} \times LS^{\beta} \times FS^{\gamma} \times N^{\delta} \times V_t^{\varepsilon}$$
$$t_c = c \times HS^{\alpha} \times N^{\beta} \times V_t^{\gamma}$$

SFC data series (six and four variables):

$$t_c = c \times s^{\alpha} \times CS_a^{\beta} \times LS_a^{\gamma} \times FS_a^{\delta} \times N_t^{\varepsilon} \times Q^{\zeta}$$
$$t_c = c \times s^{\alpha} \times HS_a^{\beta} \times N_t^{\gamma} \times Q^{\delta}$$

where:
t_c = cycle time (minutes);
c = coefficient (value of axis intersection);
s = change-over distance (m);
CS = hardship score of crookedness (score/tree);
CS_a = average value of hardship score of crookedness (score/cycle);
LS = hardship score of limbiness (score/tree);
LS_a = average value of hardship score of limbiness (score/cycle);
FS = hardship score of forkedness (score/tree);
FS_a = average value of hardship score of forkedness (score/cycle);
HS = total hardship score (total score/tree);
HS_a = average value of total hardship score (score/cycle);
N = number of assortment (pcs/tree);
N_t = total number of assortment (pcs/cycle);
V_t = timber volume (m^3/tree);
Q = timber volume (m^3/cycle);
$\alpha \ldots \zeta$ = exponents.

Regression-analysis was also done for specific time demand (t_{sp}) and performance (P). The time-equations have similar formats than the ones shown above (Table 2.).

Table 1: Some examples on establishing the data series.

Species	Data series ID	Data series No.	No. of variables	Dependent	Independent
				variables	
Black locust	SF-BL-tc	392	6	t_c	CS, LS, FS, N, Vt
Beech	SF-B-tsp	135	6	t_{sp}	CS, LS, FS, N, Vt
Turkey oak	SF-TO-P	593	6	P	CS, LS, FS, N, Vt
Hornbeam	SF-HB-tcHS	275	4	t_c	HS, N, Vt
Hardwoods	SF-HW-tspHS	1426	4	t_{sp}	HS, N, Vt
Noble poplar	SF-NP-PHS	501	4	P	HS, N, Vt
All deciduous	SFC-AD-tc	1089	7	t_c	s, CSa, LSa, FSa, Nt, Q
Spruce	SFC-S-tsp	37	4	t_{sp}	s, Nt, Q
Scotspine	SFC-SP-P	185	7	P	s, CSa, LSa, FSa, Nt, Q
Black pine	SFC-BP-tcHS	592	5	t_c	s, HSa, Nt, Q
All conifers	SFC-AC-tspHS	814	5	t_{sp}	s, HSa, Nt, Q
Black locust	SFC-BL-PHS	154	5	P	s, HSa, Nt, Q

Table 2: Created time-equations and their mathematical reliability parameters (excerption).

Number	Species	Data series ID	Data of series		Dependent variable	Independent variables										Variance analysis	Multi correla-tion			Axis inter-sec.	Degree of freedom		t	F
			Line	Column		CS		LS		FS		N (pcs/tree)		Vt (m3/tree)							Numerator	Denominator	Value of probe on a 5% significance level	
			száma			Reg.coef.	t probe	Reg.coef.	t probe	Reg.coef.	t probe	Reg.coef.	t probe	Reg.coef.	t probe	F probe	R	R2	Hr%					
1	Black locust	SF-BL-tc	392	6	tc (min/tree)	0,0520	1,0095	0,1368	2,6529	0,5607	6,1661	0,0867	0,4825	0,4910	3,1559	108,614	0,7646	0,58	48,8793	1,9825	5	386		2,23
2	Beech	SF-B-tc	135	6	tc (min/tree)	-0,2748	-2,5114	0,2456	2,4106	0,3984	2,3008	0,8871	3,6405	0,0616	0,2948	30,610	0,7366	0,54	77,4009	0,3151	5	129		2,27
3	Turkey oak	SF-TO-tc	593	6	tc (min/tree)	0,0194	0,4628	0,2618	5,8547	0,3920	3,8102	1,3301	4,8612	-0,4159	-1,6161	110,199	0,6958	0,48	73,0304	0,1070	5	587		2,22
4	Hornbeam	SF-HB-tc	275	6	tc (min/tree)	-0,0470	-0,7222	0,3700	5,9100	0,2522	2,0713	1,0769	8,3060	-0,3307	-2,4885	71,622	0,7557	0,57	53,1863	0,1357	5	269		2,23
5	Hardwoods	SF-HW-tc	1426	6	tc (min/tree)	-0,0405	-1,4722	0,2531	8,9567	0,4363	7,8370	0,8549	16,0059	-0,1226	-3,2439	316,940	0,7262	0,53	67,2509	0,2727	5	1420		2,21
6	Noble poplar	SF-NP-tc	501	5	tc (min/tree)			0,9065	6,7641	0,4419	1,4074	0,9142	12,0402	0,0953	1,3277	196,174	0,7828	0,61	45,0569	0,0602	4	496	1,96	2,38
7	All deciduous	SF-AD-tc	1928	6	tc (min/tree)	0,1676	5,7796	0,1907	6,2213	0,9190	16,3124	0,1823	4,3458	0,2021	5,7765	207,455	0,5920	0,35	82,4183	0,7827	5	1922		2,21
8	Scotspine	SF-SP-tc	496	6	tc (min/tree)	0,1275	0,0591	0,5283	0,0528	0,3881	0,1574	0,7773	0,0503	0,2332	0,0230	150,526	0,7783	0,61	52,4299	0,3004	5	490		2,22
9	Black pine	SF-BP-tc	1026	6	tc (min/tree)	0,1436	3,0999	0,3523	13,8956	0,5618	9,6346	0,6433	28,0189	0,0700	3,5437	271,479	0,7556	0,57	33,0965	0,3005	5	1020		2,21
10	Spruce	SF-S-tc	153	3	tc (min/tree)							-0,2766	-1,6755	0,6936	4,9413	20,470	0,4630	0,21	34,8752	2,8238	2	150		3,06
11	All conifers	SF-AC-tc	1675	6	tc (min/tree)	0,1762	4,8980	0,4083	17,1432	0,4968	8,5364	0,6769	42,7395	0,1613	11,9109	522,700	0,7812	0,61	40,4035	0,3215	5	1669		2,21
1	Black locust	SF-BL-tsp	392	6	tsp (min/m3)	0,0526	1,0215	0,1364	2,6449	0,5575	6,1292	0,0937	0,5211	-0,5109	-3,2831	25,645	0,4994	0,25	48,9625	1,9614	5	386		2,23
2	Beech	SF-B-tsp	135	6	tsp (min/m3)	-0,2755	-2,5189	0,2457	2,4135	0,3986	2,3032	0,8862	3,6390	-0,9380	-4,4902	6,152	0,4388	0,19	76,7502	0,3157	5	129		2,27
3	Turkey oak	SF-TO-tsp	593	6	tsp (min/m3)	0,0195	0,4639	0,2616	5,8528	0,3921	3,8139	1,3296	4,8621	-1,4150	-5,5021	15,813	0,3445	0,12	72,2668	0,1072	5	587		2,22
4	Hornbeam	SF-HB-tsp	275	6	tsp (min/m3)	-0,0475	-0,7286	0,3698	5,9044	0,2524	2,0726	1,0765	8,3000	-1,3304	-10,0085	24,361	0,5583	0,31	53,2308	0,1358	5	269		2,23
5	Hardwoods	SF-HW-tsp	1426	6	tsp (min/m3)	-0,0403	-1,4655	0,2532	8,9628	0,4359	7,8333	0,8557	16,0273	-1,1221	-29,7058	317,548	0,7266	0,53	66,8023	0,2725	5	1420		2,21
6	Noble poplar	SF-NP-tsp	501	5	tsp (min/m3)			0,9065	6,7669	0,4410	1,4052	0,9138	12,0394	-0,9039	-12,5932	77,822	0,6210	0,39	44,9575	0,0603	4	496	1,96	2,38
7	All deciduous	SF-AD-tsp	1928	6	tsp (min/m3)	0,1680	5,7939	0,1906	6,2208	0,9192	16,3166	0,1820	4,3395	-0,7969	-22,7758	423,266	0,7239	0,52	81,7137	0,7835	5	1922		2,21
8	Scotspine	SF-SP-tsp	496	6	tsp (min/m3)	0,1277	2,1599	0,5283	10,0190	0,3883	2,4671	0,7760	15,4279	-0,7664	-33,2803	319,957	0,8749	0,77	52,4459	0,3013	5	490		2,22
9	Black pine	SF-BP-tsp	1026	6	tsp (min/m3)	0,1436	3,0992	0,3526	13,8995	0,5618	9,6299	0,6433	28,0044	-0,9283	-46,9888	789,152	0,8914	0,79	33,1055	0,3010	5	1020		2,21
10	Spruce	SF-S-tsp	153	3	tsp (min/m3)							-0,2758	-1,6711	-0,3071	-2,1885	20,206	0,4607	0,21	34,8298	2,8176	2	150		3,06
11	All conifers	SF-AC-tsp	1675	6	tsp (min/m3)	0,1763	4,9009	0,4084	17,1494	0,4971	8,5424	0,6770	42,7536	-0,3831	-61,9010	1294,678	0,8916	0,80	40,3983	0,3216	5	1669		2,21
1	Black locust	SF-BL-P	392	6	P (m3/min)	-0,0519	-1,0089	-0,1372	-2,6650	-0,5517	-6,0768	-0,1064	-0,5928	0,5210	3,3546	25,660	0,4995	0,25	50,3421	0,5257	5	386		2,23
2	Beech	SF-B-P	135	6	P (m3/min)	0,2750	2,5171	-0,2441	-2,4000	-0,3942	-2,2794	-0,8826	-3,6274	0,9343	4,4763	6,093	0,4371	0,19	58,9160	3,1404	5	129		2,27
3	Turkey oak	SF-TO-P	593	6	P (m3/min)	-0,0179	-0,4270	-0,2626	-5,8732	-0,3921	-3,8113	-1,3334	-4,8730	1,4181	5,5107	15,835	0,3448	0,12	58,9252	9,4062	5	587		2,22
4	Hornbeam	SF-HB-P	275	6	P (m3/min)	0,0484	0,7438	-0,3652	-5,8420	-0,2543	-2,0913	-1,0715	-8,2767	1,3225	9,9668	24,065	0,5559	0,31	62,4795	7,2354	5	269		2,23
5	Hardwoods	SF-HW-P	1426	6	P (m3/min)	0,0418	1,5194	-0,2525	-8,9441	-0,4351	-7,8246	-0,8577	-16,0777	1,1230	29,7529	317,977	0,7268	0,53	58,8249	3,6810	5	1420		2,21
6	Noble poplar	SF-NP-P	501	5	P (m3/min)			-0,9025	-6,7266	-0,4320	1,3744	-0,9167	-12,0614	0,9054	12,5941	77,676	0,6206	0,39	70,2735	16,5662	4	496	1,96	2,38
7	All deciduous	SF-AD-P	1928	6	P (m3/min)	-0,1668	-5,7517	-0,1898	-6,1933	-0,9189	-16,3119	-0,1834	-4,3719	0,7975	22,7940	422,684	0,7237	0,52	70,7936	1,2789	5	1922		2,21
8	Scotspine	SF-SP-P	496	6	P (m3/min)	-0,1278	-2,1436	-0,5388	-10,1328	-0,3856	-2,4297	-0,7826	-15,4284	0,7699	33,1524	319,030	0,8747	0,77	47,6217	3,3738	5	490		2,22
9	Black pine	SF-BP-P	1026	6	P (m3/min)	-0,1406	-3,0243	-0,3519	-13,8249	-0,5630	-9,6166	-0,6422	-27,8614	0,9283	46,8266	782,738	0,8907	0,79	36,0303	3,3180	5	1020		2,21
10	Spruce	SF-S-P	153	3	P (m3/min)							0,2759	1,6689	0,3079	2,1906	20,205	0,4607	0,21	40,7622	0,3548	2	150		3,06
11	All conifers	SF-Asp-P	1675	6	P (m3/min)	-0,1764	-4,8764	-0,4108	-17,1564	-0,4974	-8,5025	-67,8840	-42,6419	0,8400	61,7119	1287,774	0,8912	0,79	42,5145	3,1242	5	1669		2,21

2.3 The effect of the independent variables of time-equations

Not all of the harvester heads used for logging in conifer stands can be used for harvesting deciduous trees. This is particularly true in case of heads with 2 or 4 forwarding cylinders and 4 archblades. Because of their structure these heads are longer and they are less able to follow the bends of trees. A shorter harvester head is needed to overcome spatial curvedness which has 1 pair of forwarding cylinders and 2 or 3 moving blades and occasionally 1 fixed blade. For cutting off stronger limbs enforced archblades are more favourable. The use of harvesters in deciduous stands is growing worldwide so the demand for the improvement of heads in these directions is rising as well. One of the key points of developing harvester heads for deciduous stands is that we understand what influence each different independent variable has. International studies prove as well that the process of delimbing – where crookedness and limbiness has to be fought against the most – can take up to 70-77% of the time spent on harvesting a tree (Dargnat et al., 2014, Chakrouni – Cacot, 2014).

3. Results

3.1 Examination of multivariate power equations

Here we present the two functions set up from the data series gathered from the measurements taken in deciduous stands (SF-AD-tc, SF-AD-tsp) as well as their evaluation together with their mathematical reliability parameters (Szakálosné Mátyás K., 2012).

The function enabling the calculation of cycle time (tc; productive minute/cycle):

$$t_c = 0{,}78269 \times CS^{0{,}16758} \times LS^{0{,}19065} \times FS^{0{,}91896} \times N^{0{,}18230} \times V_t^{0{,}20211}$$

Through the function the time needed for a tree to be harvested (minute/tree) can be determined, depending on the crookedness, limbiness, forkedness, number of assortments and timber volume.

The values characterizing the mathematical reliability of the function are:
R (total correlation coefficient) = 0,59; that is a medium correlation.
R² (determination coefficient) = 0,35; that means that the cycle time is determined by the five independent variables in 35%. This can be explained by the fact that the measurements were taken in different stands, with different logging methods, different machines and different operators so the data series are loaded with variables which are hard to quantify.
F (value of F-probe) = 207,45 (numerator's degree of freedom: 5, denominator's degree of freedom: 1922); the table value on a 5% reliability (significance) level is 2,21; so our F-value is bigger. This means that the function can be used reliably.

T-probe values (degree of freedom: 1922) are:
CS t1 = 5,779
LS t2 = 6,221
FS t3 = 16,312
N t4 = 4,345
V_t t5 = 5,776

The table values on a 5% reliability level are: 1,96 (0,1% level: 3,29). The t-probe has the highest convincingness so high values guarantee that the specific exponents are reliable on their own.

Hr and Hr' (relative percentage of errors) = 52,2% and 82,4%. At the duration of a cycle we can calculate approximately with such a difference. The resulting high value does not reduce the reliability of the function because the differences within a shift start to equal each other out more and more at the total values and the value converges to an error around zero. This is supported by a regression-analysis done on a 208 row data set of a turkey oak regeneration cutting where Hr' = 79,17%. The equaling-out of the error percentages can be determined with the cumulated average of the measured data and the one calculated based on the time-equation. According to that the error equals out to a value around -10%.
The reason for this are the effects of influencing factors not taken into the equation (or they can hardly be taken in). We can see that this mathematical reliability value is much less important than the t-probe.

Calculating with specific time demands (min/m³) is more practical. We also prepared the regression-analysis for specific time demends. In that case the cycle times (t_c) and the quotients of harvested timber in the cycle (V_t, and Q) are present in the data series (SF-AD-tsp).

We present the new function regarding specific time demand (tsp; productive minute/m³) and its reliability values now without detailed description:

$$t_{sp} = 0{,}78350 \times CS^{0{,}16799} \times LS^{0{,}19063} \times FS^{0{,}91918} \times N^{0{,}18203} \times V_t^{-0{,}79686}$$

Values characterizing mathematical reliability:
R (total correlation coefficient) = 0,72; that is a strong relationship.
R² (determination coefficient) = 0,52; that means that the specific time demand is determined by the five independent variables in 52%.
F (value of F-probe) = 423,27 > 2,21 (numerator's degree of freedom: 5, denominator's degree of freedom: 1922), which is bigger than the table value on a 5% reliability value, so the whole function can be used reliably.

T-probe values (degree of freedom: 1922):
CS t1 = 5,794
LS t2 = 6,221
FS t3 = 16,317
N t4 = 4,340
V_t t5 = -22,776

The table values on a 5% reliability level are: 1,96; so the different exponents are reliable values on their own.

Hr and Hr' (relative error percentage) = 52,23% and 81,71%.

3.2 Normtables for logging with harvesters

Based on the reliable m*ultivariate power time-equati*on acquired during regression-analysis as well as on the operation-hour costs norm tables can be set up for different stands. Norm tables consist of three sections (Table 3.). The 'Timenorm table' contains the time needed for the harvesting of 1 m³ timber (minutes) besides the given parameters. The 'Performance table' contains the volume of timber that can be logged in one hour, and the 'Cost table' contains the specific costs of logging (Eur/m³).

Table 3: Norm table for deciduous stands.

n=	1928	pcs		**Harvester**	k_0=	49,26	Eur/o. h.
P=	70	%		**Valmet 911.3**	L_a=	1	pers.
t_1=	5,79	t_4=	4,34		R^2=	0,52	
t_2=	6,22	t_5=	-22,78	**Deciduous stand**	F=	423,27	
t_3=	16,32				$F'_{5\%}$=	2,21	
$t''_{5\%}$=	1,96				$H_r'\%$=	81,71	

Time equation (min/m³)

$$t_{sp} = 0{,}7835 * CS^{0{,}168} * LS^{0{,}191} * FS^{0{,}919} * N^{0{,}182} * V_t^{-0{,}797}$$

Timenorm table (min/m³)

FS		CS											
1		**1**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**3**	**3**	**3**	**3**
		LS											
Vt	**N**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
0,1	**5**	9,4	10,7	11,6	12,2	10,6	12,1	13,0	13,8	11,3	12,9	13,9	14,7
0,3	**5**	3,9	4,5	4,8	5,1	4,4	5,0	5,4	5,7	4,7	5,4	5,8	6,1
0,5	**5**	2,6	3,0	3,2	3,4	2,9	3,3	3,6	3,8	3,1	3,6	3,9	4,1
0,7	**5**	2,0	2,3	2,5	2,6	2,2	2,6	2,8	2,9	2,4	2,7	3,0	3,1
0,9	**5**	1,6	1,9	2,0	2,1	1,8	2,1	2,3	2,4	2,0	2,2	2,4	2,6
0,1	**10**	10,7	12,2	13,1	13,9	12,0	13,7	14,8	15,6	12,8	14,6	15,8	16,7
0,3	**10**	4,4	5,1	5,5	5,8	5,0	5,7	6,2	6,5	5,3	6,1	6,6	7,0
0,5	**10**	3,0	3,4	3,6	3,9	3,3	3,8	4,1	4,3	3,6	4,1	4,4	4,6
0,7	**10**	2,3	2,6	2,8	2,9	2,5	2,9	3,1	3,3	2,7	3,1	3,4	3,5
0,9	**10**	1,9	2,1	2,3	2,4	2,1	2,4	2,6	2,7	2,2	2,5	2,7	2,9

Performance table (m³/o. h.)

FS		CS											
1		**1**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**3**	**3**	**3**	**3**
		LS											
Vt	**N**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
0,1	**5**	6,4	5,6	5,2	4,9	5,7	5,0	4,6	4,4	5,3	4,7	4,3	4,1
0,3	**5**	15,3	13,4	12,4	11,8	13,6	11,9	11,1	10,5	12,7	11,2	10,3	9,8
0,5	**5**	23,0	20,2	18,7	17,7	20,5	18,0	16,6	15,7	19,1	16,8	15,5	14,7
0,7	**5**	30,1	26,4	24,4	23,1	26,8	23,5	21,7	20,6	25,0	21,9	20,3	19,2
0,9	**5**	36,8	32,2	29,8	28,2	32,7	28,7	26,5	25,1	30,6	26,8	24,8	23,5
0,1	**10**	5,6	4,9	4,6	4,3	5,0	4,4	4,1	3,8	4,7	4,1	3,8	3,6
0,3	**10**	13,5	11,8	11,0	10,4	12,0	10,5	9,7	9,2	11,2	9,8	9,1	8,6
0,5	**10**	20,3	17,8	16,5	15,6	18,1	15,8	14,6	13,9	16,9	14,8	13,7	13,0
0,7	**10**	26,5	23,2	21,5	20,4	23,6	20,7	19,2	18,1	22,1	19,3	17,9	16,9
0,9	**10**	32,4	28,4	26,3	24,9	28,9	25,3	23,4	22,2	27,0	23,6	21,9	20,7

Cost table (Eur/m³)

FS		CS											
1		**1**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**3**	**3**	**3**	**3**
		LS											
Vt	**N**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
0,1	**5**	7,72	8,81	9,51	10,05	8,67	9,89	10,69	11,29	9,28	10,59	11,44	12,09
0,3	**5**	3,21	3,67	3,96	4,19	3,61	4,12	4,45	4,70	3,87	4,41	4,77	5,04
0,5	**5**	2,14	2,44	2,64	2,79	2,40	2,74	2,96	3,13	2,57	2,94	3,17	3,35
0,7	**5**	1,64	1,87	2,02	2,13	1,84	2,10	2,27	2,39	1,97	2,25	2,43	2,56
0,9	**5**	1,34	1,53	1,65	1,74	1,51	1,72	1,86	1,96	1,61	1,84	1,99	2,10
0,1	**10**	8,75	9,99	10,79	11,40	9,83	11,22	12,13	12,81	10,53	12,01	12,98	13,71
0,3	**10**	3,65	4,16	4,50	4,75	4,10	4,68	5,05	5,34	4,39	5,01	5,41	5,71
0,5	**10**	2,43	2,77	2,99	3,16	2,73	3,11	3,36	3,55	2,92	3,33	3,60	3,80
0,7	**10**	1,86	2,12	2,29	2,42	2,09	2,38	2,57	2,72	2,23	2,55	2,75	2,91
0,9	**10**	1,52	1,73	1,87	1,98	1,71	1,95	2,11	2,22	1,83	2,09	2,25	2,38

3.3 Examination of the effects of independent variables in multivariate power equations

By examining the inner correlations of the functions acquired as a result of the calculations it is visible that the effect of each factor is different, they influence cycle time, specific time demand and performance on a different level. This effect sequence looks as follows in the case of the cycle time function (tc; productive minute/cycle) described above in detail.

By substituting the power bases gathered from the measurement data series (CS = 1, LS = 2, FS = 1, N = 6, V_t = 0,538) we get the following equation.

$$t_c = 0{,}78269 \times 1^{0{,}16758} \times 2^{0{,}19065} \times 1^{0{,}91896} \times 6^{0{,}18230} \times 0{,}538^{0{,}20211}$$

$$t_c = 0{,}78269 \times 1 \times 1{,}141 \times 1 \times 1{,}386 \times 0{,}882$$

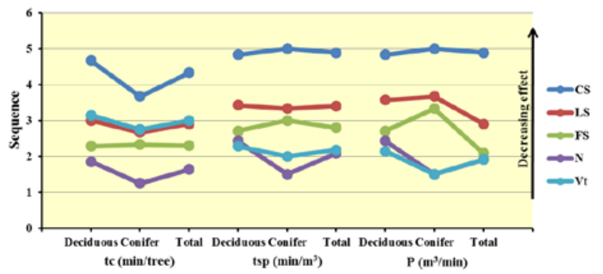

Figure 1: Percentage influence of time-equation factors from SF data series (CS-LS-FS).

The individual product factors show the (mathematical) priority of the factors influencing cycle time. The bigger the value, the more it influences cycle time. So the effect sequence is: Assortment number (N = 1,386), Limbiness (LS = 1,141), Forkedness (FS = 1) and Crookedness (CS = 1), as well as Volume (Vt = 0,882).

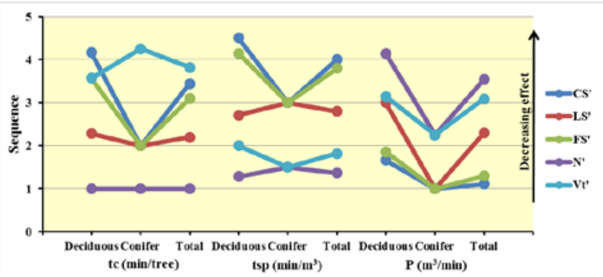

Figure 2: Prioritization of time-equation factors from FS data series (CS-LS-FS).

The exponents show the percentage change of the dependent variables at a 1% increase of their base, so the normative cycle-time change at harvesting under circumstances other than usual (e. g. at cutting down a tree with a 10% bigger volume than average – and at the other characteristics having usual values – the increase of cycle-time will be 2,02%). The effect seguence is the following: Forkedness (FS = 0,91896), Volume (V_t = 0,20211), Limbiness (LS = 0,19065), Assortment number (N = 0,18230) and Crookedness (CS = 0,16758). This is important in stands where individual trees show a big difference from the average.

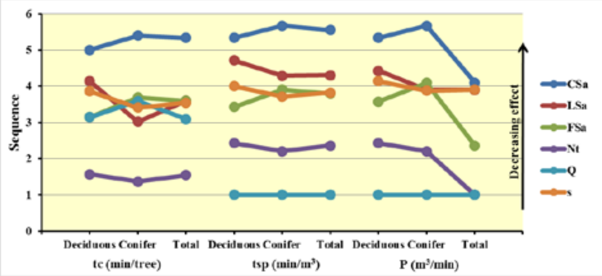

Figure 3: Percentage influence of time-equation factors from FSC data series (CS-LS-FS).

We prepared the examination of the effect sequence of influencing factors for all set up multivariate power equations. The individual factors got a serial number from 1 to 3, 1 to 4 or 1 to 5 depending on the influencing factor and the data series. The biggest is marked with 1 and 5 for example had the lowest impact. In order to set a general effect sequence the effect values belonging to the different equations got averaged for each equation and separately for equations tied to deciduous and conifer stands. The general effect sequence values can be seen on figures 1-4 per FS and FSC data series. Within these the individual hardship factors got depicted separately (CS, LS, FS).

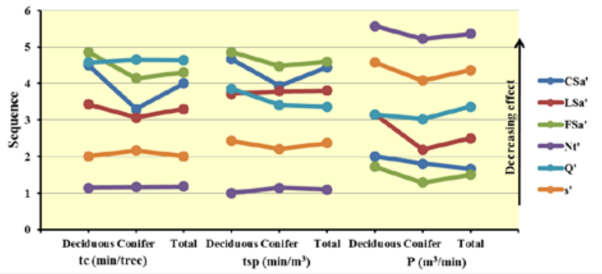

Figure 4: Prioritization of time-equation factors from FSC data series (CS-LS-FS).

In general we can say that cycle-time is mostly influenced by the number of assortments in deciduous and conifer stands as well based on both the priority and percentage change sequence. In case of specific time demand volume and change-over distance are the most important besides assortment number. In case of performance volume and the number of assortments are the most important based on percentage change effect; based on the priority sequence however crookedness, limbiness and forkedness are important.

In deciduous stands it turned out that for cycle-time and specific time demand the crookedness of harvested stems has a lower impact than their limbiness. It was visible during the field measurements as well that the cutting down of limbier bigger trees took longer than the ones wih crooked stems. In case of performance limbiness has a bigger influence than crookedness based on the effect of percentage change. While crookedness has a greater importance over limbiness according to the priority sequence within the time equation.

4. Discussion

We prepared norm tables for deciduous, hardwood, beech and conifer stands. The setting up of norm tables for other stands, logging methods and tables that can be easier used in practice (e.g. involving breast height diameter in the independent variables) as well as the investigation of independent variables on a tree species level requires further field measurements.

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Utilization of manual bucking in cutting softwood log stems in Finland

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Abstract: The study results indicated that the share of manual bucking on Norway spruce (*Picea abies* L. Karst.) log section was, on average, 46% and on Scots pine (*Pinus sylvestris* L.) log section 67%. There was statistically significant positive correlation between the shares of manual bucking of pine and spruce log stems. The operators used manual bucking more frequently in thinning stands with small-sized and defected log stems. When the utilization degree of manual bucking was high, the utilization of log sections with spruce and pine log stems was lower and the logs cut were also shorter and the volume of logs was smaller. Furthermore, log percentage and apportionment degree were significantly lower when the shares of manual bucking were higher. The relative production value of spruce logs was lower, and correspondingly the relative production value of pine logs was higher when using plenty of manual bucking.

Keywords: forest biomass, supply, future, regional

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1. Introduction

1.1. Operational environment

The cut-to-length (CTL) method is used for the wood procurement of industrial roundwood in Finland and also in many other countries in the world. In customer-driven wood procurement process, stems are bucked into favorable log dimensions at the harvesting site. In this process, the sawmill customers have information about the demand of the markets of sawn goods, and thus order the target distribution of logs based on the demand of end-product markets. In the forest, harvester computer calculates the optimal bucking proposals for each stem by taking into account the bucking instructions of forest stand. The bucking instructions consist of target distribution, price matrix and the various other bucking parameters and guidelines. The goodness of bucking outcome can be evaluated with several attributes, for instance using apportionment degree (Malinen & Palander, 2004).

When cutting Norway spruce (*Picea abies* L. Karst.) log stands, guideline for the harvester operator is to utilize as much as possible the bucking proposals by the harvester computer (i.e. automatic bucking) because there is a belief that, hence, the bucking outcome of log stems can be maximized at the harvesting site (e.g. Uusitalo et al., 2004; Kivinen, 2007). Of course, the harvester operator can utilize manual bucking (i.e. the operator him-/herself decides the cross-cutting points of log, or in other words, no bucking with the suggestions supplied by the harvester's automatic system) with damaged or defected parts of log stems – for instance butt rot, crookedness, top changing, vertical branch, large branch – or some other reasons in the stand.

The quality of Norway spruce does not fluctuate much and the values of different lumber grades are quite small. Correspondingly, the values of Scots pine (*Pinus sylvestris* L.) lumber are significantly dependent on the quality of pine log (e.g. Uusitalo et al., 2004). The log sections of Scots pine stem are generally regarded as dividing into three quality zones: 1) a knotless or slightly knotty butt zone, 2) the dead knot zone in the middle of the stem, and 3) the fresh knot zone on the upper part of the log section in the stem.

Consequently, when cutting pine log stems, the quality bucking is conducted and the bucking is not necessarily managed by according to target and price matrices. Hence, it is a target that the harvester operator will utilize a lot of manual bucking on the log section of pine. However, in the research by Uusitalo et al. (2004), automatic bucking of pine log stems did not markedly lower the amount of good-quality lumber compared to quality bucking with the study material of 100 sample pine stems. Besides, several research groups (Wang et al., 2004; 2009; Akay et al., 2010; 2015; Serin et al., 2010) have compared the bucking options and underlined that the gains of automated or computer-aided bucking are bigger than manual bucking.

During the last six years (2010–2015) in Finland, the annual cuttings of softwood logs have been, on average, 22.2 million solid m^3 over the bark (late only: m^3) of which the proportion of spruce log cuttings has been 54% and the share of pine log loggings 46% (Hakkuukertymä Metsäkeskuksittain, 2016). Nevertheless, how much softwood logs harvested are bucked manually and automatically? Currently, this information is not at all known in Finland.

1.2. Aims of the study

Accordingly, so far no comprehensive studies have been carried out on the frequencies of using automatic and manual bucking with softwood (i.e. Norway spruce and Scots pine) log stems in Finland. Therefore, Stora Enso Wood Supply Finland, the University of Eastern Finland, Metsäteho Ltd. and Ponsse Plc. undertook a study on:

- the frequency of two different – automatic and manual – bucking options with softwood log stems,
- the profile of harvesting conditions where utilizing the manual bucking the most,
- the main reasons for using plenty of manual bucking, and

- the effects of the utilization of manual bucking on the bucking outcome.

The hypotheses of our study were:

1) With Norway spruce log stems, the best bucking outcome is achieved when manual bucking is minimized, and
2) In cutting of Scots pine log stands, the best bucking result is reached when manual bucking is maximized.

2. Material and methods

2.1. Data from stm files and production systems

For the study, the stm files of 55 harvesters were collected in June and August 2015 from the harvesters of eastern Finland and in December 2015 and January 2016 from the harvesters operating in southern Finland at the harvesting sites of Stora Enso Wood Supply Finland. The starting point of stm data collection was the beginning of 2014. All harvesters of the study were PONSSE harvesters. When analyzing the stm data and calculating the shares of manual bucking on the log section of stems, the manual bucking volumes were considered the following cross-cuttings:

1) logs with bucking carried out manually by the operator,
2) offcut pieces by sounding log section, and
3) pulpwood poles cut from the log section of stem.

All other buckings on the log section of stems were classified automatic bucking in the study.

The total stm data of softwood log section was 958,416 m^3. There were totally 5,634 harvesting sites in the study. The stm material varied from 1,848 to 52,897 m^3/harvester. Utilization of bucking options was examined at harvesting site level. All figures calculated from the stm data were weighted by the volumes of log sections or logs cut.

In addition to the stm data, in order to investigate the consequences of manual bucking, data from forest information system and sawmill production systems were collected. Total data from forest information system was 91,496 m^3 and from sawmill production systems 74,803 m^3.

In the study, the goodness of bucking outcome was evaluated with the following attributes:

- the utilization of log section (volume, length, top diameter of log section),
- log percentage,
- log dimensions (volume, length, top diameter of log cut),
- reject percentage,
- apportionment degree, and
- the relative production value of logs.

Of the attributes of the consequences of manual bucking, the reject percentage, apportionment degree, and the production value of logs were investigated at the batch level of harvesting sites (i.e. the combination of 1…n harvesting sites). The rest of the attributes (i.e. the utilization of log section, log percentage, and log dimensions) were the harvesting site-specific variables in the study.

2.2. Operator interviews

Moreover, all harvester operators who worked during 2015 in the harvesters studied (N=81) were aimed at to interview for the study. Total of 74 harvester operators were interviewed with phone by two research scientists in December 2015 – January 2016. Thus, the response rate of interview survey was 91%. When the operators were interviewed, they were asked to estimate how much they had bucked Norway spruce and Scots pine logs with manual bucking of their total log volumes cut during the last year, for a period of December 2014 – November 2015.

In the interview survey, the following questions were also asked:

- which bucking option (i.e. manual or automatic bucking) produces better bucking result in the opinion of an operator,
- which elements do the good bucking outcome consist of,
- what are the effects of harvesting conditions and the other variables on the utilization degree of manual bucking on the log section of spruce and pine log stems,
- what are the most common reasons for the utilization of manual bucking with spruce and pine log stems, and
- is the operator willing to take part in bucking education if the education will be organized.

3. Results

3.1. Data of stm files

The frequency of manual bucking

The results illustrated that the share of manual bucking on spruce log section was, on average, 45.5% and on pine log section 67.4%. There was statistically significant positive correlation (r_s=0.579) between the shares of manual bucking of pine and spruce logs: when the share of manual bucking with spruce was low, also the manual bucking percentage on pine log section was low at the harvesting site in question, and vice versa (Figure 1).

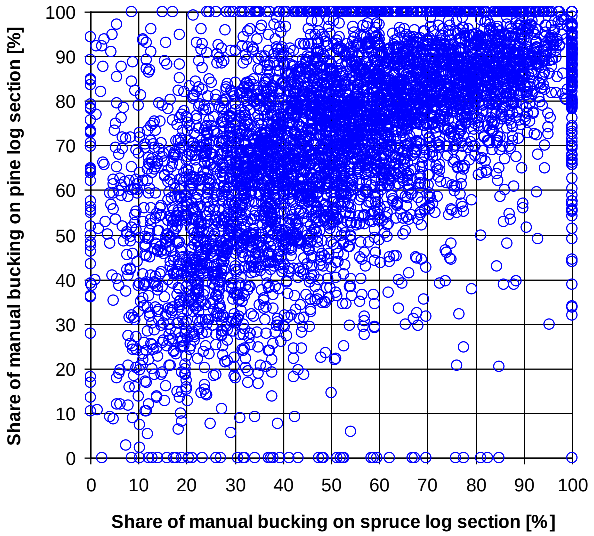

Figure 1: The shares of manual bucking on Norway spruce and Scots pine log sections by harvesting site (n=4,964) in the study.

Figure 1 indicated also that there was a huge variation of the shares of manual bucking on harvesting sites of the study. Furthermore, there was a significant difference between the shares of manual bucking by harvester in cutting both spruce and pine log sections (Figure 2).

The influence of harvesting conditions on the utilization degree of manual bucking

The results illustrated that the operators used manual bucking with both spruce and pine log stems more frequently in thinning stands with small-sized and defected log stems (Tables 1 and 2). Respectively, some manual bucking was used when bucking log stems from regeneration fellings with large-diameter and good-quality log stems. On the contrary, forest site class had no significant effect on the utilization of manual bucking in the study (Tables 1 and 2).

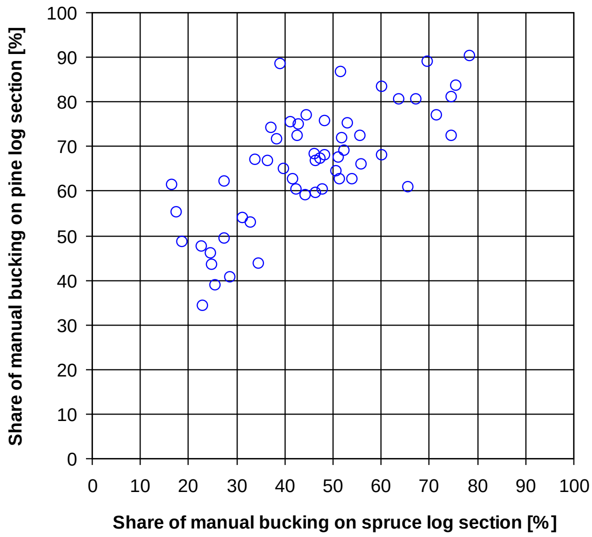

Figure 2: The shares of manual bucking on Norway spruce and Scots pine log sections by harvester (n=55) in the study.

The consequences of manual bucking

The consequences of the utilization of manual bucking were significant in the study. When the degree of the utilization of manual bucking was high, the utilization of log section with spruce and pine log stems was lower: the length of log section was shorter, the top diameter of log section was thicker, and the volume of log section was smaller (Tables 3 and 4). When using plenty of manual bucking, the logs cut were also shorter and the volume of logs was smaller. Furthermore, log removal and log percentage were lower on the harvesting site (Tables 3 and 4).

There was no significant connection between the degree of the utilization of manual bucking and the reject percentage of logs. Nonetheless, with spruce and pine log stems the apportionment degrees were significantly lower when the shares of manual bucking were higher (Tables 3 and 4).

When looking at the production value of logs, the relative production value of spruce logs was lower, when the share of manual bucking was high. Correspondingly, the relative production value of pine logs was higher, when the share of manual bucking was high (Tables 3 and 4).

3.2. Operator interviews

Attitude to bucking options

More than a half (55%) of the harvester operators interviewed regarded automatic bucking as significantly better or better than manual bucking to produce the highest bucking outcome with spruce log stems (Figure 3). Only 11 percent of the operators believed that the manual bucking causes clearly better or better bucking result than automatic bucking in cutting spruce logs.

In cutting pine log stems, 40 percent of the operators considered that automatic bucking yields significantly better or better bucking outcome than manual bucking. On the contrary, 29 percent of the operators estimated that manual bucking produces clearly better or better bucking result than automatic bucking (Figure 3).

Table 1: Harvesting conditions and the classified shares of manual bucking on Norway spruce log section in the study.

Harvesting site attribute	**Total**	**Share of manual bucking on spruce log section [%]**		
		<30	**30 – 60**	**>60**
Cutting method [%]				
Regeneration felling	80.6	86.2	80.7	68.6
Thinning	15.9	11.8	17.8	26.8
Other cutting	3.4	2.0	1.5	4.6
Height of removal of spruce log stems [m]	18.5	18.9	18.7	17.7
DBH of removal of spruce log stems [cm]	28.2	28.4	28.5	27.4
Volume of removal of spruce log stems [dm^3]	738	765	763	665
Share of defected timber on spruce log section [%]	13.3	11.9	13.3	14.8
Tree species of log removal [%]				
Spruce	59.7	63.4	63.8	55.8
Pine	34.3	32.1	30.6	36.2
Deciduous tree	6.0	4.4	5.6	8.0
Forest site class [%]				
Upland forest with grass-herb vegetation	28.2	26.6	28.1	29.1
Moist upland forest site	68.0	71.8	69.2	65.0
Dry upland forest site	3.8	1.5	2.7	5.9

Table 2: Harvesting conditions and the classified shares of manual bucking on Scots pine log section in the study.

Harvesting site attribute	**Total**	**Share of manual bucking on pine log section [%]**		
		<60	**60 – 80**	**>80**
Cutting method [%]				
Regeneration felling	78.5	82.6	82.9	70.2
Thinning	18.8	14.5	14.5	27.0
Other cutting	2.7	2.8	2.6	2.8
Height of removal of pine log stems [m]	18.9	19.1	18.9	18.7
DBH of removal of pine log stems [cm]	27.9	28.0	28.1	27.7
Volume of removal of pine log stems [dm^3]	724	728	732	709
Share of defected timber on pine log section [%]	14.8	12.3	15.0	17.4
Tree species of log removal [%]				
Spruce	59.7	61.6	56.8	56.8
Pine	34.3	33.5	37.6	35.5
Deciduous tree	6.0	4.8	5.6	7.7
Forest site class [%]				
Upland forest with grass-herb vegetation	10.6	17.5	8.6	6.6
Moist upland forest site	73.4	82.5	66.3	78.8
Dry upland forest site	16.0	0.0	25.1	14.6

Table 3: The effects of the utilization of manual bucking with Norway spruce logs in the study.

	Total	**Share of manual bucking on spruce log section [%]**		
		<30	**30 – 60**	**>60**
Length of spruce log section [m]	10.8	11.5	11.0	9.7
Top diameter of spruce log section [cm]	18.6	18.3	18.6	19.0
Volume of spruce log section [dm^3]	578	604	601	503
Length of spruce logs [m]	4.83	4.97	4.83	4.68
Top diameter of spruce logs [cm]	22.6	22.5	22.8	22.4
Volume of spruce logs [dm^3]	252	258	257	238
Spruce log percentage [%]	75.5	77.6	76.0	72.5
Reject percentage of spruce logs [%]	2.38	2.80	2.33	2.10
Apportionment degree of spruce logs [%]	68.1	75.1	69.4	59.0
Relative production value of spruce logs [%]	100.0	100.6	100.3	99.1

Table 4: The effects of the utilization of manual bucking with Scots pine logs in the study.

	Total	**Share of manual bucking on pine log section [%]**		
		<60	**60 – 80**	**>80**
Length of pine log section [m]	11.0	11.5	11.1	10.5
Top diameter of pine log section [cm]	18.8	18.5	18.9	19.2
Volume of pine log section [dm^3]	564	584	563	541
Length of pine logs [m]	4.82	4.85	4.83	4.77
Top diameter of pine logs [cm]	22.0	21.9	22.1	22.1
Volume of pine logs [dm^3]	238	237	241	237
Pine log percentage [%]	73.8	75.9	73.9	71.3
Reject percentage of pine logs [%]	3.87	4.01	3.96	3.52
Apportionment degree of pine logs [%]	63.0	70.0	63.3	52.5
Relative production value of pine logs [%]	100.0	99.1	100.4	100.9

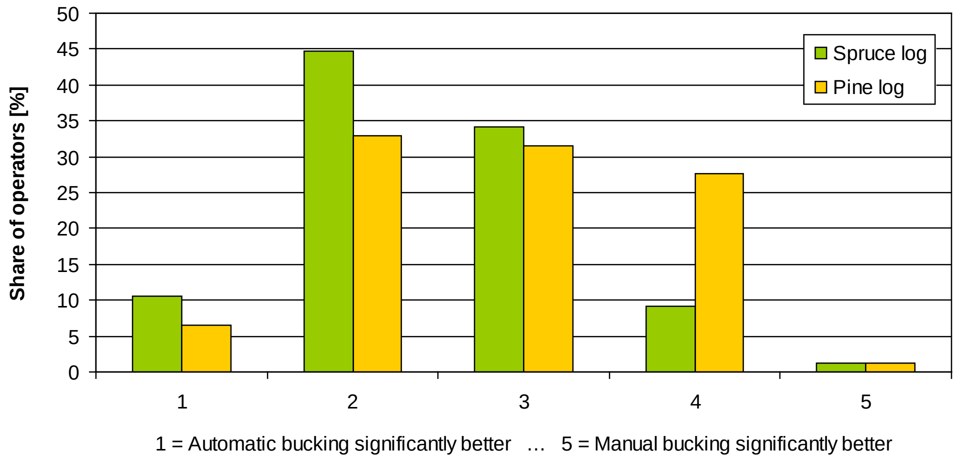

Figure 3: The estimates of the operators (n=74) interviewed which bucking option produces better bucking outcome in cutting spruce and pine log stems.

Elements of good bucking outcome

The high log percentage received the highest weight for the good bucking outcome. Its weight was, on average, 29 percent with both spruce and pine log stems. Nonetheless, the variation was quite large between the statements among the harvester operators interviewed (Figure 4).

In addition to the log percentage, the operators raised the importance of low reject percentage, the high production value of logs, and high apportionment degree as the elements for the good bucking outcome. The weights of these elements were, on average, 20–25 percent (Figure 4). With both spruce and pine log stems, the average weights were at very similar levels.

The main reasons for manual bucking

The operators told that the most significant reason for using manual bucking with spruce log stems is rot on log section, mainly on the butt of a stem; then the operator has to sound one offcut piece or several pieces or pulpwood pole(s) from the butt of stem. With spruce log stems, the second and the third most important reasons for manual bucking were crook in a stem and defect part on log section. On the other hand, with pine log stems, the most important reason for utilization of manual bucking was crook on log section. The second and the third most important reasons were defect part on log section and corkscrew on log section.

Besides, the operators were asked when they utilize most frequently manual bucking. The results indicated that the operators use manual bucking most frequently in poor-quality and relative small-sized thinning stands which locate in vigorous forest sites (Figure 5). Correspondingly, a little manual bucking is utilized in high-quality and large-diameter regeneration fellings which are poor in nutrients (Figure 5).

Willingness to bucking education

The harvester operators were strongly willing to take part in bucking education. Only less than one tenth (8%) of the operators reported that they are not willing to attend bucking education if it will be arranged in the near future.

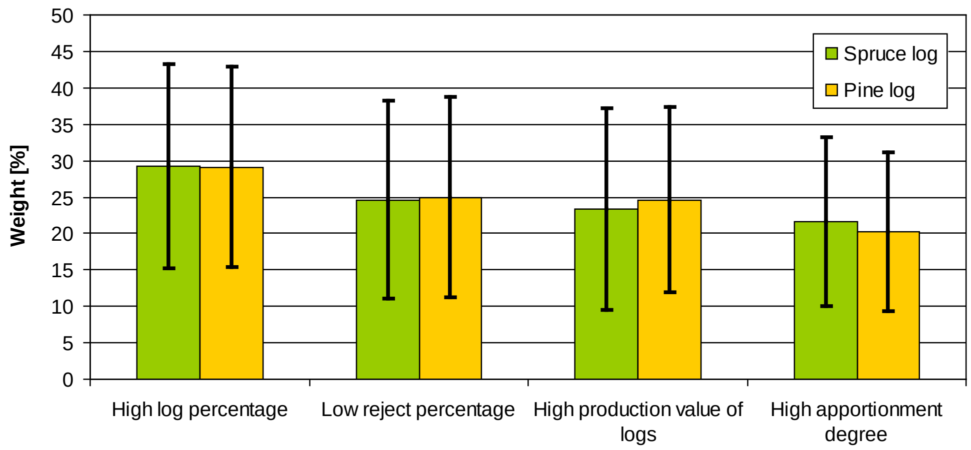

Figure 4: In the view of the operators (n=74), the weights of the selected elements for the good bucking outcome in cutting log stands. The bars describe the average and the black lines the standard deviation.

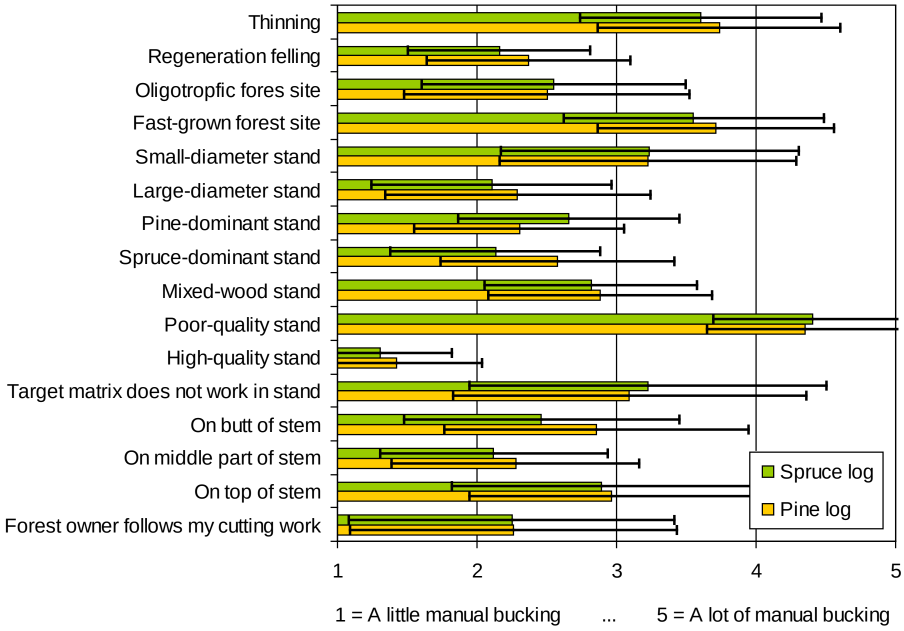

Figure 5: The evaluations of the operators (n=74) where they utilize a little and where they use a lot of manual bucking when they are cutting spruce and pine log stems. The bars describe the average and the black lines the standard deviation.

4. Discussion

The data, especially the stm data for the study was large. Correspondingly, the data on the production systems were smaller but it can be estimated that also this data gave reliable findings. In the study, the shares of manual bucking for each operator cannot be calculated because the stm data used did not consist of a mark on operator information. Nevertheless, it can be assumed that there was also a significant difference between the harvester operators in the study because there was a huge variation between the percentages of manual bucking in the harvesters (cf. Figure 2).

The results demonstrated that there is a strong correlation between manual bucking percentages with spruce and pine log stems by harvesting site, by harvester, as well as by harvester operator. This is not a desirable situation when you have to minimize the share of manual bucking with spruce log stems and maximize the share of manual bucking with pine log stems.

Depending on the issue, with which criterion the goodness of bucking outcome is evaluated, two recommendation sets for the utilization of manual bucking can be drawn up:

A. If the ultimate target for bucking is to maximize the production value of logs cut, then the study results point out that you have to minimize the manual bucking percentage with spruce log stems and maximize the manual bucking percentage with pine log stems.
B. If your main bucking target is some other one (i.e. other than the high production value of logs in cutting), hence it is useful to minimize your manual bucking percentage with both spruce and pine log stems.

Whatever the bucking target is, it can be estimated that the manual bucking share with spruce log stems must be at the lower level than currently. In the study, the average manual bucking percentage was 46% with spruce log stems. The target for the manual bucking percentage of spruce must be less than 20% of total volume of log sections cut. In order to achieve this target, the wood harvesting entrepreneurs and harvester operators, as well as harvesting officers in wood procurement organization must be offered the bucking education sessions. It was great to notice that almost all harvester operators of the study were very willing to participate bucking education if the education will be organized.

Besides, some follow-up studies after bucking education sessions will be needed in 2017. Likewise, more accurate survey on the reasons why the operator utilizes manual bucking in his/her cutting work must be carried out in the near future. Namely in the interview survey, it was just asked to the operators which are the most important reasons for selecting manual bucking option.

The results showed that the production value of pine log stems cut can be increased with utilization of manual bucking. It is a great potential in the future. Nowadays, the harvester operator can conduct a quality bucking with pine log stems. It calls, however, extremely close attention in bucking work for the harvester operator. Our target must be fully automatic or semi-automatic and harvester computer-aided quality bucking based on the quality grades of the log section zones of log stems. It will require some mobile laser scanning and machine vision applications for harvesters in the future (cf. Marshall & Murphy, 2004).

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The effect of quality bucking and automatic bucking on harvesting productivity and product recovery in a pine dominated stand under Bavarian conditions

Eric R. Labelle*, Moritz Bergen, Johannes Windisch

Abstract: On-board computers of harvesting machines can now provide optimized bucking (task of cutting stems into different log lengths) by relying on value and demand matrices. Despite existing benefits of these systems in certain countries, they remain largely under-utilized and generally poorly understood in German mechanized forest operations. The study aimed to compare and quantify the differences in value recovery and machine productivity between two treatments (quality bucking (OFF) and automatic bucking (ON)). A mature forest stand with a high proportion of Scots pine (Pinus sylvestris L.) was divided into (30 m x 100 m) plots where both treatments were randomly distributed and replicated 10 times. Pre-harvest inventory was performed on each tree targeted for removal via a commercial thinning operation. Mechanized harvesting was performed with an excavator based Atlas Kern T23 Königstiger harvester. The same assortment specifications and prices were used for both treatments but on-board bucking solutions were applied in the ON plots whereas the operator had full control of the products to be recovered in the OFF plots. During harvesting operations, continuous time and motion was done within all tested plots. Harvesting productivity was very similar between both treatments when isolating pine trees, while spruce trees showed more differences, especially as dbh increased. A higher product recovery and revenue per cubic meter when using automatic bucking for spruce trees but the opposite for pine trees was also found.

Keywords: scots pine, product recovery, mechanized operations, automatic bucking, processing

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1. Introduction

Approximately half of the total volume harvested in Germany is with full mechanized operations. Moreover, single-grip harvesters used for felling and processing trees into various assortments are by far the most commonly used machine in mechanized forest operations. On-board computers (OBC) placed in the cabin of harvesting machines have been available since the early 1990's. Aside from providing detailed monitoring of engine and hydraulic systems, on-board computers of modern cut-to-length harvesters can also optimize bucking (task of cutting stems into different log lengths) by relying on value and demand matrices (Uusitalo, 2010). The price matrix provides the bucking computer with information on how to prioritize various diameter-length combinations within the same grade, while the demand matrix specifies the desired proportion for each combination (Kivinen, 2004). This prioritizing differs depending on if the optimization maximizes the value of total log outputs from an individual tree, a stand, or a group of stands (Uusitalo et al. 2004)

According to Kivinen (2007), determining the optimal bucking pattern for a tree stem is one of the most challenging operations in timber harvesting. This is primarily due to the high irregularity in tree shapes and characteristics that remain poorly known at the time of bucking. Since it remains uneconomic to feed the stem twice into a harvesting head (first to obtain stem architecture and characteristics and second to buck), bucking is normally decided based on the diameter of the stem as measured by the harvesting head. The question of what type of assortment (product, length, diameters, grades) should a tree be bucked into can significantly impact the profitability of harvesting operations (Kivinen, 2007). This is attributed to two main reasons: 1- the properties of the logs resulting from the bucking activities determine the products that can be produced from a stem and hence its value (Fobes, 1960) and 2- results from poor or improper bucking are rather difficult to compensate for at subsequent manufacturing stages (Kivinen, 2007). According to Uusitalo et al. (2003), there exist three types of optimal-bucking.

- Automatic bucking – if no significant changes in quality exists within the stem, it can be bucked automatically using the cross-cutting decisions from the optimization system.
- Automatic quality bucking – changes in quality are entered into the optimization system and the system takes the quality changes into account when calculating the optimal cross-cutting decisions. The decisions are automatically carried out by the harvester.
- Quality bucking – pre-selected species and log lengths or diameters (Coyner, 2004 as cited by Marshall, 2005) are entered into the computer and can be assigned to "hot keys" on the operator's joystick controls.

Despite shown benefits of these on-board bucking optimization systems (Opti4G, MaxiXplorer, TimberMatic, etc.) in increasing product recovery, they remain largely under-utilized and generally poorly understood in German mechanized forest operations. In an attempt to gain further knowledge and improve our understanding of these systems, the project was designed to address two main research objectives:

i) Determine and quantify the influence of using quality bucking compared to automatic bucking on harvesting productivity in pine and spruce trees.

ii) Quantify the effect of using quality bucking compared to automatic bucking on product recovery (m^3/tree) and associated value for pine and spruce trees.

When an up-to-date value matrix (a.k.a price list/matrix) is used during automatic bucking optimization, we anticipate reaching higher revenues of harvesting operations. The benchmark in this project will be the product recovery and associated harvester productivity when quality bucking is applied.

2. Material and Methods

2.1. Stand description

This study was performed near the town of Seugast (49° 6.125´N and 11° 8.846 ´E), Germany, located in the State of Bavaria. The site selected was a 9.6 ha coniferous stand consisting of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies*) with a species composition of 95% and 5%, respectively. The stand is publicly owned and managed by the forest district Schnaittenbach, was of mixed age varying between 89 and 143 years with an average age of 120 years. Average standing volume prior to treatment was estimated at 280 m³/ha. The silvicultural treatment chosen by the district forester was a commercial thinning where 25-30% of the standing volume was to be harvested.

2.2. Machine specifications

Mechanized harvesting was performed by the forest operations unit of the BaySF with an excavator based Atlas Königstiger T23 (property of BaySF) weighing 28 metric tons including the harvesting head (Figure 1). The harvester was equipped with a Ponsse H6 harvesting head mounted on a 14.5 m long telescopic boom (Figure 1B). Harvesting was performed from Friday June 24, 2016 to July 4, 2016 during regularly scheduled forest operations using a single operator working only during day shifts. Following the harvest, the processed logs were transported from the stand to roadside by a John Deere 1110D Eco III eight-wheel forwarder.

Figure 1: A) Atlas Königstiger T23 single-grip harvester with B) Ponsse H6 harvesting head

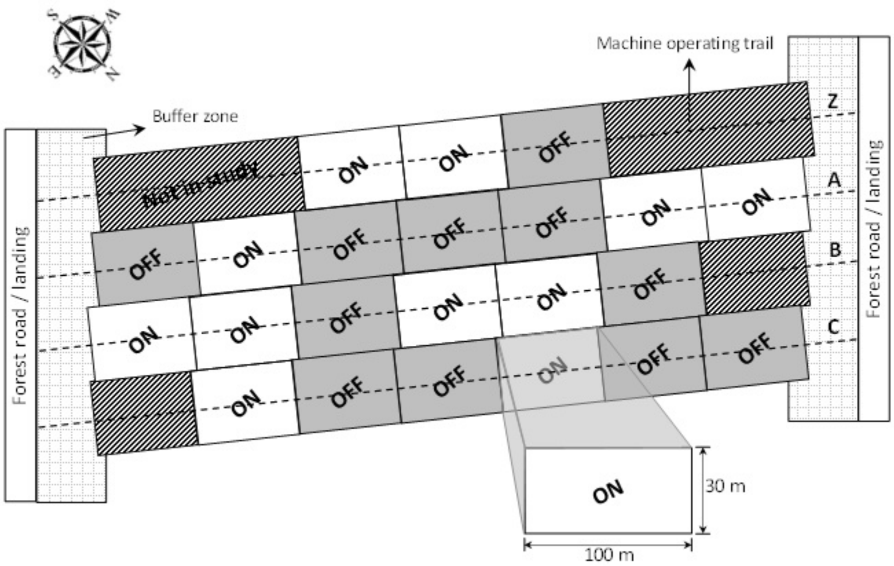


Figure 2: Experimental design depicting treatment plots where quality bucking (OFF) and automatic bucking (ON) was applied.

2.3. Experimental design and tree inventory

Prior to forest operations, the experimental design presented in Figure 2 was established in the field. In total, 22 plots each measuring 30 m wide by 100 m in length, were erected on four adjacent machine operating trails with a spacing of 30 m between centrelines. Treatments consisting of automatic bucking (ON) and quality bucking (OFF) were randomly assigned to constitute 11 plots per treatment. The beginning of each plot was clearly marked with paint on the trees adjacent to the machine operating trail and indicated the treatment to be performed by the operator (ON or OFF). The end of a respective plot was identified by the treatment that was to begin in the subsequent plot. Trees used for identifying start and end of a plot were also marked by two rows of flagging tape for ease of identification. At the beginning and the end of each machine operating trail a buffer zone measuring 20-30 m in length was left to avoid boundary effects. Following the plot layout, all trees pre-selected for removal by the district forester were inventoried and the parameters species, diameter at breast height (dbh), and height were collected. After recording relevant inventory data, telescopic paint dispensers were used to number trees consecutively at a height of 2.5 to 3 m to permit easy identification during the time and motion.

2.4. Operational parameters and conditions

An identical species dependent assortment type price matrix (product, length and diameter categories) provided by BaySF was used in both ON and OFF plots (Table 1). In this matrix, prices were assigned to different products with specific length and diameter categories. The price matrix was given to the operator as a guide for use in the OFF plots and entered in the on-board computer Opti4G system for the ON plots. For confidentiality reasons, the price list will not be presented.

Table 1: Assortments, lengths, and diameters used in the study.

Species	Assortment and length [m]	Small-end diameters [cm]*
Pine	sawlog (4)	≥ 12
	pallet (2.35)	≥ 13
	pulpwood (2)	≥ 9
Spruce	sawlog (4 and 5)	≥ 12 for both
	pallet (2.35)	≥ 13
	pulpwood (2 and 3)	≥ 7 and ≥ 9

* outside bark measurements

In all OFF plots, the operator performed quality bucking while only making use of the hot-keys and did not have access to any stem predictions from the Opti4G system. The operator had a copy of the price matrix during the entirety of the harvesting operation and consulted it on demand with the goal of maximizing value per tree. In the ON plots, the Opti4G system provided automatic bucking solutions aimed at maximizing value per tree according to the prices listed in the matrix. When processing began, the Opti4G used the first meter of the stem for stem curve prediction and associated product distribution. The prediction was then modified automatically as the trees were processed.

2.5. Logistics of operations

To avoid hindering machine productivity with any additional machine pass-overs, both treatments (ON and OFF) within a machine operating trail were harvested sequentially in order of appearance. During harvesting operations within all plots, conventional time and motion was performed with a hand-held computer using the UMT Plus software. Beside recording time for each work cycle element, the identification numbers marked on each tree were also noted in the hand-held computer. To combine the time and motion data with the data saved in the OBC, a video camera was installed in the harvester cabin and aimed at the monitor of the OBC (displaying the count of harvested trees) during the entire operation. In addition, the operator called out loud the number of the tree he was cutting, which was recorded by the camera. For better and efficient data handling, all information was saved plot wise. After each plot the operation was stopped for a short time to save data (time and motion, OBC, video camera) and to create or start new files for the next plot.

2.6. Data analysis

Individual tree dbh and heights were measured during pre-harvest inventory. From these two parameters and considering tree species, stem volume per tree was calculated using stem volume equations from Zianis et al. (2005). During the time and motion study, individual work cycles were divided into the following elements: boom-out; felling; processing; manipulation; tracking; operational delays; non-operational delays. The complete time and motion dataset was used to compute a standardized duration for work elements that were not common to all trees, such as machine tracking and manipulation. All data presented in this manuscript focuses on productive time. In the different files from the OBC (ascii, .pri, .prd, .apt, .stm, etc.) all information about the harvested trees was saved. For this study, ascii- and the .pri-files were most important. These files contain detailed information (assortment, length, volume, and diameter) of every log that was cut. Out of these different data sets (inventory, time and motion, OBC) a single metadata was created with rows relating to individual trees.

3. Results and discussion

3.1. Description of harvested trees

During operations of the 22 plots, exactly 800 trees (380 trees in OFF, 420 trees in ON) were harvested and used for analysis (Table 2). The proportion of spruce in ON plots (13 %, 55 trees) was slightly higher than for the OFF plots (11 %, 42 trees). The measurements yield an average dbh of 29.3 cm (OFF) and 27.9 cm (ON) as well as a standard deviation of 0.39 cm and 0.37 cm, respectively. The difference in the mean dbh between ON and OFF is statistically significant (level of significance = 0.05). Average diameters in all OFF plots range from the minimum of 24.6 cm in plot Z1 to the maximum of 33.2 cm in plot C2. In both cases the average diameter in the ON plots is lower (minimum: 23.5 cm, maximum: 32.2 cm).

Although the mean height of trees located in OFF plots (23.7 m) is higher than in ON plots (23.2 m) there is no significant difference between treatments. The lowest average height was in plot Z1 with 20.9 m for OFF and in plot A1/Z3 with 21.0 m for ON. The plots with the highest trees on average were plot C2 for OFF with 27.2 m and B3 for ON with 26.2 m. The standard deviation in height was the same for both treatments (0.21 m). Mean volume (m^3) per tree based on the inventory measurements varies from 1.14 m^3/tree (C2) to 0.53 m^3/tree (Z1) in all OFF plots which results in an average volume per tree of 0.83 m^3. This equals to a difference of 0.08 m^3/tree to the ON plots (0.75 m^3/tree) which is statistically significant. The lowest mean volume per tree for ON plots was 0.48 m^3 in plot Z2, while the highest mean volume per tree was 1.04 m³/tree in plot B3. The standard deviation is equal (0.02 m³/tree).

3.2. Duration and distribution of work cycle elements

Before analyzing productive machine time, a simple comparison of duration of the work cycle elements for both treatments was performed. The average duration (sec) of each work cycle element is presented in Table 3. At this early stage, no cycle elements are standardized. There is a slightly shorter duration for pine as well as spruce for total cycle time associated with ON plots. A significant difference between ON and OFF is only detected for spruce but not for pine. For felling a pine tree and processing it into desirable logs it takes slightly more than one second in OFF plots (71.00 sec) than in the ON plots (69.57 sec). For spruce, cycle time in general is lower than for pine and the difference between ON and OFF treatments is considerably higher (9.54 sec).

Table 2: General mensuration of harvested trees as measured during pre-harvest inventory. Different lower case letters indicate a statistical difference between treatments at alpha 0.05.

Treatment	Plot ID	Sample size	DBH [cm]*		Height [m]		Stem vol. [m^3/tree]**	
		Pine/Spruce	Avg.	Std. err.	Avg.	Std. err.	Avg.	Std. err.
OFF	A3	33P / 6S	30.6	1.12	22.9	0.62	0.86	0.07
	A4	24P / 11S	28.7	1.70	21.6	0.88	0.82	0.11
	A5	41P / 5S	25.2	1.22	22.5	0.64	0.62	0.07
	A7	33P / 2S	29.7	1.40	25.2	0.58	0.90	0.09
	B1	32P / 0S	32.2	0.93	26.4	0.40	1.03	0.08
	B4	28P / 0S	32.3	1.06	26.6	0.36	1.05	0.08
	C1	33P / 1S	29.8	1.19	25.4	0.58	0.89	0.08
	C2	24P / 0S	33.5	1.11	27.2	0.52	1.14	0.09
	C4	27P / 0S	29.3	1.28	22.9	0.70	0.78	0.08
	C5	38P / 5S	29.9	0.92	21.8	0.44	0.76	0.06
	Z1	26P / 12S	24.6	1.09	20.9	0.75	0.53	0.06
ON	A1	26P / 13S	26.2	1.30	21.0	0.89	0.64	0.07
	A2	29P / 12S	27.7	1.44	22.1	0.79	0.77	0.10
	A6	49P / 6S	27.7	0.93	23.7	0.48	0.73	0.06
	B2	32P / 0S	29.3	1.04	26.1	0.57	0.86	0.06
	B3	32P / 0S	32.2	1.10	26.2	0.38	1.04	0.09
	B5	29P / 0S	31.2	0.91	25.4	0.48	0.93	0.07
	B6	36P / 2S	30.2	1.13	24.5	0.53	0.89	0.08
	C3	23P / 0S	31.4	1.37	22.8	0.71	0.88	0.08
	C6	42P / 1S	28.0	1.15	23.2	0.63	0.74	0.07
	Z2	29P / 11S	23.5	1.01	21.1	0.62	0.48	0.05
	Z3	38P / 10S	23.9	1.15	21.0	0.66	0.53	0.07
Summary								
OFF	11 pl.	338P / 42S	29.3*a*	0.39	23.7*a*	0.21	0.83*a*	0.02
ON	11 pl.	365P / 55S	27.9*b*	0.37	23.2*a*	0.21	0.75*b*	0.02

* outside bark measurements; ** estimated stem volume derived from species dependent equations

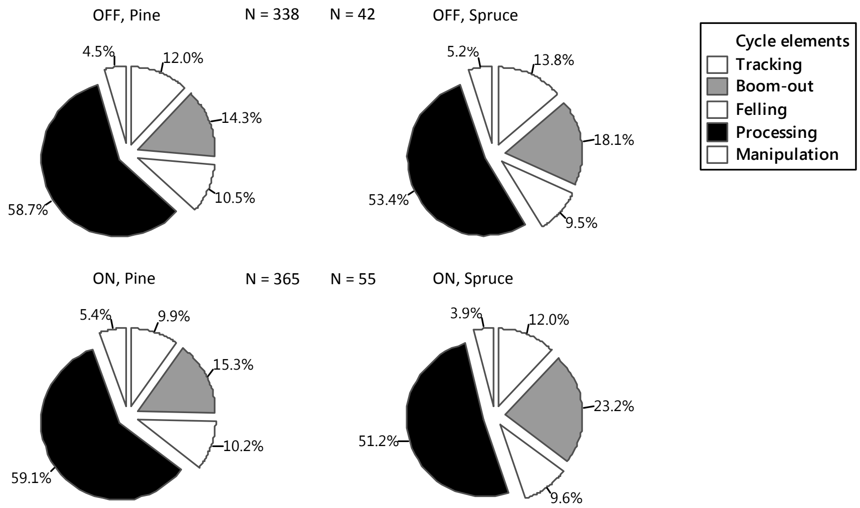


Figure 3: Average percent distribution of productive work cycle elements.

Table 3: Average time per cycle element and total cycle time separated for species and treatment. Different lower case letters indicate a statistical difference between treatment within the same species at alpha 0.05.

Species	**Treatment**	**Average time per tree [sec]**					
		Boom-out	**Felling**	**Processing**	**Manipulation**	**Tracking**	**Total cycle**
Pine	OFF	9.43*a*	7.07*a*	41.57*a*	4.05*a*	8.89*a*	**71.00***a*
	ON	9.72*a*	6.73*a*	40.94*a*	4.89*a*	7.29*b*	**69.57***a*
Spruce	OFF	9.54*a*	5.09*a*	29.24*a*	4.19*a*	8.87a	**58.80***a*
	ON	10.78*a*	4.53*a*	24.86*a*	2.39*a*	6.69a	**49.26***b*

Aside from a lower percent *Tracking* in ON plots, no other considerable difference in the percentages of work cycle elements between ON and OFF plots were detected when considering pine trees (Figure 3). For spruce there is no statistically significant difference for any element between treatments. In either case (ON and OFF) approx. 60 % of the average work cycle time was attribute to *Processing*. Considering only spruce trees the *Processing* element (ON 51.2 %, OFF 53.4 %) shows also the highest share in the work cycle followed by *Boom-out*, *Tracking*, *Felling* and *Manipulation*.

3.3. Harvesting productivity

From this point forward, standardized times for cycle elements not common to all trees were applied for *Manipulation* and *Tracking*. Irrespective of treatment, average harvesting productivity (m^3/pmh) was higher for pine (34.9 m^3/pmh) than spruce (14.6 m^3/pmh; Figure 4). Within pine, average productivity was 5.9 % higher in OFF plots (36.0 m^3/pmh) compared to ON plots (34.0 m^3/pmh). Compared to other productivity studies in pine the average harvesting productivity in this study is on a high level. The latest study from Mederski et al. (2016) describes 22.60 m^3/pmh as an average productivity in pure Scots pine stands (24.9 cm mean dbh) in Poland. On the other site Mizaras et al. (2013) reported an average productivity of 40.8 m^3/pmh in pine (stem size of 0.8 m^3) for a Timberjack 1270D in Lithuania. Comparing these results with the result in this study the displayed productivity is comprehensible. Even if the used machine in the current study is an excavator based harvester (high tracking time), the combination of Atlas Kern T23 and Ponsse H6 head is powerful and fast in processing. Within spruce, this difference was reduced to 3.3 % (OFF 14.9 m^3/pmh, ON 14.4 m^3/pmh). These results relate nicely to the study from Mizaras et al. (2013) that described a harvester productivity of 15.1 m^3/pmh at a stem size of 0.2 m^3 for spruce. Hiesl and Benjamin (2014) found out a variation of productivity from 6.1 m^3/pmh to 13.1 m^3/pmh in spruce-fir stands in west-central Maine for small diameters (13.1 cm to 18.7 cm). Because of these results a productivity of about 14.5 m^3/pmh in small diameter seems plausible despite the small sample size for spruce trees.

However, one-way ANOVA's showed no statistical differences in harvesting productivity between both treatments for each species. Plotting the harvesting productivity of individual trees in function of dbh and adding a regression curve (third-order polynomial for pine, power for spruce) results from both treatments demonstrate a common trend where machine productivity increases with increasing tree diameter (Figure 4). For pine trees (Figure 4A), there is a slightly higher productivity in the lower diameter range until approx. 25 cm dbh. From that diameter until approx. 37 cm dbh the productivity towers when bucking manually by the operator. For trees with dbh greater than 37 cm the two curves start to separate themselves with a higher productivity for automatic bucking. However, an overall difference in productivity between both treatments is not evident. Because of low sample points of trees having a dbh greater than 37 cm (two trees with about 85 m^3/pmh and 100 m^3/pmh), a disproportional effect for the automatic bucking is plausible. It is likely that the difference in productivity for larger diameters would be the same as the diameters below if sample size in this diameter range would be expanded.

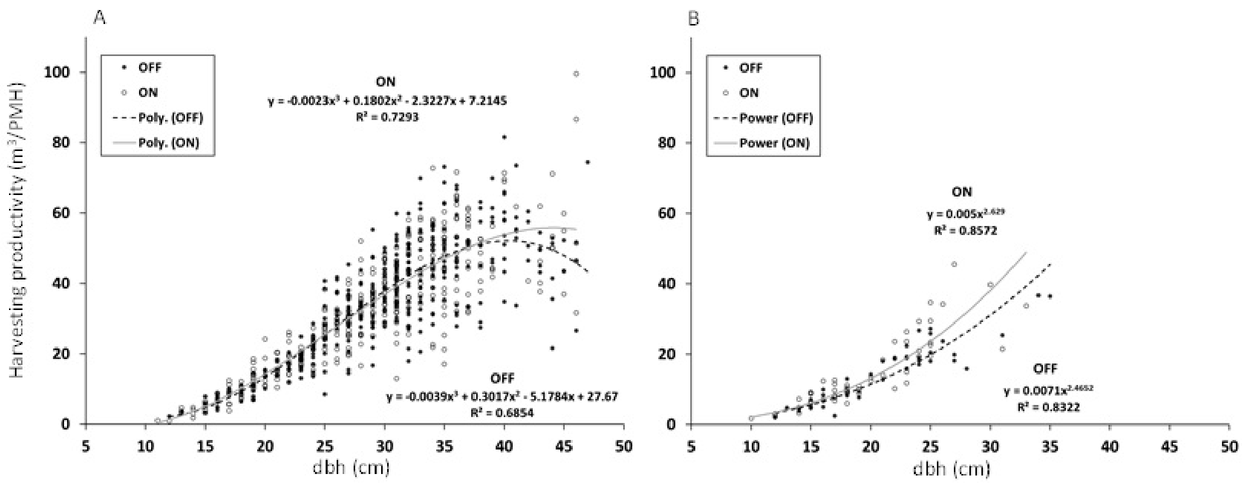


Figure 4: Harvesting productivity in function of dbh and treatment for A) pine, and B) spruce trees.

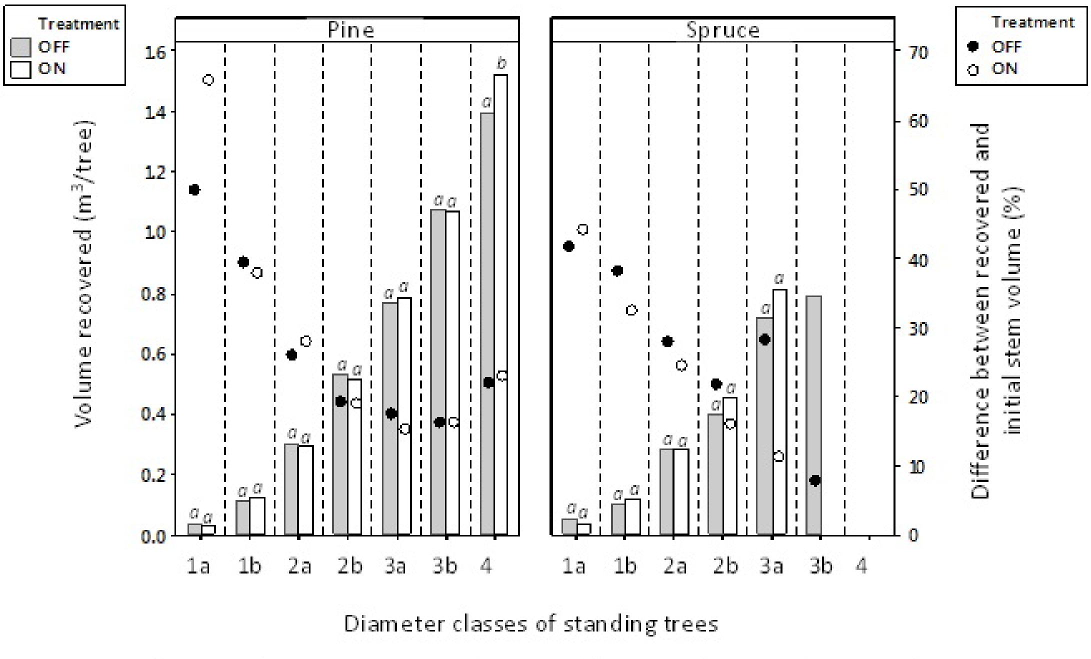
Similarly, the productivity curve for spruce shows generally a higher productivity for ON (Figure 4B). In addition, with increasing dbh the difference between both treatments increases. Again the low sample points in larger tree diameters affect the curve's progression disproportionally compared to trees with smaller diameter. As well the obvious difference is not significant for spruce. A difference in harvesting productivity was expected at the start of the study. During the operation it was noticed that the operator had to make more boom movements when using the OBC for the prediction. In German forestry it is a frequent practice for operators to pile every log being cut to the appropriate assortment pile. While the operator performed quality bucking, he frequently decided to cut e.g. three logs of *sawlog* followed by two logs of *pallet*, followed by three logs of *pulpwood*. After each change of assortment, the operator had to move the boom to the next place to pile the corresponding log. When using the OBC and the automatic bucking the computer suggested to cut a single *pallet* log first, followed by three logs of *sawlog*, followed again by a single log *pallet*, followed by two logs of *pulpwood*. Because the assortment change happened several times while performing automatic bucking, the boom movements were of higher frequency. This could be the reason why the expected effect of higher productivity for ON plots could not occur.

3.4. Volume recovery

Volume recovery expressed as m^3/tree, increased as the diameter class of standing trees increased for both species and treatments tested (Figure 5). When focusing on pine, volume recovered was highly similar between treatments for diameter classes 1a through 3b inclusively. However, a statistically higher volume recovered in ON compared to OFF plots was detected for diameter class 4. This finding holds true for spruce trees where the highest diameter class tested when both treatments are present, was class 3a. Since the amount of volume recovered is dependent on the initial stem volume, we also present these results in percentage using the right ordinate. The difference between calculated stem volume and recovered volume seems to be lower as tree size increase. Largest differences are found in diameter class 1a for pine and diameter class 3a in spruce, but for opposite treatments. Aside from the smallest diameter class, ON treatments usually offer a better recovery percentage for spruce trees as compared to OFF treatments with the most considerable difference occurring at diameter class 3a.

3.5. Value recovery

Value recovery (€/m^3) for pine was quite stable for diameter classes 1a to 2a and then increased beyond this diameter for both ON and OFF treatments (Figure 6). Statistically higher average revenue per cubic meter for the OFF treatment was calculated for diameter classes 3a, 3b, and 4. For the most part, higher variation in average revenue per diameter class was observed for spruce trees. Despite not detecting any statistical differences, higher percent differences between treatment means were measured for all diameter classes were both treatments were represented and for diameter class 1b, 2b, and 3a automatic bucking provided a higher revenue per cubic meter compared to quality bucking.



1a	1b	2a	2b	3a	3b	4
10 - 14 cm	15-19 cm	20-24 cm	25-29 cm	30-34 cm	35-39 cm	≥ 40 cm

Figure 5: Volume recovered (left ordinate) in function of dbh diameter classes. Different lower case letters indicate a statistical difference between treatments at alpha 0.05. Percent difference between recovered and initial stem volume (right ordinate). Both results are in function of treatments and species.

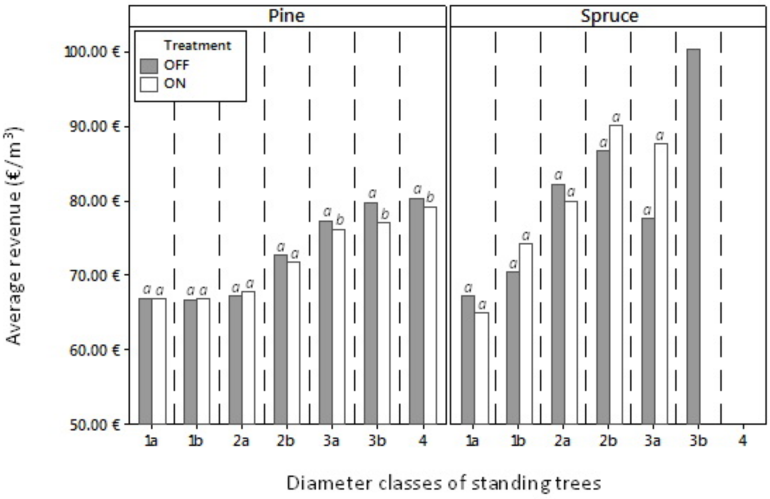


Figure 6: Average revenue per cubic meter in function of diameter classes, treatments, and species.

In total the average revenue for pine in ON plots (73.30 €/m³) was lower than for OFF plots (74.93 €/m³). During the operations we were questioning the rational for the OBC to regularly suggest/predict a pallet for the first log especially for stems with a large diameter. This procedure may be useful indeed to match exactly the lowest diameter of the assortments e.g. 9 cm for pulpwood (see Table 1). In this case the product and the value recovery would be the highest. Unfortunately, this rarely happened in pine. We anticipate the main reason is the prediction whose algorithm was designed for Scandinavian pine which show a slim crown architecture similar to spruce trees compared to a wide crown and many forks for pines in Germany.

Concerning spruce and focusing on the diameter classes where both treatments were represented, average revenue per cubic meter between treatment was almost equal for OFF plots (71.36 €/m³) and ON plots (77.24 €/m³). Despite automatic bucking demonstrating higher average revenues for diameter class 1b, 2b, and 3a, no statistical differences were detected between treatments. A note of caution should be issued for spruce trees due to the low sample size.

4. Conclusion

The response of quality (OFF) and automatic (ON) bucking on product recovery, revenues, and harvesting productivity in a pine dominated stand was assessed. Based on our results, which were derived from one single-grip harvester operated by a single operator, quality bucking yielded higher average revenue per cubic meter compared to automatic bucking when harvesting Scots pine in Germany. With the high frequency and sweeps, crooks, and forks present in Scots pine trees, the operator seemed to perform better under such conditions as compared to automatic bucking. Possibilities and potential upsides of using OBC for automatic bucking need further investigation and better understanding of why such trends occurred will be gained by prolonging the study and assessing the influence of tree form and other tree species on product and value recovery.

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Productivity of a single-grip TimberPro 620 harvester with a LogMax 7000 harvesting head in a beech dominated stand

Eric R. Labelle*, Johannes Windisch

Abstract: The forest conversion from spruce dominated forests to close-to-nature stands with considerable shares of broad-leaved tree species is of high importance in Germany. For mechanized harvesting operations, the complex tree architecture and high wood density of broad-leaved tree species, in particular of beech, pose a challenge during the processing phase. Usually more powerful machinery is required than for softwood stands of comparable age and tree dimensions. This pilot-study assessed the productivity of a TimberPro 620 single-grip harvester with a LogMax 7000 harvesting head in a mature mixed-wood stand located in southern Germany. A total of 82 trees previously inventoried were harvested using one of two silvicultural treatments (clear-cut in plot A or selective-cut in plot B). A conventional time and motion study was performed on the selected trees using a handheld computer with the UMT Plus software. Results demonstrate considerable differences in percent distribution of the work cycle elements between the two tested silvicultural treatments, particularly with machine movement. Based on single-tree volume estimations, average harvesting productivity was determined to be 32.2 m^3/PMH for spruce and 28.9 m^3/PMH for beech, irrespective of silvicultural treatment.

Keywords: mechanized operations, beech, spruce, processing, selective-cut

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1. Introduction

The use and associated productivity of machines during forest operations has been well documented, particularly in softwood stands. In Germany, single-grip harvesters capable of felling, delimbing, and bucking stems into different assortments has been the preferred machine in softwood mechanized forest operations. However, with the advent of a higher proportion of forest stands being managed in a close-to-nature philosophy, the distribution and frequency of hardwoods is increasing. Due to their higher wood density and generally more complicated stem and crown architecture, hardwood trees can present more pronounced challenges compared to softwood, in particular when dealing with fully-mechanized harvesting systems. When using a single-grip harvester, trees of larger diameter often require a back-cut before the head is repositioned at the base of the tree in order to complete the felling. Aside from this technique, most of the challenges in mechanized hardwood operations are linked to the processing phase where trees are delimbed and bucked to size. During this work cycle element, large branches and complex tree crowns can considerably reduce harvesting machine productivity, especially if product recovery is of high importance. According to Labelle et al. (2016), harvesting productivity of a single-grip harvester operated in a sugar maple dominated stand was on average 18% higher for trees with an acceptable form compared to unacceptable. Unacceptable trees were defined as having on or more of the following characteristics: presence of large branches or multiple stems within the first 5 m, inclination of the main stem of more than 15º (Pelletier et al. 2013). A large branch was also defined as having a diameter greater than one third of the main stem measured below the branch.

Within the given budget and logistic constraints, such a detailed analysis could not be performed. However, this pilot study was erected to determine the productivity of a single-grip harvester in beech and in spruce following two silvicultural treatment; clear-cut and selective-cut. It was also of interest to identify and assess potential bottle necks during the mechanised harvesting operations. Results and experiences learned throughout the pilot study will be used to formulate a larger scale project aimed at evaluating the influence of hardwood tree characteristics on fully-mechanized forest operations performed in a central European context.

2. Material and Methods

2.1. Stand description

The harvest block was located in proximity to the market town of Titting (48° 9.851´N and 11° 2.682 ´E) in the rural district of Eichstätt in the federal state of Bavaria, Germany (Figure 1). It was a 4.5 ha mixed stand consisting of common beech (Fagus sylvatica), Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris* L.), with a species composition of 65%, 30% and 5%, respectively. The stand was of mixed age varying between 75 and 110 years with an average age of 90 years. Total standing volume prior to treatment was estimated at 280 m³/ha.

2.2. Machine specifications

All mechanized harvesting was performed with a TimberPro TB620-E six-wheel single-grip harvester weighing 21.5 metric tons (Figure 2). The harvester was equipped with a LogMax 7000 harvesting head mounted on a 9.6 m long telescopic boom (Table 1).

Table 1: Specifications of harvesting head.

Height	1742 mm
Weight	1619 kg
Feed force	42.1 kN
Feed speed	5.2 m/sec
Maximum roller opening	713 mm
Bar length / maximum cut capacity	90 cm / 75 cm

Steel flexible tracks were installed on the bogie axle located underneath the cab. All harvesting was performed during regularly scheduled forest operations using a single operator working only during day shifts. Following the harvest, processed logs were transported from the stand to roadside by a forwarder.

2.3. Layout and field data collection

The harvest block selected for the study was divided into two plots to assess the influence of two silvicultural treatments on the productivity of the harvester. The first plot (A) had an area of 0.5 ha and was subjected to a clear-cut where all merchantable trees were to be harvested. The second plot (B) had a size of 4 ha and was treated with a selective-cut, where only trees selected by the district forester were to be harvested. Both study plots had a relatively gentle terrain topography with a maximum slope of 5%. Spacing between the pre-existing machine operating trails (centreline to centreline) was 30 m.

Before operation commenced, inventory of the 52 selected trees in plot B was performed where measurements of tree dbh and heights were recorded and entered in a handheld computer. Each of the trees inventoried were also marked with an individual number painted on the bark for future identification during the time and motion study. Due to time restrictions, only tree dbh was measured for the 30 trees to be harvested in plot A, while tree heights were later calculated based on species dependent functions differentiated from the measurements from plot B (equations 1 and 2):

$$h_{beech} = 5.5221x^{0.4169} \qquad (1)$$

$$h_{spruce} = 7.5881x^{0.3501} \qquad (2)$$

where: h is the species specific tree height in meters and x is the dbh in cm

Throughout harvesting operations (February 19 and 20, 2015), continuous time and motion measurements were collected for every study tree using a handheld computer and the software UMT Plus. Considering the trail spacing of 30 m and the limited reach of the boom, trees that were beyond the range of the harvester were felled motor-manually towards the machine operating trail and then processed by the harvester. However, to keep results from this manuscript focused solely on fully-mechanized operations, these trees including all corresponding time elements were omitted.

2.4. Data analysis

As mentioned, the dbh and heights of all trees selected for harvest within the selective-cut (Plot B) plot were measured during inventory. Merchantable volume per harvested tree was then calculated using species dependent stem volume equations by Zianis et al. (2005), with dbh, and height of individual trees as input. A similar calculation was performed for trees in the clear-cut (Plot A), while using the calculated heights obtained from the species specific regression functions between tree dbh and height of trees in plot B.

During the time and motion study, individual work cycles were divided into the following elements: boom-out; felling; processing; manipulation; moving; operational delays; non-operational delays. The complete time and motion dataset was used to compute a standardized duration for work elements that were not common to all trees, such as machine movement (moving) and manipulation. All data presented in this manuscript focuses on productive time.

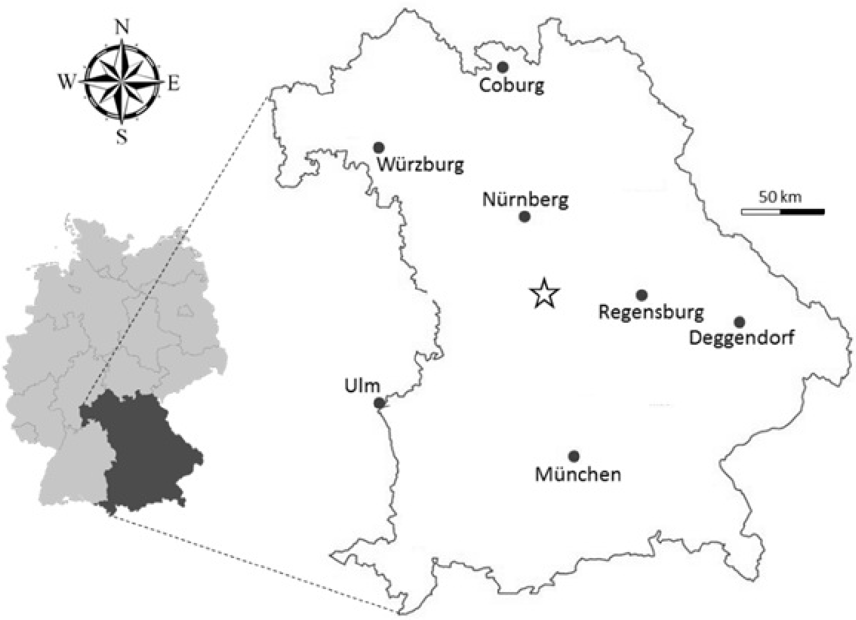

Figure 1: Bavarian state within Germany and the location of the test site depicted by star symbol.

3 Results and discussion

3.1 Description of harvested trees

Despite not having any statistical difference between average dbh of harvested trees within the same treatment, average dbh of beech trees was 13% lower in the clear-cut plot and 9% lower in the selective-cut plot compared to spruce trees (Table 2). Moreover, when comparing dbh between treatments, the average dbh increased by 21% for beech and 25% for spruce between clear-cut and selective-cut, respectively. Even though the average diameter of spruce trees was higher than beech, estimated merchantable volumes, as expressed in m^3/tree, were very similar between species but varied greatly between treatments. Higher average merchantable volume per tree in the selective-cut plot would most likely be attributed to larger diameter and taller trees compared to those studied in the clear-cut treatment.

3.2. Distribution and duration of work cycle elements

Analysis of the productive machine time per tree and corresponding work cycle elements was first performed. During this initial stage, the average percent distribution of the productive cycle elements are presented (Figure 2). The highest percentage was linked to the processing element for both treatments and species tested. For beech trees, approx. 64% of the average cycle time was attributed to processing. This result is in line with results from Labelle et al. (2016), where the element processing accounted for an average of 71% of the entire cycle time during a high removal silvicultural treatment in a sugar maple dominated stand harvested with a Landrich single-grip harvester. When considering only spruce trees, about 45% of the average work cycle was associated with processing, which is comparable with findings from Simões et al. (2008) as cited in Hiesl and Benjamin (2013), who reported that on average 52% of the cycle time in a Eucalyptus plantation was associated with processing. Differences in the percent distribution and ranking on time consumption per element begin to occur for the remaining elements depending on silvicultural treatment or species harvested. A higher percentage was linked to the moving element for both species during the selective-cut (above 25% of total productive time) as compared to the clear-cut (below 13% of total productive time).

As the percent distribution of average work cycle time (as presented in Figure 2) varies between treatments and species, it was also of interest to compare the distribution of work cycle elements in terms of average duration (seconds; Figure 3A) and also average duration in relation to the theoretical merchantable volume per tree (seconds/m^3; Figure 3B). As expected, the most time consuming work cycle element regardless of species and treatment was processing. For a respective species, the average processing time was longer in the selective-cut compared to the clear-cut.

Table 2: General information from harvested trees along with one-way ANOVA results (different superscript letters indicate a statistical difference at alpha = 0.05 between treatments).

Treatment	Species	Number of trees	DBH of harvested trees [cm]		Estimated merchantable volume [m^3/tree]*	
			Average	Standard error	Average	Standard error
Clear-cut (Plot A)	Spruce	15	34.3^a	2.27	1.18^a	0.178
	Beech	15	29.7^a	2.15	1.13^a	0.157
Selective-cut (Plot B)	Spruce	22	43.6^a	1.96	2.03^a	0.197
	Beech	30	38.6^a	1.42	2.11^a	0.153
Total	All	82	37.5	1.16	1.74	0.100

* estimated merchantable volume derived from species dependent biomass expansion factors

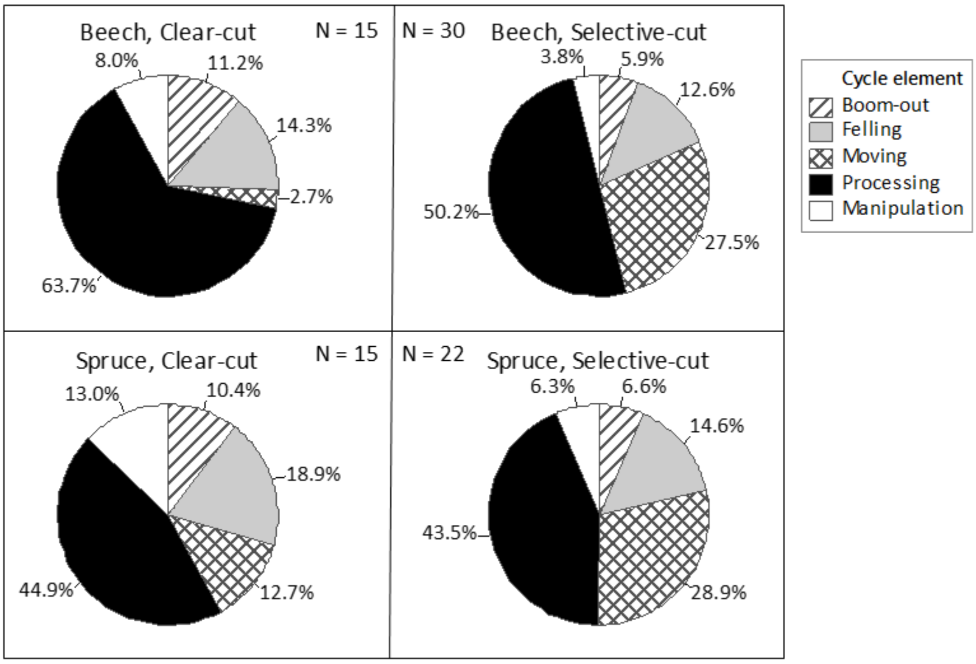

Figure 2: Average percent distribution of productive work cycle elements measured. Non-productive times were removed from analysis.

The main reason for this is the higher average diameter of trees harvested in the selective-cut (41 cm) compared to clear-cut (32 cm; additional information in Table 2). Another noteworthy finding is the higher processing time required for beech trees compared to spruce. Based on a one-way ANOVA, a statistical difference (p = 0.018) in average processing time per tree was observed between beech and spruce in the selective-cut treatment. With an increasing mean tree dbh, beech trees often exhibit complex crown architecture and average branch diameter increases, both combining to increase time required for processing, thus reducing harvesting productivity.

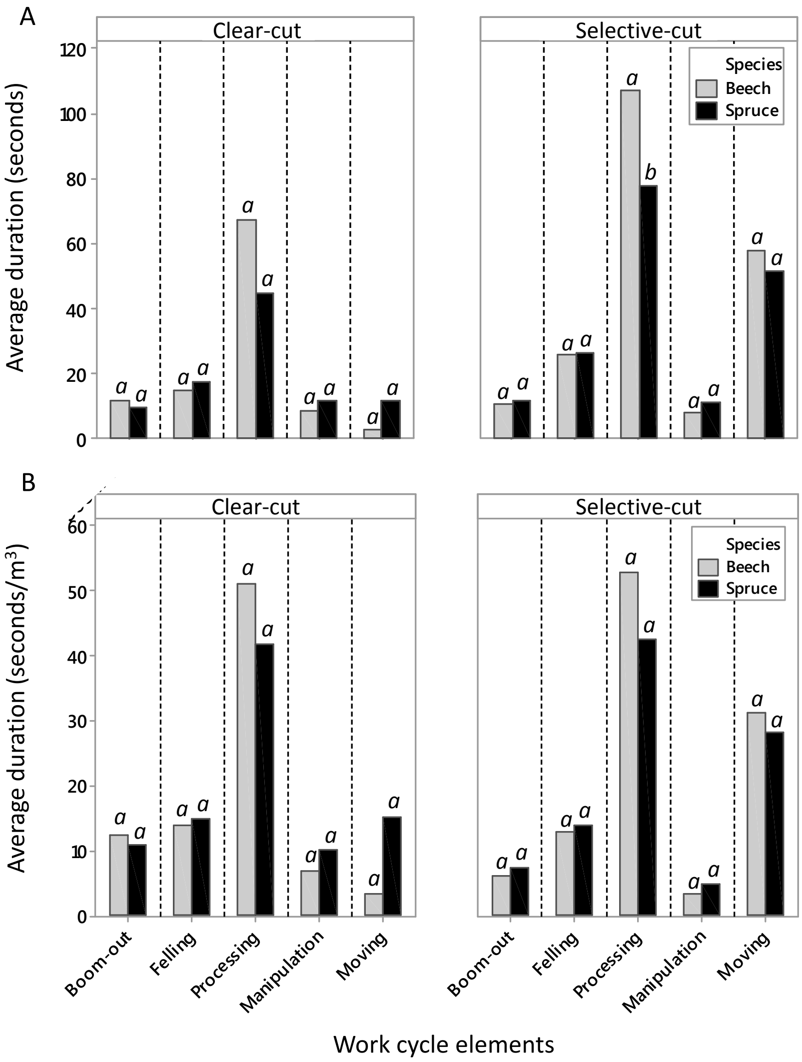

Figure 3: A. Average duration of each work cycle element and B. Average duration of each cycle elements in relation to the theoretical merchantable volume harvested (seconds/m^3) as a fonction of silvicultural treatment and species. Different letters indicate a statistical difference at alpha = 0.05 between species within the same treatment and work cycle element based on one-way ANOVA's.

Table 3: Average harvesting productivity as a function of silvicultural treatment and species along with one-way ANOVA results (different superscript letters indicate a statistical difference at alpha = 0.05 between treatments).

Treatment	Species	Number of trees	Harvesting productivity [m^3/PMH] Average	Standard error
Clear-cut (Plot A)	Spruce	15	34.5^a	2.68
	Beech	15	29.5^a	1.69
Selective-cut (Plot B)	Spruce	22	29.9^a	2.19
	Beech	30	28.2^a	1.69
Total	All	82	30.0	1.04

Machine moving took on average longer for spruce trees compared to beech trees in the clear-cut. The natural spatial distribution of trees to be harvested is likely a key contributor to this difference and perhaps more spruce trees were outside boom reach and required motor-manual felling as compared to beech. Due to the lower removal rate in the selective-cut treatment, machine moving was considerably higher for both species compared to the clear-cut. When combining results from both species, average machine tracking per tree was increased by a factor of 7 (avg. of 7 seconds/tree in clear-cut and 55 seconds/tree in selective-cut) between selective and clear-cut treatments.

When considering the theoretical merchantable volume per tree (based on dbh, height, and biomass expansion factors), average work cycle elements exhibited very similar trends, expressed in seconds/m3, to those discussed above (Figure 3B). However, in this analysis, no statistical differences could be detected between species for a respective element.

3.3. Harvesting productivity

Aside from removing delays (operational or non-operational), results presented thus far contained all original time and motion data. As an example, if a specific tree did not have any time associated to the element moving, then this was treated as 0 seconds but still contributed to the average element moving element for all trees. However, since not all work cycle elements were common for all trees harvested, we determined a standardized time for moving and manipulation and applied it to all trees. From this point forward, all results will account for the standardization.

Irrespective of treatment, harvesting productivity was higher for spruce than beech although the difference was more pronounced for the clear-cut plot. Within the clear-cut treatment, average harvesting productivity was 17% higher (34.5 m^3/PMH) for spruce compared to beech (29.5 m^3/PMH), whereas this difference was reduced to only 6% in the selective-cut (Table 3). However, one-way ANOVA's showed no statistical differences in harvesting productivity between species for each of the treatments. Harvesting productivity results in the clear-cut treatment are similar to the findings obtained by Glöde (1999) where harvesting productivity of a Valmet 982/960 single-grip harvester during a final felling of a shelterwood treatment in a mixed-wood stand varied between 16 and 34 m^3/PMH.

When ploting the harvesting productivity (m^3/PMH) of individual trees in function of dbh and adding a second order polynomial trendline, results from both species in the clear-cut illustrate a common relationship where machine productivity increases with an increase in tree diameter until the optimum productivity is reached and then decreases with a further increase in diameter (Figure 4A). This refers to the well-known "sweet-spot" of harvesting equipment (Visser et al., 2009). In the clear-cut treatment, the sweet-spot of the tested TimberPro varied depending on tree species with the highest peak productivity observed for spruce compared to beech. A higher harvesting productivity in spruce was anticipated because of the simpler architecture of the trees as opposed to the more complex crowns, larger branch diameters found on beech trees and also due to the height where harvested spruce trees were on average 1.5 m taller than beech trees.

During the selective-cut, harvesting productivity results were more sporadic, particulary with respect to beech. In this treatment, the data collected did not provide the same noticeable sweet-spot as in the clear-cut. In fact, when plotting a second order polynomial trendline, which yielded a respectable R^2 (0.75) for spruce, productivity increased with increasing tree dbh until the maximum diameter tested of 60 cm. One possible explanation for the different shapes of the two spruce curves could be linked to the very low sampling points above 45 cm dbh in the clear-cut plot. With only two data points above this diameter, it becomes very difficult to understand exactly if the suggested trendline is representative for larger diameters. Another possible limitation would be the use of merchantable volume estimations instead of actual measurements of recovered volume. Harvesting productivity, particularly for the studied beech trees, are most likely over-estimated since complex crown architecture and larger branches would have probably affected the recoverable volume to a higher extent in relation to spruce trees. This would in turn decrease harvesting productivity.

A strong and well documented positive relationship exists between tree dbh and its corresponding piece size (m^3/tree). Using the estimated merchantable volume per tree, we also plotted harvesting productivity data in function of individual piece size (Figure 4B). Very similar trends as shown in Figure 4A were observed for both species, in particular within the clear-cut treatment. The only noteworthy difference was for the beech trees harvested within the selective-cut treatment, where a ceiling in machine productivity seemed to be discernable as stem size increased. However, because of the relatively low sample size, one should be careful not to extract too much from this tendency. Once again, it is also important to mention that the calculated harvesting productivity rates in this article would probably be lower should actual recovered volume per tree have been measured.

4. Conclusion and future work

This pilot study investigated the influence of different tree species (beech and spruce) and silvicultural treatments (clear-cut and selective-cut) on the harvesting productivity of a TimberPro TB620 single-grip harvester. Despite the limited sample size and lack of replicates, interesting preliminary findings were discovered that can be used as basis for an expanded project. Under clear-cut operations, average harvesting productivity was 34.5 m^3/PMH for spruce compared to 29.5 m^3/PMH for beech, thus indicated a 17% higher productivity in spruce. Harvesting productivity results presented herewith were based on calculated pre-harvest merchantable volumes and not from recovered volumes.

For safety and productivity reasons and for the fact that more forest cover has been and will continue to be converted to mixed wood stands, it is highly probable that the use of single-grip harvesters increase. The goal of the expanded full-scale project will be to determine which tree related characteristics influence mechanized harvesting productivity the most in mixed-wood or hardwood stands and develop best management practices aimed at helping operators process trees with more complex architecture while maintaining acceptable product recovery and harvesting productivity.

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Does order of stems in harvesting count – the effect on bucking outcome when utilizing bucking-to-demand approach

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Abstract: Modern cut-to-length (CTL) harvesters utilize bucking-to-demand approach, where log length-diameter distribution is controlled by price list, including a price for each timber assortment, log length and diameter, together with demand matrix, where the request for the share of each log quality and size class is defined. The known problem with bucking-to-demand approach is that the method requires up to 10 hours work before the apportionment index, a key figure utilized in comparison of demand and actual output, reaches its threshold where it does not grow anymore. In the study, three different stem harvesting orders, random, ascending size and descending size, and their effect on apportionment index in a typical Finnish stand were compared by bucking simulations. According to the results, the ascending harvesting order was the best in three out of four cases, and the descending harvesting order was the worst.

Keywords: Harvester, Bucking, Optimization, Work model

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1. Introduction

Although the maximization of the volume of the most valuable timber assortments is crucial for many stakeholders in wood procurement chain, also the distribution of log length-diameter classes of sawn timber has importance. Saw mill sales men sell upcoming production beforehand, and saw mill manager's responsibility is to produce species, dimensions and qualities sold. Due to heterogeneous nature of roundwood as a raw material, the fit between demanded distribution and actual output is never perfect, and the result of this is sawn goods which does not have contracted end user. These sawn goods are seldom easy to sell, and the price is what bends. Therefore, the maximization of the fit, or minimization of unwanted proportion of log length-diameter classes, is crucial for profitability of saw mill. As the total value of the wood procurement chain is defined in the product value, this has effect on all the wood procurement chain.

Cut-to-length (CTL) harvesting utilizing bucking-to-demand approach aims to maximize the fit between demanded and harvested log length-diameter distribution. For this approach, two different methods are applied: adaptive price list –method and close-to-optimal -method. The adaptive price list method follows the accumulation of logs, and if log length-diameter class has surplus, the system decreases the price of the class, and in the case of shortage, the system increases the price. Usually the value is adjusted within given price range, for example ±5% from the original value. In the close-to-optimal -method, the system calculates the priority for each cutting pattern of the stem before actual cutting, and selects the pattern which has highest priority within given value decrease tolerance. The priority is calculated according to the accumulation of logs, and logs to be harvested according to the selected pattern. Thus, both methods require certain amount of logs to be harvested before the bucking-to-demand approach starts to take effect.

Although in theory, bucking optimization adapts to needs of end-product dimensions, there are difficulties to create useful bucking instructions. In practice, many sawmills change their bucking instructions in 6 month phases (Helstadt 2006) and real time steering, or fulfilling of special demands, is considered impossible.

According to Imponen (1999), harvesters bucking automation should not be based on single machine, but rather of group of harvesters in online connection. For a one machine, when starting to use new bucking instructions, it takes up to 10 hours of work until apportionment index reaches the threshold where it does not anymore grow, the first 4 or 5 hours being most crucial. The group-guiding of harvesters lead to faster threshold than a sum of individual harvesters. However, the total apportionment index in the end did not diverge between group-guiding and individual harvesters. Despite this quite early notification, CTL harvesting is still conducted based on single harvester optimization.

Tikkanen et al. (2009) utilized two step group guiding of harvesters. The first step was independent harvesting of first stands by utilizing close-to-optimal -method with 5% tolerance for value deviation. The seconds step was to adapt harvester's price lists according accumulated log length-diameter distribution. Controversy to findings of Imponen (1999), Tikkanen et al. (2009) received almost 9 % better apportionment index by group-guiding than by individual harvesters.

Most of the studies concerning bucking of logs into demanded log length-diameter distribution requires accurate stemwise pre-harvest information (e.g. Kivinen & Uusitalo 2002, Murphy et al. 2004, Kivinen 2004). However, this kind of data is seldom available, although methods for producing detailed data are continuously developed (e.g. Malinen et al. 2001, Malinen 2003, Peuhkurinen 2007).

Despite the practice, where bucking instructions may be updated every six months, saw mills do receive special orders which differs from basic production. Since current bucking optimization has its disadvantages, sawmills face three options when special orders are placed: 1) we do it anyway since the customer is important, 2) we do it, but we have to get high price because of the amount of unwanted log dimensions, 3) we do not do this kind of orders.

If pre-harvest information of stand is not available, one way within current bucking optimization to accelerate the rise of apportionment index is to consider harvesting order within a stand. Should small trees be harvested first since the amount of bucking patterns in those are limited, or should the largest trees be bucked first since the accumulation of volume and different kinds of logs is fastest from them?

In this experimental case study, the effect of harvesting order of stems on bucking outcome was studied utilizing bucking simulation approach and harvester collected stem database of one stand. Different stem orders were produced and bucking outcomes compared utilizing apportionment index between demanded log length diameter distribution and accumulation of logs.

2. Material and Methods

2.1. Study material

The study data utilized in the study was collected by Ponsse Ergo CTL harvester in North Karelia, June 2010, and saved in stm-format (Arlinger at al. 2012). For the study, only Norway spruce trees (*Picea Abies*) were selected. In Nordic countries, Norway spruce is typically harvested by automatic bucking aiming to maximize the value and length-diameter distribution, whilst Scots pine and birch are more often bucked according quality. Selected stand represents typical Finnish clear cutting stand (Table 1), and it contained 396 spruce trees. The diameter distribution included both small and big saw log sizes trees (Fig. 1).

Table 1: Minimum (Min), maximum (Max) and average (Avg) values of diameter at breast height (DbH), height of the utilized section and volume (Vol) of the utilized section for the study stand.

	Min	Max	Avg
DbH (cm)	6.50	51.00	26.40
Height (m)	3.04	24.98	17.51
Vol (m^3)	0.0095	2.056	0.645

2.2. Bucking simulations

Data management and adjustments, creation of bucking objectives and bucking simulations were done utilizing Ponsse OptiOffice2 4.725 package. Bucking simulations utilized adaptive price list –method with 4% of allowable adaptation. For the study, three different stem banks with different stem harvesting order according breast height diameter were generated: 1) original harvesting order, 2) ascending harvesting order, and 3) descending harvesting order.

Neither bucking instructions (apt-file) or actual output (prd-file) from the harvesting were not available. However, the price matrix (Table 2) and corresponding demand matrix 1 (Table 3) were attained from other study area and represent a practical approach in the study. The effect of bucking instructions was studied by creating new bucking instructions. The aim of the demand matrix 2 (Table 4) was to weight importance of long log lengths. The demand matrix 3 (Table 5) aimed to evenly distributed weighting of length-diameter classes, and the demand matrix 4 was exacerbated version of demand matrix 1 (Table 6).

Table 2: Price matrix utilized in bucking simulations.

Diameter	**Length, cm**								
mm	**370**	**400**	**430**	**460**	**490**	**520**	**550**	**580**	**610**
160	34	34	48	48	48	48	48	48	48
180	34	34	46	46	46	46	46	46	46
200	34	34	46	46	46	46	46	46	46
220	34	34	46	46	46	46	46	46	46
240	30	30	46	46	46	46	46	46	46
260	30	30	46	46	46	46	46	46	46
280	30	30	46	46	46	46	46	46	46
320	30	30	46	46	46	46	46	46	46
340	30	30	46	46	46	46	46	46	46
360	30	30	46	46	46	46	46	46	46
380	30	30	46	46	46	46	46	46	46
400	30	30	46	46	46	46	46	46	46

Table 3: Demand matrix 1, a real life demand matrix.

Diameter	**Length, cm**								
mm	**370**	**400**	**430**	**460**	**490**	**520**	**550**	**580**	**610**
160	7	8	14	15	15	17	14	5	5
180	9	7	12	13	13	26	12	4	4
200	7	4	9	13	7	26	25	5	4
220	4	4	5	16	11	16	30	7	7
240	2	2	5	16	12	17	32	8	6
260	2	2	9	16	14	11	33	7	6
280	2	2	10	16	16	11	29	7	7
320	2	2	5	13	16	17	31	7	7
340	2	2	6	13	21	25	14	9	8
360	2	2	6	13	21	25	14	9	8
380	2	2	6	13	21	25	14	9	8
400	2	2	6	13	21	25	14	9	8

Table 4: Demand matrix 2, weighting importance of long logs.

Diameter	**Length, cm**								
mm	**370**	**400**	**430**	**460**	**490**	**520**	**550**	**580**	**610**
160	2	4	8	12	12	14	14	16	18
180	2	4	8	12	12	14	14	16	18
200	2	4	8	12	12	14	14	16	18
220	2	4	8	12	12	14	14	16	18
240	2	4	8	12	12	14	14	16	18
260	2	4	8	12	12	14	14	16	18
280	2	4	8	12	12	14	14	16	18
320	2	4	8	12	12	14	14	16	18
340	2	4	8	12	12	14	14	16	18
360	2	4	8	12	12	14	14	16	18
380	2	4	8	12	12	14	14	16	18
400	2	4	8	12	12	14	14	16	18

Table 5. Demand matrix 3, evenly distributed weighting.

Diameter	Length, cm								
mm	370	400	430	460	490	520	550	580	610
160	11	11	11	11	12	11	11	11	11
180	11	11	11	11	12	11	11	11	11
200	11	11	11	11	12	11	11	11	11
220	11	11	11	11	12	11	11	11	11
240	11	11	11	11	12	11	11	11	11
260	11	11	11	11	12	11	11	11	11
280	11	11	11	11	12	11	11	11	11
320	11	11	11	11	12	11	11	11	11
340	11	11	11	11	12	11	11	11	11
360	11	11	11	11	12	11	11	11	11
380	11	11	11	11	12	11	11	11	11
400	11	11	11	11	12	11	11	11	11

Table 6. Demand matrix 4, exacerbated real life demand.

Diameter	Length, cm								
mm	370	400	430	460	490	520	550	580	610
160	2	5	10	20	26	20	10	5	2
180	2	5	10	20	26	20	10	5	2
200	2	5	10	20	26	20	10	5	2
220	2	5	10	20	26	20	10	5	2
240	2	5	10	20	26	20	10	5	2
260	2	5	10	20	26	20	10	5	2
280	2	5	10	20	26	20	10	5	2
320	2	5	10	20	26	20	10	5	2
340	2	5	10	20	26	20	10	5	2
360	2	5	10	20	26	20	10	5	2
380	2	5	10	20	26	20	10	5	2
400	2	5	10	20	26	20	10	5	2

2.3. Apportionment index

Bucking simulations were compared by using apportionment index (Bergstrand 1990), which is a key figure depicting the fit between demanded and actual log length-diameter distribution. It can be calculated as follows:

$$A = \left(100 - 0.5 \cdot \sum_{i=1} m \cdot \sum_{j=1} n \cdot \left|f_{ij}^* - t_{ij}^*\right|\right) \quad (1)$$

$$f_{ij}^* = \frac{f_{ij}}{\sum_{i=1} m \cdot \sum_{j=1} n \cdot f_{ij}} \quad (2)$$

$$t_{ij}^* = \frac{t_{ij}}{\sum_{i=1} m \cdot \sum_{j=1} n \cdot t_{ij}} \quad (3)$$

A = Apportionment index
m = Number of diameter classes
n = Number of length classes
f_{ij} = Number of logs in the i^{th} diameter class and j^{th} length class in the actual output log distribution
t_{ij} = Number of logs in the i^{th} diameter class and j^{th} length class in the demanded log distribution

3. Results

The ascending harvesting order produced the highest apportionment index for tree demand matrices out of four (Table 7). The exception was demand matrix 1, a copy of actually used apt file, when the random order was the best. The descending harvesting order produced the lowest apportionment in three cases, the apportionment index for the random order being lower for the demand matrix 3, where evenly distributed weighting was applied. On overall, the differences between apportionment indexes were moderate. The biggest difference, 3.81 percentage points, was between the random harvesting order and the descending harvesting order when using demand matrix 1.

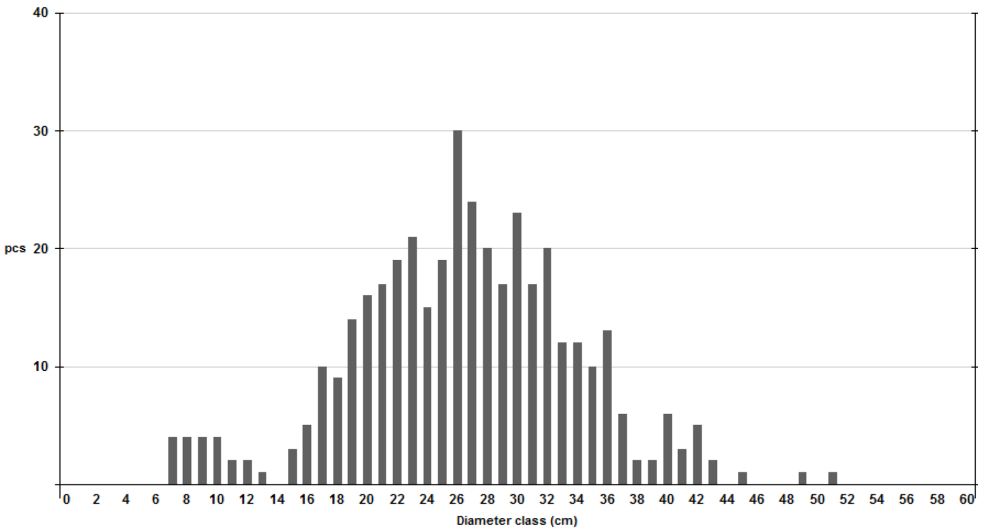

Figure 1: Diameter distribution of the study data.

Table 7: The effect of harvesting order on apportionment index.

Demand matrix	Apportionment index Random	Ascending	Descending
1	80.37	78.26	76.56
2	78.98	81.60	78.04
3	69.59	70.39	69.81
4	81.08	81.44	77.86

Closer examination of difference matrices between demand and actual output reveals the problems in the bucking-to-demand approach (Tables 8-10). As the prices for length classes 370 cm and 400 cm was set notable lower compared to other length classes, the bucking-to-demand approach is incapable to produce demanded share of length classes, and as a result, length class 430 has notable surplus in all harvesting orders. Although the phenomenon is understandable if the theory behind bucking-to-demand with adaptive price list is considered, the outcome might be unwanted. The utilized price list and demand matrix 1 were derived from actually used apt-file, and clearly the contradiction between demand matrix and price list hasn't been understood.

The changed bucking order reveals the other problem. In the Tables 8, 9 and 10, the only difference is the harvesting order, the price list, demand matrix and the group of stems remains the same. Although the apportionment index is relatively close in each case, log length-diameter class specific differences are enormous. For a certain diameter classes, such as 200 mm, 380 mm and 400 mm, the surplus and deficit seems to locate randomly. The reason for the phenomenon is that adaptive price list -method requires certain amount of logs to be cut before the price list adaptation begins. If the size of these first stems are close to each other, like the case with ascending and descending harvesting order, notable surplus of certain log size classes has already been reached before the adaptation begins.

Table 8: The relative deviation between demand and actual output matrices for demand matrix 1 with the random harvesting order. Positive value marked in red represents surplus of logs in a class, and negative value marked in green represents a deficit.

Diameter, mm	Length class, cm 370	400	430	460	490	520	550	580	610
160	-5	-7	0	-5	0	1	1	1	15
180	-5	-7	14	2	0	-4	-3	0	3
200	-7	-4	18	1	1	-7	-4	2	1
220	-4	-4	6	1	1	-2	-1	1	1
240	-2	-2	7	1	2	0	-9	1	1
260	-2	-2	1	2	-1	0	-2	1	2
280	-2	-2	2	1	-1	-1	2	1	1
320	-2	-2	3	2	7	-2	0	1	-7
340	-2	-2	3	5	6	-7	-5	0	1
360	-2	-2	-6	7	-1	-5	6	11	-8
380	-2	-2	14	7	-1	-5	6	-9	-8
400	-2	-2	-6	-13	-21	25	36	-9	-8

Table 9: The relative deviation between demand and actual output matrices for demand matrix 1 with the ascending harvesting order. Positive value marked in red represents surplus of logs in a class, and negative value marked in green represents a deficit.

Diameter mm	Length class, cm 370	400	430	460	490	520	550	580	610
160	-6	-7	-1	-4	0	1	1	1	15
180	-4	-7	14	-1	-1	0	-3	1	3
200	-7	-4	19	1	1	-1	-10	1	1
220	-4	-4	3	1	1	1	0	1	1
240	-2	-2	8	1	1	-1	-8	1	2
260	-2	-2	2	2	2	0	-4	2	1
280	-2	-2	3	1	1	1	-4	1	1
320	-2	-2	4	5	2	1	-4	-7	2
340	-2	-2	5	9	1	-3	-3	-9	3
360	-2	-2	5	9	1	-14	-3	2	3
380	-2	-2	19	12	4	-25	11	-9	-8
400	-2	-2	-6	-13	29	-25	36	-9	-8

Table 10: The relative deviation between demand and actual output matrices for demand matrix 1 with the descending harvesting order. Positive value marked in red represents surplus of logs in a class, and negative value marked in green represents a deficit.

Diameter mm	Length class, cm 370	400	430	460	490	520	550	580	610
160	-6	-7	0	-1	-1	-4	1	1	16
180	-4	-7	20	1	1	-6	-3	1	-2
200	-7	-4	13	-2	0	-1	-3	1	2
220	-4	-4	8	1	1	-1	-2	0	1
240	-2	-2	12	2	1	1	-8	-2	-1
260	-2	-2	2	1	0	2	-5	2	2
280	-2	-2	1	2	2	2	-4	1	2
320	-2	-2	6	9	6	-6	-9	-7	4
340	-2	-2	11	4	4	0	-6	-9	0
360	-2	-2	8	1	8	4	0	-9	-8
380	-2	-2	14	7	-1	15	-14	-9	-8
400	-2	-2	44	-13	-21	-25	36	-9	-8

4. Discussion

In this experimental case study, the effect of harvesting order of stems on log diameter distribution was studied. The results consider only one stand, and therefore they are not comprehensive, nor generalizable. The purpose of the study was to present factors affecting on bucking-to-demand outcome, and pre-study the magnitude of the effect of harvesting order.

Compiled ascending and descending harvesting orders for the study are not in any means feasible in practice. However, there are cases where harvesting of a stand could be started from the location where trees are bigger than on average, or smaller than on average, if there is a specific reason to start harvesting from one end of size distribution of trees.

The performance of bucking-to-demand approach is greatly dependent on the range of price adaptation in adaptive price list -method or price deviation tolerance from maximum in close-to-optimal -method (Piira et al. 2007, Kivinen 2007). This was also the most probable reason for the success of Tikkanen et al. (2009) when they achieved received almost 9 % better apportionment index by group-guiding than by individual harvesters. In their method, each individual harvester utilized close-to-optimal bucking with 5% maximum value deviation, which for further complimented with price adjustments up to 25%.

The apportionment index may also be affected by the measurement errors due to bad calibration of harvester or non-optimal prediction of tapering of stem. According Vuorenpää et al. (1997) the apportionment index could increase at most 5% if taper curve prediction is replaced by measured stem profiles.

The principles of bucking-to-demand approach was presented by Bergstrand (1990), but the actual methodology utilized in modern CTL-harvesters is not reported. In the study, a bucking simulator developed by Ponsse was used and therefore it can be assumed that these results are in line with bucking optimization of Ponsse harvesters.

As a conclusion of the study it can be noted that there are no great means to affect on bucking outcome by selecting small or big sized trees to be harvested first. However, if possible, it might be better to harvest small trees first as their size restricts bucking optimization, and complete the harvesting of stand by big trees since the number of bucking patterns is the greatest in them, and those trees can be utilized to fulfill size classes where the shortage exists.

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Investigation and evaluation of the methodology of determination of solid volume according to the stacked volume on roadside, in forwarder and in truck loads for logistics purposes in LATVIA

Ziedonis Miklašēvičs

Abstract: In the Latvian forest industry the roundwood delivery costs represent about 10-20% of the total round wood production cost. The quantity measurements of the roundwood are required throughout the logic chain of wood from forest to the sawmills but inspite of a large proportion of the total cost the term "true volume" of roundwood is equally actual for suppliers and processors of wood.
The roundwood volume results differ measured the same load by measuring the diameters of log in short intervals using harvester measurement systems and measured according to the group measurement methods used for forwarder loads and truck loads volume calculation.
According to Standard LVS 82:2003 „Apaļo kokmateriālu uzmērīšana" (*Apalo*…, 2003), the permitted volume deviation from the actual volume for round wood, measured according to the group measurement method, is 10%. According to the investigation results made in the Sweden forest industry, the actual deviation reaches 23% if forwarder or truck loads are measured (Erkki and Jari, 2005). Standard deviation reaches 14% if the timber stack (7-16m^3) is measured in vehicle and 20% if the timber stack (<20 m^3) is measured in landing measured (Erkki and Jari, 2005). This means that it is a great interest in industry to develop the measurement methods and systems to have a lower cost and more efficient algorithm to determine the wood volume because the roundwood deliveries are planned according to the data of stacked volume on a roadside given by forwarder operators and information given by truck drivers regarding to delivered loads.
The purpose of this study is to compare the forwarder and truck loads volume values and the results made by the group measurement methodology approved by SDC's instructions for timber measurement "Measurement of roundwood stacks " (*Measurement…*, 2014) to calculation results made by the most accurate manual and automatic measurement methods (Miklasevitcs 2013; Miklasevics 2015) and give the recommendations for minimizing the difference of the results and improving the efficiency of roundwoood delivery process.

Keywords: roundwood; group measurement methods; forwarder loads; volume

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1. Introduction

For logistics operations planning it is important to to know how much roundwood is leaving in stacks during harvesting. That's why it is important to estimate timber volumes either in the forest or when leaving.

The selection of an appropriate measurement method must be made by those responsible for the roundwood processing.

The selection of a roundwood measurement method suitable for a particular situation should always be guided by the need for cost effectiveness. The avaibility of resources such as skills, labour, equipment, time, money, precision demands will have a large impact on the choise of measuring method. For example, stack measurement at roadside is possible to manage by using manual measurement equipment (*Round and…*, 2006; *Timber…*, 1999), by using photometric method (Sscale) (*Wood…*, 2016) or by using photogrammetric technique (Knyaz and Maksimov, 2014; Knyaz et al. 2004). Beside mentioned factors, factors like managment flexibility, species and timber security influence the choise of measurement method.

According to the roundwood stack measurement method: "Determination of solid volume according to the stacked volume" by standard LVS 82:2003 (*Apaļo*…, 2003), the permitted volume deviation from the actual volume for the roundwood, measured according to the group measurement, is 10%. The measurement method should be selected according to the technical options and required levels of precision (Lars, 2007). Because of that, the more precisious (standard deviation 2.5%), but high cost photometric measuring method (Sscale) for stack measuring (*Wood…*, 2016) or fully automatic system Mabema for measuring woodpile volume on trucks (*Mabema GPV*, 2016) which ensure precision (standard deviation 3.17%) or Fotoweb measuring system (Erkki, 2005) are not appropriate for achieving less accurate measurement results. Concerning to measurement methods developed for forvarder loads measuring, the investigations are being made at Forestry Faculty of Zagreb University (Duka et al., 2014; Bosner et al., 2008; Milorad and Dusan 2014).

In Latvia only stack measurement results of roundwood yards, information about forvarder and truck loads are used for logistic operations planning. On one hand roundwood haulage faces the challenge of transporting enough material within strict legal dimensions and gross vehicle volume restrictions for trucks (Devlin et al., 2008). On the other hand interest of logistics is to receive full truckloads at roundwood-yards in harvesting places and to minimize transportation costs (Devlin et al., 2008). Achieving these goals is possible by using unbiased information about measuring results in each stage of roundwood supply chain**.** For this purpose the roundwood group measurement methods should be used.

The purpose of this study is to assess the actual precision levels of measured roundwood volumes of forvarder loads, stacks and truck loads according to the group measurement algorithm.

2. Materials and methods

The following procedures were used to achieve the required objective:

1. To compare the truck loads volume data calculated by truck drivers to roundwood volume calculation data made in sawmill by measuring diameter in short intervals using electronic 3D systems for the period 01.01.2016-01.03.2016.
2. To compare the forvarder loads volume data calculated by forvarder operators to measurement results calculated by harvester measuring systems for the period 2015.
3. To approbate the developed group measuring method based on methodology (*Measurement*…, 2014) and technical information of forvarder load space options (cross section area m^2).
4. To develop the experimental investigation and to assess the precision of the roundwood volume measurements in each technological stage of roundwood processing, the adequate tasks have been proposed:
   - 4.1. To control and evaluate the measurement accuracy of the harvester measuring system by collecting and analysing the harvester measurement data in connection with the measuring results of identified logs in sawmill by measuring diameter in short intervals using electronic 3D systems.
   - 4.2. To calculate the volume of deffective logs according to the requirements of model of volume calculation developed for Swedish roundwood (Anon, 2000).
   - 4.3. To deliver and load roundwood assortiments harvested according to quality requirements and specification in the separate stack and to measure and calculate the stack volume by using methology (*Measurement*…, 2014).
   - 4.4. To compare the solid volume data calculated by forvarder operators using developed methodology to measurement results calculated by measuring diameter in short intervals using electronic 3D systems.
   - 4.5. To compare the truck loads volume data calculated by truck drivers to measurement results calculated by measuring diameter in short intervals using electronic 3D systems.
   - 4.6. To give the recommendations for the most appropriate group measurement method which provide the least wood volume deviation comparing to the results given by harvester and electronic measurement system in each technological stage of roundwood processing.

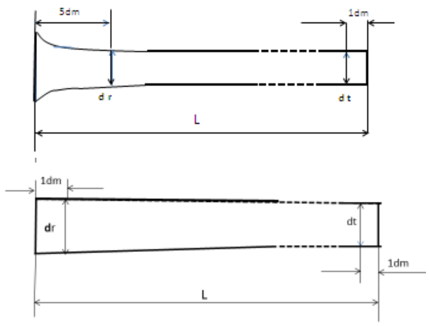
The following measurement methods were applied in the investigation:

1. Expert method (experience method) used by forvarder operators and truck drivers for load volume calaculation.
2. Individual measuring method according to the top and butt diameter measurements by model of volume calculation (Table1.).
3. Individual measurement method by measuring diameter in short intervals using harvester measurement system.
4. Individual measurement method by measuring diameter in short intervals using electronic 3D system.
5. Group measurement method by using methology approved by SDC's instructions for timber measurement "Measurement of roundwood stacks " (2014).
6. Developed group measurement method for forvarder loads measuring.

The following equipment were applied in the experimental investigation:
manual measuring equipment; harvester *Ponsse Ergo;* forvarder *John Deer 1110D;* trucks: *Volvo FH-14, Scania 460* and automatical measuring system *(3D scanner Microtec).*

The object of the investigation were assortiments harvested according to the specification (Table2.).

Table 1: Determination of the volume according to the Top and Butt Diameter Measurements.

Determination of the volume	**The formula**	**Measurement method for logs from neiloid and paraboloid zone of stem**
According to the Top and Butt Diameter Measurements by model of volume calculation developed for Swedish roundwood (Anon 2000),where V = Volume, m^3 Dt = Diameter in top end, cm Db = Diameter in butt end, cm L = Log nominal length, dm α = Constant according to the Table	$\text{v} = \frac{1}{100000} \cdot \frac{\pi}{4} \cdot l \cdot [\alpha Dr^2 + (1-\alpha) \cdot Dt^2]$	

Top diameter (cm)	Length class (cm)		
	-349	350-449	450+
-14	0.485	0.485	0.485
15-24	0.465	0.460	0.455
25+	0.440	0.430	0.420

Table 2: Specification of roundwood assortiments.

Assortiment, mm	Identification of the top diameter, mm	Top diameter (min/max), mm	Nominal lenght (m)						Max. diameter, mm
				3	3.6	4.2	4.8		
			Actual length and length deviation (-1cm), m						
			<3.07	**3.07**	**3.67**	**4.27**	**4.87**	**6.32<**	
100x140	100-119	99	<3.07						
	120-139	100/119	<3.07	3.07	3.67	4.27	4.87	6.32<	610
140x180	140x159	140/159	<3.07	3.07	3.67	4.27	4.87	6.32<	610
	160x179	160/179	<3.07	3.07	3.67	4.27	4.87	6.32<	610
180x279	180x199	180/199	<3.07	3.07	3.67	4.27	4.87	6.32<	610
	200x219	200/219	<3.07	3.07	3.67	4.27	4.87	6.32<	610
	220x239	220/239	<3.07	3.07	3.67	4.27	4.87	6.32<	610
	240x259	240/259	<3.07	3.07	3.67	4.27	4.87	6.32<	610
	260x279	260/279	<3.07	3.07	3.67	4.27	4.87	6.32<	610
280<	280x299	280/299	<3.07	3.07	3.67	4.27	4.87	6.32<	610
	300x319	300/319	<3.07	3.07	3.67	4.27	4.87	6.32<	610
	320x339	320/339	<3.07	3.07	3.67	4.27	4.87	6.32<	610
	340x359	340/359	<3.07	3.07	3.67	4.27	4.87	6.32<	610
	360x379	360/379	<3.07	3.07	3.67	4.27	4.87	6.32<	610
	380x399	380/399	<3.07	3.07	3.67	4.27	4.87	6.32<	610
	400x419	400/419	<3.07	3.07	3.67	4.27	4.87	6.32<	610
	420x439	420/439	<3.07	3.07	3.67	4.27	4.87	6.32<	610
	440x459	440/459	<3.07	3.07	3.67	4.27	4.87	6.32<	610
	460x479	460/479	<3.07	3.07	3.67	4.27	4.87	6.32<	610
	480x499	480/499	<3.07	3.07	3.67	4.27	4.87	6.32<	610

3. Results and discussion

The roundwood volumes of 451 truck loads were calculated by drivers and the measurement results were compared with the volume values calculated by measuring diameter in short intervals using electronic 3D scanner "*Microtec*" (Table 3.).

Table 3: The measurement results of the truck loads.

Criteria	Measurments
Number of loads	451
Amount of the loads volume by measured by drivers, m^3	14402
Amount of the loads volume by measuring diameter in short intervals using electric 3D systems, m^3	14057.144
Average load volume measured by drivers, m^3	32
Average load volume by measuring diameter in short intervals using electronic 3D systems, m^3	31.238
Deviation from actual load volume 0-3.0%	41.91
Deviation from actual load volume 3.1-10.0%	50.55
Deviation from actual load volume 10.1>%	7.53
Standard deviation, %	7.67
Standard error, %	0.35

The accuracy of free selected 5 truck loads volume calculation results made by the truck drivers are given (Table 4.)

The forvarder load volumes of roundwood assortiments harvested according to specification (Table 2.) and calculated by forvarder operators were compared with the volume values calculated by measuring diameter in short intervals using harvester measuring systems. The measurement results of the forvarder loads according to amount of roundwood volume in the roundwood-yards are given (Table 5.)

For improving the professional skills using group measuring methods the training seminars for 451 forvarder and harvester operators were organized in 8 Latvia regions. After theoretical course, participants managed practical measurements of the stacks according to *SDC's instructions for timber measurement: "Measurement of roundwoood stacks"* (*Measurement…*, 2014) and forvarder loads according to developed group measuring method (Fig. 4) based on methodology (*Measurement*…, 2014) and technical information of the forvarder load space options (cross section area m^2).

The calculated volumes given by forvarder operators were compared with the results of the most precisious measurement methods by measuring diameter in short intervals using harvester measuring system and individual measuring method according to the top and butt diameter measurements by model of volume calculation developed for Swedish roundwood (Table 1.). The results are given (Table 6.).

Table 4: The measurement results of the selected loads.

Selected truck loads	Characterization of loads			Driver measurements, m^3	Amount of loads by measuring diameter in short intervals using electronic 3D systems, pcs./m^3	Deviation, %
	Species	Diameter group, mm	Nominal length, m			
	Spruce	160-280	4.8	32*	250/32	10.6
	Spruce/Pine	120-280	4.2; 4.8	32*	320/31.61	1.21
	Spruce/Pine	160-280	3.0; 3.6; 4.8	32*	311/31.13	2.72
	Spruce/Pine	160-280	3.6; 4.2; 4.8	32*	311/31.48	1.63
	Spruce/Pine	140-280	3.6; 4.2; 4.8	32*	250/35.78	11.1

p.s. (*). *According to inquiry of the truck drivers, the load volume values were acquired by drivers expierence without using group measuring methods.*

According to the task: to develop the experimental investigation and to assess the precision of measured roundwood volume in each technological stage of roundwood processing, the wood felling area (Fig. 1) was chosen (Am)-*Vacciniosa mel.* The study was carried out in February 2016 in the region Kurzeme in Latvia.

For appreciation the rate of roundwood volume deviation in the measurements made by forvarder operators of the forest exploitation company involved in the investigation, the statistics data were analyzed (Table 7.).

For controlling and evaluation the measurement accuracy of the harvester measuring system, 5 (five) pine stems were selected and identified (Fig. 2). After harvesting all logs were numbered to facilate the identification. The identified logs were harvested according to the specification (Table 2.). The data of harvester measurement system were analyzed in connection with the measuring results of the identified logs in sawmill by measuring diameter in short intervals using electronic 3D systems (Table 8.). The measurement results of the roundwood assortiments harvested in the wood felling area according to the specification (Table 2.) are given (Table 9.).

For controlling and evaluation the measurement accuracy of the developed methodology of determination of solid volume in forvarder loads, the free selected and measured forvarder load was separetly stacked. The measurement methodology of determination of solid volume in forvarder load is given (Fig. 4). For obtaining the ojective results, the assortiments of the load were identified in the stack (Fig. 4) and individually measured in sawmill by measuring diameter of logs in short intervals using electronic 3D system. The volume deviation from the actual volume was 2.76%.

The volume of the deffective log (Fig. 6) was calculated according to the requirements of model of volume calculation (Table 1.).

The solid volume of roundwood assortiments were measured using "*SDC's instructions for timber measurement of roundwood stacks*" (*Measurement…*, 2014) (Fig. 7) and individually measured in sawmill by measuring diameter in short intervals using electronic 3D system. The measuring results are given (Table 10).

The measuring results of the truck loads calculated by the truck drivers were compared with the measuring results using electronic 3D system (Table 11.).

Table 5: The measurement results of the forvarder loads according to amount of roundwood volume in the roundwood-yards.

Criteria	Variable
Species	Spruce/Pine
Diameter group of measured assortiment according to specification, mm	100-139, 140-179, 180-279, 28>
Assortiment lenght, m	3.0, 3.6, 4.2, 4.8
Roundwood- yards	428
Min. volume amount of assortiments in roundwood- yard, m^3	**1,1**
Max. volume amount of assortiments in roundwood- yard, m^3	**60,08**
Amount of measured roundwood loads by forvarder operators, m^3	10696
Amount of measured roundwood loads using harvester measured system, m^3	10919,77
Average amount of assortiments in roundwood-yard, m^3	25,63
Median, m^3	21,23
Standard deviation of measured roundwood loads , %	**20,66**
Standard error of measured roundwood loads, %	**1,06**
Species	Spruce/Pine
Diameter group of measured assortiment according to specification, mm	100-139, 140-179, 180-279, 28>
Assortiment lenght, m	3.0, 3.6, 4.2, 4.8
Roundwood- yards	99
Min. volume amount of assortiments in roundwood- yard, m^3	**61,35**
Max. volume amount of assortiments in roundwood- yard, m^3	**100,16**
Amount of measured roundwood loads by forvarder operators, m^3	7668
Amount of measured roundwood loads using harvester measured system, m^3	7717,79
Median, m^3	78,17
Standard deviation of measured roundwood loads , %	**9,71**
Standard error of measured roundwood loads, %	**0,97**
Species	Spruce/Pine
Diameter group of measured assortiment according to specification, mm	100-139, 140-179, 180-279, 28>
Assortiment lenght, m	3.0, 3.6, 4.2, 4.8
Roundwood- yards	112
Min. volume amount of assortiments in roundwood- yard, m^3	**200,74**
Max. volume amount of assortiments in roundwood- yard, m^3	**669,13**
Amount of measured roundwood loads by forvarder operators, m^3	34841
Amount of measured roundwood loads using harvester measured system, m^3	35195,37
Median, m^3	302,72
Standard deviation of measured roundwood loads , %	**8,06**
Standard error of measured roundwood loads, %	**0,76**

p.s. (*). *According to inquiry of the forvarder operators, the load volume values were acquired by operators expierence without using group measuring methods*

Figure 1: Wood felling area and the technological scheme of harvesting.

Table 6: The measuremen results of the forvarder loads and stacks

Variable	**The results of measured forvarder loads**							
Wood felling area	North Kurzeme forest region	East Vidzeme forest region	South Kurzeme forest region	Central Daugava forest region	South Latgale forest region	West Vidzeme forest region	CentralDougava forest region	Zemgale forest region
Forwarder brand								
	John Deere 1110E	**John Deere 1110E**	**John Deere 1110D**	**John Deere 1110E**	**Ponse Buffalo**	**Valmet 840.3**	**John Deere 1110D**	**Timberjack 810D**
Forvarder load space options. Cross sectional area, m^2	5.7	4.7	3.5	4.3	4	3.5	4	4.3
Characteristic of the measured forvarder load	Pine A rate sawlogs - 44pcs.	Veneer logs- 48pcs.	Veneer logs -51pcs.	Pine A rate sawlogs- 44pcs.	Veneer logs- 39gb.	Spruce sawlods- 20gb.	Pine A rate sawlogs- 25pcs.	Pine sawlogs- 67gb
	Diameter group: 260-330mm	Diameter group: 180-340mm	Diameter group: 180-300mm	Diameter group: 270-360mm	Diameter group: 210-400mm	**Length/diameter group/pcs.:** 3.6m/260-480mm/2; 4.8m/260-570mm/10; 5.1m/290-370mm/3; 5.4m/290-330mm/4	Diameter group: 250-460mm	**Length/diameter group/pcs.**: 3.6m/180-240mm/14; 4.2m/180-260/28; 4.8m160-260mm/13; 5.1m/200-240mm/12
	Nominal length: 3.0m	Nominal length: 3.2m	Nominal length: 2.3m	Nominal length: 3.0m	Nominal length: 2.3m	Nominal length: 3.6m; 4.8m; 5.1m; 5.4m	Nominal length: 3.1m	Nominal length: 3.6m; 4.2m; 4.8m; 5.1m
Number of forvarder operators / number of measurments	54/25	65/32	54/27	44/22	70/35	60/30	48/24	56/28
Amount of the load according to top and butt diameter measurements, m^3	9.71	8.1	5.77	7.08	5.68	10.62	8.45	15.46
Standard deviation, %	7.32	9.43	11.13	7.83	10.54	11.45	7.34	10.82
Standard error, %	3.27	4.21	4.97	3.5	4.71	5.11	3.38	4.84
Median, mm	315	265	245	295	285		295	
The results of measured roundwood stacks								
Assortiment in the stock	Pine A rate sawlogs	Veneer logs	Veneer logs	Pine A rate sawlogs	Veneer logs	Spruce sawlogs	Pine A rate sawlogs	Pine sawlogs
Nominal length, m	3.0m	3.2m	2.3m	3.0m	2.3m	3.6m; 4.8m; 5.1m; 5.4m	3.1m	3.6m; 4.2m; 4.8m; 5.1m
Number of forvarder operators / number of measurments	54/5	65/5	54/5	44/5	70/5	60/5	48/5	56/5
Amount of the load by measuring diameter in short intervals using harvester measurement systems, m^3	85.6	257.92	138.7	94.67	87.66	145.98	45.67	458.98
Standard deviation, %	8.74	5.73	8.4	6.67	7.27	4.43	9.58	5.55
Standard error, %	3.91	2.56	3.75	2.98	3.25	1.98	4.28	2.48

Table 7: The measurement results given by forvarder operators of forest exploitation company involved in the investigation for the year 2015.

Criteria	**Variable**
Species	Spruce/Pine
Diameter group of measured assortiment according to specification, mm	100-139, 140-179, 180-279, 28>
Assortiment lenght, m	3.0, 3.6, 4.2, 4.8
Roundwood- yards	73
Min. volume amount of assortiments in roundwood- yard, m^3	**9.78**
Max. volume amount of assortiments in roundwood- yard, m^3	**2072.96**
Amount of measured roundwood loads by forvarder operators, m^3	1801
Amount of measured roundwood loads using harvester measured system, m^3	17960.41
Average amount of assortiments in roundwood-yard, m^3	242.7
Median, m^3	121.58
Standard deviation of measured roundwood loads , %	**14.94**
Standard error of measured roundwood loads, %	**1.48**

Figure2: The identified stems and asortiments.

Table 8: The measurement results of the identified assortiments.

Number of stem	**Number of the assortiment in the stem**	**Diameter group, mm**	**Harvester measurement, m^3**	**The results of measurement made by measuring diameter in short intervals using harvester measurement system, m^3**	**Deviation, %**
1	1	180-280	0.309	0.302	2.27
	2	180-280	0.193	0.186	3.63
	3	180-280	0.208	0.203	2.4
	4	140-180	0.142	0.142	0
2	5	280<	0.321	0.25	1.25
	6	180-280	0.309	0.31	0.32
3	7	140-180	0.096	0.094	2.08
	8	100-140	0.058	0.053	8.62
4	9	180-280	0.231	0.225	2.6
	10	180-280	0.217	0.213	1.84
	11	180-280	0.14	0.139	0.71
	12	140-180	0.087	0.096	10.34
5	13	180-280	0.241	0.243	0.83
	14	180-280	0.201	0.214	6.47
	15	140-180	0.104	0.112	7.69
Total			**2.857**	**2.857**	

Table 9: The measurement results of the roundwood assortiments.

Species	Diameter group, mm	Nominal lenght, m	Average taper, cm/m	Amount of assortiment by measuring diameter in short intervals using electronic 3D systems, m^3	Number of logs	Amount, m^3
Spruce	100-120	4.8	0.8	0.066	1	0.066
	100-140	3	0.77	0.263	5	0.999
		3.6	1.1	0.267	5	
		4.8	0.82	0.469	6	
	140-180	3	0.92	0.382	6	3.245
		3.6	0.76	0.729	10	
		4.8	0.99	2.13	19	
	180-280	3	1.03	0.283	3	6.956
		3.6	0.95	1.304	8	
		4.2	0.87	0.482	3	
		4.8	0.99	4.887	22	
					88	**11.266**
Pine	140-180	3	1	0.864	12	4.223
		3.6	0.88	0.895	10	
		4.2	1.05	0.242	2	
		4.8	0.97	2.22	18	
	180-280	3	0.96	1.255	12	51.956
		3.6	0.76	8.728	46	
		4.2	0.77	0.482	17	
		4.8	0.72	37.775	150	
	280<	4.8	0.61	1.784	6	1.784
	280< deffective log*	4.8		0.435	1	0.435
					274	**58.398**

Figure 3: The developed methodology of determination of solid volume in forvarder loads according to formula $V=SL \times S \times (Kf_1+Kf_2) \times Ks$, where:

SL the average lenght of logs, 4.2 m
S forvarder cross sectional area, 4 m^2
Kf_1 fill of forvarder load space, 100%
Kf_2 fill over forvarder load space, 15%
Ks stacking coefficient, 0.62
V solid volume of the load, *11.97* m^3

Figure 5: The identified assortiments in the stack and the results of individual measurement, where: V_{stack} - actual volume of the assortiments, calculated by measuring diameter in short intervals using electronic 3D system

Figure 6: The deffective log, where the top diameter - 355mm, the nominal lenght - 4.8m, the volume - 0.435m^3

Figure 7: The calculation results of the round wood stack according to formula *V=L x B x H x k,* where:

L	stack lenght, 14.5m	B	width, 4.2m
H	height, 1.75m	k	stacking coefficient, 0.65
V	stack volume, 69.27m^3		

Table 10: Comparison of the measuring results.

Species	By measuring diameter in short intervals using harvester measuring systems			By measuring diameter in short intervals using electronic 3D systems		By measuring using group measuring method	Forwarder loads volumes calculated by forwarder operator	Truck loads volumes calculated by drivers
	Diameter group, mm	**Number of logs**	**Volume, m^3**	**Number of logs**	**Volume, m^3**	**Volume, m^3**	**Volume, m^3**	**Volume, m^3**
Pine	280<defective log			1	0.435			
	280<	36	12.98	6	1.784			
	180-280	163	37.39	226	51.956			
	140-180	69	7.54	41	4.223			
	100-140	6	0.54					
		274	**58.45**	**274**	**58.398**			
Spruce	280<	3	1.39					
	180-280	18	3.65	36	6.956			
	140-180	33	3.76	35	3.245			
	100-140	34	2.15	16	0.999			
	100-120			1	0.066			
		88	**10.95**	**88**	**11.266**			
Total		**362**	**69.4**	**362**	**69.664**	**69.27**	**66**	**68**

Table 11: Comparison of the measurement results**.**

Truck loads	**Characterization of the loads**			**Driver measurements, m^3**	**Amount of roundwood in the the load by measuring diameter in short intervals using electronic 3D systems pcs./m^3**	**Deviation, %**
	Species	**Diameter group, mm**	**Nominal lenght, m**			
	Spruce/Pine	100-280	3.0; 3.6; 4.2; 4.8	34	188/36.19	6.44
	Spruce/Pine	100-280	3.0; 3.6; 4.2; 4.8	34	174/32.903	3.22

4. Conslusion

In 92.46% cases the measurement precision of truck load measurements correspond to the requirements of Standard LVS 82:2003 „Apaļo kokmateriālu uzmērīšana", where the permitted volume deviation from the actual volume for roundwood, measured according to the group measurement method, is 10%. Standard deviation reaches 7.62% if the average volume of truck loads are approx.32 m^3.

Standard deviations reaches 20.66 % if the forvarder loads are measured by using expert method and the volume of delivered forvarder loads in roundwood-yards are 1.1-60.08m^3, standard deviations reaches 9.71 % if the volume of delivered forvarder loads in roundwood-yards are 61.35-100.16m^3, standard deviations reaches 8.06% if the volume of delivered forvarder loads in roundwood-yards are 200.74-669.13 m^3.

Standard deviation reaches 11.45% if the forvarder loads (5.68-15.46 m^3) are measured by using developed group measuring method based on methodology: *"SDC's instructions for timber measurement of roundwood stacks"* and technical information of forvarder load space options (cross section area m^2).

Standard deviations reaches 9.58 % if the roundwood stacks are measured by using the group measurement method based on methodology *"SDC's instructions for timber measurement of roundwood stacks"*

5. Proposals

For achieving the operative information useful for logistics purposes regarding to volume values in the roundwood stacks, the measurement should be based on stacks measurement using the group measurement method based on methodology *"SDC's instructions for timber measurement of roundwood stacks"* and on truck loads measuring data.

6. Remarks

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Assessing the possibility of incorporating Japanese small-scale logging systems into forest operations in Kenya

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Abstract: Kenyan forestry uses manual logging where chain saws are used in felling and processing, and then forwarding by human labor. The aim of this research was to analyze the operational efficiency of Japanese small-scale logging systems, and determine whether it is feasible for them to be used Kenyan forestry. Results showed that resultant cost (14.8 USD/m^3) for manual logging is much lower than that of the mini-forwarder (36.6 USD/m^3). A deeper analysis showed that an increase in Kenyan labor cost sharply increases the resultant costs of manual logging by a higher magnitude as opposed to mechanized logging. This means that labor costs are the major determinants for introduction of mechanized logging in Kenya. We conclude that, in the current economic situation, manual logging is still the most efficient method in Kenya, but as the economy grows, it might be favorable for Kenya to adopt mechanized small-scale logging.

Keywords: small-scale logging systems, operational efficiency, forest harvesting methods, Kenyan forestry, Japanese forestry

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1. Introduction

Forest technologies are highly advancing, especially those relating to logging; i.e. tree harvesting, processing and transportation. These technologies are well applied in countries such as Japan where forest mechanization is wide spread. It is also a fact that mechanized logging has more benefits, ranging from higher productivity, improved worker safety and sustainable forestry practices, compared to manual logging. Low-mechanized systems might be outdated in industrialized countries but they are highly applicable in developing countries that have low labor costs (Silversides and Sundberg, 2010a), such low-mechanized systems include the use a winch and sulky in tractors to enable small-scale logging operations (Spinelli and Magagnotti, 2012). Nakahata *et al*. (2014) further support this idea that small-scale mechanization is possible in developing countries because of the low-level investment compared to larger mechanized systems. Notably, small-scale logging operators highly participate in procurement processes of selling logging residues in Japan, meaning they are important part in forestry logging operations (Suzuki *et al.*, 2009). According to Samset (1985), easier communication between various regions in the world has made the way of living more alike, thus calling for innovations that can be applied universally in any part of the world. Although this might be the case, Kenya is yet to adopt such innovations (i.e. logging technologies in this case). Its common method of harvesting is labor intensive where chain saws are used in felling and processing of trees followed by forwarding by human labor. Although this method is less costly, it is quite time consuming and its productivity is quite low, therefore need to address this issue. Although the Kenyan current economic status may not help much in large scale mechanizing of its forests, small-scale systems might be applicable. Therefore, the aim of this research was to assess the operational efficiency of small-scale logging systems, and determine how suitable they can be for Kenyan forestry.

2. Materials and methods

2.1. Materials

The following steps were used in the study: 1) visiting small-scale logging sites that use mini-forwarder, 2) calculation of average cycle times of various work elements, 3) developing equations to calculate productivities and costs of the logging system, and 4) analyzing how the logging system compares with manual logging to come up with better recommendations for Kenyan forestry. Data collection was done at two forest sites: 1) Mr. Okamoto's forest on October 2015, and 2) Kochi Prefectural Forest Technology Centre on May 2016. Both sites are located at the Kami City, Kochi Prefectural, Japan. Site 1 is a Sugi (*Cryptomeria japonica*) and Hinoki (*Chamaecyparis obtusa*) plantation owned by a private individual and is utilized for commercial purposes, while site 2 is under the Kochi Prefectural government and is planted with various tree species majorly utilized for research purposes.

The two sites used different mini-forwarders, and for purposes of this research, we decided to work with one (Yamabiko BY 1202, Dump) that we thought was closer to the two in relation the maker and the specifications. The machine specifications were obtained from the manufacturer's website, Canycom (2016). A 9.2 kW, Kubota Z482 type of engine, which uses Vertical 4 Cycle liquid cooled diesel, powers the machine. It has 4 forward and 2 reverse gears, with the fastest gear having a speed of 6.56 km/h and lowest gear of 1.5 km/h. The winch has various speeds in its front and back. A wireless radio system (called CANYCOM R/C winch) controls movement of the winch. This means that even one person can do the logging process. The wireless system has the ability to prevent collapsing of the loading process and absorb shock at the loading deck. A hydraulic dump system is installed in the loading deck to shorten the unloading time. The machine has a rotating chair where the operator sits during movement from place to another. Its weight is 870 kg when empty, and 1200 kg at maximum payload capacity. Figure 1 shows a virtual sketch of the cable logging system as set in the actual site:

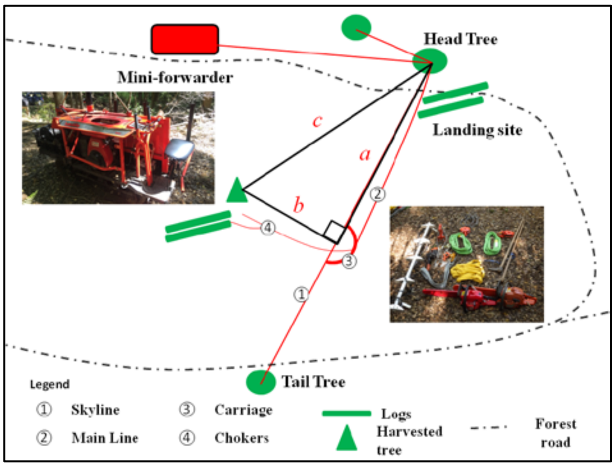

Figure 1: Virtual Site of the Mini-forwarder Logging System
Note: a=main logging distance, b=lateral logging distance, c=manual logging distance (more explanation in the Data Collection and Statistical Analysis section).

2.2. Data Collection and Statistical Analysis

The major method of data collection was time study (using a video recorder) to determine average cycle times of various work elements in a main logging process. The major work elements were 1) rigging up, 2) felling and processing, 3) extraction process, 4) rigging down, and 5) forwarding. A video recorder was used during the logging process, and the videos were later analyzed to calculate the average speeds of the various work elements. Data for 17 cycles (1 log/cycle= 17 logs) and 3 cycles (1.3logs/cycle=4 logs) was collected from site 1 and 2, respectively. We were not able to record the rigging up time, and therefore used a formula by Umeda *et al.* (1982), who proposed that rigging down time is 35-40% of rigging up time.

The standard deviation, SD, of the volume of the 17 logs was calculated and then it was used to come up with three different volume ranges; i.e. 1) average volume+ standard deviation, *Vhi*, 2) average volume, *Vav*, and 3) average volume – (minus) standard deviation, *Vlo*. The main line and lateral movement times were related to distance, using regression analysis. Similarly, the forwarding times were related to distance using regression analysis. For uniformity purposes, we set similar logging and forwarding distances for both mini-forwarder and manual logging. As shown in figure 1, we assumed that the intersection of main line logging distance, *a*, and lateral logging distance, *b*, form a right-angled triangle, and therefore used Pythagoras' theorem to estimate the manual logging distance, *c*.

$$c = \sqrt{a^2 + b^2} \quad (1)$$

Average cycle time, T (s/cycle), and average volume, V (m^3/cycle), were used to calculate the productivity, P (m^3/h) of a particular logging operation:

$$P = \frac{3{,}600 \; x \; V}{T} \quad (2)$$

Productivity for felling and bucking were taken as constants for both mini-forwarder and manual logging, and taken from Nakahata *et al.* (2014). Average productivities were then calculated to determine the overall productivity of a full logging cycle.

Productivity for manual logging was estimated from Umeda *et al.* (1982). In estimating productivity per hour, we used 6 hours as the standard productive time per day. Umeda *et al.* (1982) classified manual logging into three types in relation to terrain; i.e. easy for steep terrain, medium for average terrain, and difficult for flat terrain (Figure 2). Most plantation areas and suitable areas for plantation farming in Kenya are located on relatively flat terrain; we therefore chose to work with the difficult level of manual logging.

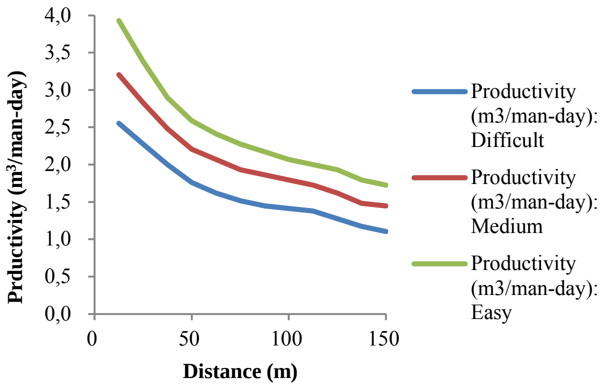

Figure 2: Manual Logging Productivity.
Note: Source: Umeda et al. (1982)

Since there were two currencies involved (i.e. Kenyan Shilling, KES and Japanese Yen, JPY), there needed to be uniformity for comparison purposes. We used World Bank (2016a) statistics in addition to considering current fluctuations in exchange rates, to approximate the amount of each currency in US dollars, USD. In this research, 1 USD is equivalent to 110 JPY and 100 KES. The machinery hourly costs (USD/crew hour) were obtained from various sources that used standard methods of calculations.

Table 1: Operational costs obtained from various sources.

Parameter		Cost (USD/crew hour)	Source
Chain saw		3.15	Setiawan *et al.* (2013)
Mini-forwarder (*adjusted)		18.73 (20.6)	Canycom (2016) & Suzuki *et al.* (2015)
	High, *Lhi*	0.948	Setiawan *et al.* (2013)
Labor	Average, *Lav*	0.664	Ministry of Labour (2015)
	Low, *Llo*	0.381	Ministry of Labour (2015)

Note: *An adjusting factor of 10% was applied to the mini-forwarder hourly cost to cater for the costs of a cable set that is normally bought separately.

They (machinery hourly cots) were assumed constant for both Kenya and Japan. This is because Kenya gives tariffs on Agricultural imports, meaning if the products were to be imported from Japan, the cost will be relatively at the same level. There is a huge disparity in wages in Kenya, therefore quite difficult to come up with a common figure for hourly labour cost. We therefore classified hourly labor costs (USD/man-hour) into three ranges; i.e. 1) High, *Lhi*, 2) Average, *Lav*, and 3) Low, *Llo* (Table 1).

Assuming the total hourly cost (USD/crew-hour) of forest operations (e.g. felling and bucking, logging, and forwarding) is denoted by *x*, and its productivity (m^3/crew hour) as *y*, then the resultant operational cost, *z*, (USD/m^3) will be estimated by the following equation (Setiawan *et al.*, 2013):

$$z = \frac{x}{y} \tag{3}$$

If plotted on an *x-y-z* coordinate system, *z* is a curved service that decreases uniformly with *y* and increases uniformly with *x*. To determine efficiency of the systems (both mini-forwarder and manual), we set three ranges of selling prices (USD/m^3) of logs in Kenya; i.e. 1) high, 2) average, and 3) low.

3. Results and discussion

Total manual logging distances in Kenya are quite varied depending on the location of the forest from road. An approximation of 100m was used in this research; main line, lateral and forwarding distances were set at 20m, 5m and 75m, respectively. Equation (1) was used to calculate the manual logging distance, and equation (2) was used to calculate productivity of various logging operations. Felling and bucking productivity was estimated at 2.12 m^3/crew hour from Nakahata *et al.* (2014). Productivity for manual logging was estimated from figure 1, as proposed by Umeda *et al.* (1982). The average productivities (m^3/crew hour) for both mini-forwarder and manual logging are shown in table 2.

Table 2: Average productivities for both systems at 100m logging distance.

Type of logging		Average productivity (m^3/crew hour)
Mini-forwarder	High Volume, *Vhi*	0.6416
	Average Volume, *Vav*	0.5163
	Low Volume, *Vlo*	0.3253
Manual		0.1410

Productivity at average volume, *Vav*, was 0.5163 m^3/crew hour, and this was taken as the standard productivity for the mini-forwarder. The average productivity for manual logging was 0.1410 m^3/crew hour, which is about 70% lower than the mini-forwarder productivity.

Table 3 shows the resultant costs (USD/m^3) of both systems, calculated using equation (3). The range of timber prices in Kenya was set at 1) high of 46 USD/m^3, 2) average of 33 USD/m^3, and 3) low of 20 USD/m^3). At these price ranges, resultant costs in mini-forwarder logging were very high. The resultant cost at average volume, *Vav*, and average labour cost, *Lav*, was 36.568 USD/m^3. This figure is much higher than even the average log price (33 USD/m^3).

Conversely, the resultant cost for manual logging at average labor cost, *Lav*, was 14.829 USD/m^3 and much below the lowest log price of 20 USD/m^3. The explanation for this low resultant cost of manual logging is the low labour costs in Kenya. For instance, if the labour costs were increased by a certain margin, the resultant costs for manual logging were considerably high. In adjusting the average Kenyan labor cost, *Lav*, from 0.694 USD/man-hour to 24.773 USD/man-hour (current Japanese labour cost), the resultant cost of manual logging jumps from 14.829 USD/crew hour to 185.597 USD/crew hour. If the same adjustments are applied at average volume (*Vav*) of the mini-forwarder system, the resultant cost is 97.954 USD/ crew hour. This shows that an increase in labor costs sharply increases the total hourly costs for both systems, but the impact magnitude is more in manual logging compared to mini-forwarder systems (figure 3).

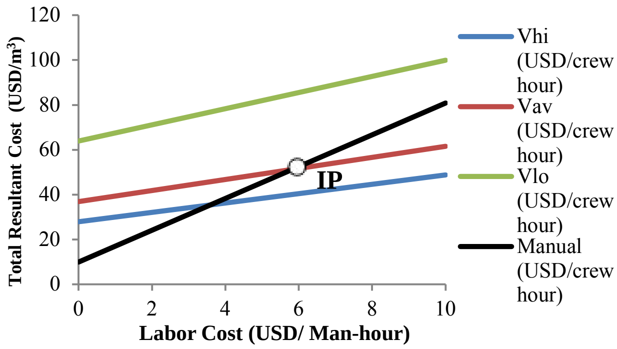

Figure 3: Relationship between labor cost and total resultant costs for both manual and mini-forwarder logging.
Note: The resultant cost for manual logging (black line) is lower than that of mini-forwarder (red line), but after the intersection point, IP, the resultant cost of manual logging becomes higher than that of the mini-forwarder.

We used the "Solver" function in Microsoft Excel to determine the labor cost value at which the resultant cost for both systems would be equal. Results showed that resultant cost of both manual logging and mini-forwarder were equal (51.3 USD/m^3) at a labor cost of 5.828 USD/man-hour. Figure 4 shows the three dimensional *x-y-z* coordinate system, with the current resultant costs of manual logging and mini-forwarder denoted by the red and blue dots, respectively.

Table 3: Resultant hourly costs for both mini-forwarder and manual logging.

Logging type	Volume (m^3)	Labor Cost (USD/man-hour) High, *Lhi*	Average, *Lav*	Low, *Llo*
Mini-forwarder	High, *Vhi*	27.727	27.327	26.843
	Average, *Vav*	37.066	36.568	35.967
	Low, *Vlo*	65.154	64.364	63.409
Manual		16.652	14.829	12.629

An introduction of the 5.828 USD/man-hour labour cost increases the hourly costs, thus a shift to points A and B for manual and mini-forwarder logging, respectively (Figure 4). This implies that a mini-forwarder can be comfortably introduced in Kenya at such labour cost (5.828 USD/man-hour).

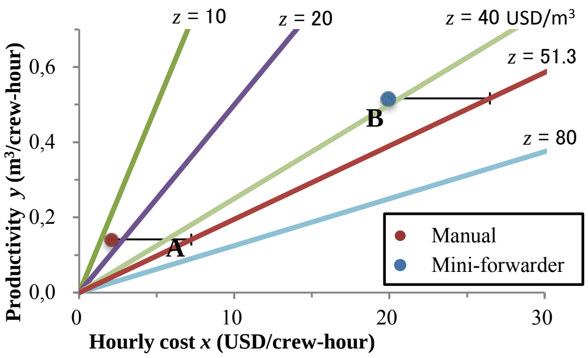

Figure 4: Relationship between Productivity (y), hourly cost (x), and resultant cost (z).
Note: z (USD/m^3) = x (USD/crew-hour) / y (m^3/crew-hour). In case of labour cost = 5.82 USD/man-hour, the resultant cost of both manual system and mini-forwarder system coincide with z = 51.3 USD/m^3.

With the current economic trends and projections in Kenya, it may take a sometime it to start implementing such forest mechanization programs. Research shows that Kenya is classified as one of the top 10 economies in Africa and among the top 3 fastest economies in the world (Gundan, 2014; Robinson, 2015). The country's economy grew by 5.3 % in 2014, and is "projected to rise to 5.9% in 2016 and 6.1 % in 2017" (KNBS, 2015; World Bank 2016b). Notably, it is expected that by the year 2030, Kenya would have sufficiently turned into a middle-income country (Vision 2030, n.d.). Improved economy means better wages, and thus high labor costs that will directly raise the hourly costs in manual logging. As figure 3 shows, the resultant cost of manual logging rapidly increases after the intersection point, IP, as opposed to the mini-forwarder. This means that manual logging will become more expensive than mini-forwarder logging, thus prompting for adoption of mini-forwarders in Kenya.

Introduction of the mini-forwarder in Kenya will lead to an increase in logging productivity among other benefits. The mini-forwarder productivity is higher (0.5163 m^3/crew hour) compared to manual logging (0.1410 m^3/crew hour) when the two have an equal resultant cost of 51.3 USD/m^3. Other benefits include promotion of sustainable forestry practices, and enhance safety and social welfare of the workers (Silversides and Sundberg, 2010b). It will also mean establishment of infrastructure such as forest roads that will directly benefit the people especially those near forest areas.

However, this is with an assumption that the log values will not decrease, and that wood imports will not negatively affect Kenyan forestry in the future. For instance, availability of wood imports reduced the demand of domestic wood, and this might be the cause of dwindling log prices in Japan (Forestry Agency, 2014; Forestry Agency, 2016). This means that import of forest products negatively affects forestry, including logging operations, in the particular country. Therefore, efforts should be put in place to ensure that there is sufficient market for domestic forest products and maintenance of their value in Kenya to ensure sustainability of mechanized logging in the future.

4. Conclusions and Recommendations

At the current situation, manual logging is still the most feasible logging system in Kenya. Notably, introduction of a mini-forwarder will help boost the efficiency of logging in Kenyan forests because it has a higher productivity compared to manual logging. We recommend that there should be studies to propose possible adjustments that can be made to such logging systems before they are introduced into Kenyan forestry.

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*: The title is a tentative translation from original Japanese title by the authors.

Airborne Laser Scanning and Gamma Ray Data in Wood Procurement Planning of Peatlands

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Abstract: Wood procurement organizations have GIS-data of soft forest soils. The aim of the study was to investigate how efficiently GIS can be used to select stands for summertime thinnings. The correlation analysis shows the low relationship between GIS and rut forming of harvesting, but reliable spatial prediction of rut forming remains challenging without field measurements. The changes in Airborne Laser Scanning (ALS) data resulted in a low change in the rut forming with a high variation inside the stand. Gamma-ray data was not accurate enough to predict rut forming. On the basis of the results, the field measurements of peat layer thickness and the hauling distance as well as the depth to the groundwater table are called for the planning of wood harvesting operations on peatlands. The later factor is the combination of ground height model (2x2 m) and ground water table. Besides, the harvesting machinery with a low nominal ground pressure (NGP) (<30 kPa) are required for thinnings during summertime.

Keywords: airborne laser scanning (ALS); rut forming; soft soils; wood harvesting

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1. Introduction

1.1. Harvesting machinery for peatlands

From 2000 to 2009, there were approximately 2,500 forwarders in the wintertime harvesting operations and in the summertime harvesting around 1,500 ones (Statistical Yearbook of Finland, 2011; The Statistical Yearbook of Forestry, 2015). Due to the seasonality in wood harvesting, a machinery utilization rate, therefore, falls (Kärhä & Poikela, 2010; Palander et al. 2012). Heikkilä (2007) has stated that increasing of the volume of harvesting machine fleet is hardly profitable, because the high-priced wood harvesting machine investments require a high level of utilization rate. On the other hand, Högnäs (1997) has found that the special harvesting machines for peatlands during summertime have already been invented, but the main problem is the profitability of harvesting operations. On the basis of the investigation of the available harvesting machine types and models, there is a significant difference between the nominal ground pressures (NGP) of machinery and the rut formation caused by machinery (Sirén et al. 1987; Airavaara et al. 2008; Lamminen 2008; Lindeman 2010; Ala-Ilomäki et al. 2011; Palander et al. 2012; Uusitalo, J. & Ala-Ilomäki 2012; Uusitalo et al. 2015). Generally speaking, thinning harvesters and harvesters based on tracked excavators are considered as suitable as the peatland harvesting machines in summertime (Ojasalo 2007). In the same study, it was recommended for forest haulage light forwarders equipped with at least eight wheels and as wide tracks as possible.

Tracked machines are suitable for peatlands better than wheeled harvesting machines, because ground pressure in these machines divides more evenly into ground than with the wheeled machine units. Bergroth et al. (2007) have found the harvesters based on tracked excavator also fit well summertime cutting operations due to the good carrying capacity of their track systems. Airavaara et al. (2008) has emphasized that the right shaped tracks improve significantly the carrying capacity of forwarder. In the study by Sirén et al. (1987) the 8-wheeled forwarders came off mainly better than 6-wheeled ones, even though the best performed front end to a streamlined 6-wheeled forwarder. In Lindeman's study (2010) the 6-wheeled forwarder caused about 30% of the deeper ruts than the 8- and 10-wheeled ones.

Airavaara et al. (2008) have pointed out that the load size should be determined by the impact on the load to the axis masses and the nominal ground pressures (NGPs). Ala-Ilomäki et al. (2005) have suggested the slightly rear-loaded weight distribution is better than the front-loaded one. Palander et al. (2012) have stated that the operator is able to influence the load balance of 6-wheeled forwarder by rear-butt length loading in such a way that the rut formation reduces. According to the same study, by using a forwarder loader operator has the potential to impact on the weight distribution of the wheels and therefore rut formation.

1.2. Planning of peatland harvesting operations

The digitization of the planning information of wood harvesting has made it possible the utilization of new information sources in planning of summertime harvesting operations on peatlands. However, currently there are no comprehensive studies about are they useful and can they develop the current classification of carrying capacity and planning systems at operational or tactical level. A general soil map in Finland (1:20,000) consists of a lot useful information for the planning (Saarelainen 1998), but more accurate basic soil map (1:10,000) is better for planning a smaller harvesting objects. By means of laser scanning it has been determined that the amount of the internal variation of height in the stand, as well as the spatial variation of tree volume and basal area in the stand have an effect on rut formation (Haavisto et al. 2011; Uusitalo et al. 2012). Correspondingly, Salmi (2011) has underlined that it is hard to find exposed spots for rut formation on harvesting site by means of harvesting condition factors produced by the height model (25×25 m). Ala-Ilomäki (2005) has emphasized that the gamma radiation maps are too broad-minded for the evaluation of rut formation. Kokkila (2011) has, nonetheless, proposed that it would be worthwhile to test gamma radiation data and the basic soil maps for illustration of spatial variability on harvesting site. Besides in the same study, it was considered more accurate height model (2×2 m) for an experiment worthy of wood harvesting planning tool.

Table 1: The carrying capacity rates for (the 8-wheeled) forwarders with 8-tonne load (Airavaara et al. 2008). Maximum nominal ground pressure: Class 1 ≤ 50 kPa, Class 2 ≤ 40 kPa, Class 3 ≤ 30 kPa.

Class 1	Class 2	Class 3
• 12 t: in front the chains and in rear ≥700 mm wide tracks. • 17 t: in front and in rear ≥700 mm wide tracks.	• 12 t: in front the chains and in rear ≥750 mm wide tracks. • 17 t: in front and in rear ≥870 mm wide tracks.	• 12 t: in front ≥700 mm wide tracks and in rear ≥700 mm wide tracks with extra axle. • 17 t: in front ≥820 mm wide tracks and in rear ≥820 mm wide tracks with extra axle.

Table 2: The carrying capacity classification for harvesting sites and wood harvesting machinery on peatland thinnings (Högnäs et al. 2009). Classes 1 to 3 represent the required carrying capacity of harvesting machine in specific harvesting conditions.

Initial tree volume, m^3 ha^{-1}	Estimated load on strip road network based on the storage, shape and size of harvesting site *		
	Low	**Moderate**	**High**
	Carrying capacity class of forwarder		
>170	1	2	3
170–120	2	3	WINTER
<120	3	WINTER	WINTER

Patches for the classes:
Depth to the groundwater table:
If the groundwater table is less than 25 cm depth in the swamp's surface, using one class smaller carrying capacity.
• If the harvesting operation has been preceded by a dry season which has lasted for more than 4 weeks, the carrying capacity will increase by one grade.
The thickness of peat layer:
• If the thickness of peat layer is less than 75 cm, the carrying capacity will increase by one grade.
*) Indicative average forest haulage distance on peatland: low <100 m, moderate 100–200 m, and high > 200 m.
* *) It is assumed that logging residues are cut to strip roads and small-sized and critical points on strip road network shall be reinforced by logging residues or in any other way

The classification for forwarders with different level of nominal ground pressures is presented in Table 1. For harvesting planning of peatlands the carrying capacity classification for harvesting sites and wood harvesting machinery is displayed in Table 2 (Högnäs et al. 2009). From the same study material the models for estimation of rut formation process has been drawn up (Lindeman 2010). Using Table 2 the suitable forwarder is suggested specifically for peatland thinning stands in summertime wood harvesting operations. Tree volume per hectare in prior harvesting operation, harvesting machinery, depth to the groundwater table, four weeks of rainfall, peat layer depth, and strip road network on harvesting site is paid attention on in the classification (Table 1).

1.3. Aims of study

The purpose of this study was to examine if wood harvesting could be planned by GIS. When planning wood harvesting operations for peatland thinnings, it is crucial that we know is the harvesting site suited for summertime or wintertime harvesting. Therefore, the study examined what factors contributed to the rut formation and moreover could factors' relationships be modelled in summertime harvesting on peatland thinning sites. In addition to GIS data, the data of harvesting conditions and harvesting results were collected from harvesting sites. By means of these factors one explanatory regression model of rut formation was evaluated and tested for selecting stands either for summertime or wintertime harvesting.

2. Material and Methods

2.1. Data of geographical information

There is basic soil map (1:20,000) in Finland. Moreover, the whole country is covered by the general soil map in the scale of 1:200,000. The numerical soil type patterns (≥6.25 ha) have been produced for this map, and related property and the quality of the data largely by interpreting, editing and making use of existing geophysical data sets of geographical information system (GIS) and image processing techniques. Amendments have also been made by mapping in the field. On the map it is displayed both surface soil and ground layers. Topographic database has been used in bordering of areas, and the geophysical data for determination of the thickness of the peat layer.

In Finland, magnetic, electronic and radio-metric measurements have been produced by airborne-geophysical mapping. These soil mapping flights was systematically carried out since 1972 in which flight height has been between 30–50 m and the distance of flight lines 200 m. All mineral soils are, to varying degrees, radioactive. That is why the radioactive elements and the isotopes of mineral soil emit short-wave electromagnetic radiance. These gamma radiation materials are interpolated on the size of the 50×50 m raster (Hyvönen et al. 2005). The radiation of potassium and other components of the material can be used to take advantage of the thickness of peat layer and identification of wetland areas. The water content of peat is, on average, 90%. That is why from the peat bogs of the natural humidity the gamma rays are impossible to detect if the peat layer thickness is more than 0.6 m (Virtanen 1990; Virtanen & Vanne 2008).

In the laser scanning, the laser pulses will be sent towards the ground surface. For instance, the pulses may hit on ground, undergrowth, tops of standing trees, or the branches of trees. Back to the reflected pulse it can be specify a location for the item receiving the pulse hits and the height of the scanner based on the location information and the laser pulse time traveled. Scanner measures also the strength of the return pulse. In this case, the set of all the items in the specified items in the box, which represents the laser pulse is a hit and did not reflect the return of pulses. The coordinate of individual laser pulses can be converted to a terrestrial coordinate systems for the height finding. Such as a point cloud obtained from processing reflections and/or from echoes, it is possible to form the continuous surface models (Hyyppä & Inkinen 1999). From differences between the models it is possible to calculate heights of stands for the height model. The values of height model are usually mild underestimates, because the laser pulse may not always hit the top of the tree (Hyyppä et al. 2001).

The following height models were used in this study: the model of ground surface (2×2 m), the height model of trees (2×2 m), as well as a descriptive model produced by laser pulse (6×6 m) reflecting the vegetation which is more than two meters height. The models were produced by the laser scanning density of a minimum of 0.5 m^{-2}. The accuracy of the height information was approximately 30 cm. This data included among others the number of trees, the density of trees in the stand, the basal area of whole stand and also by tree species. Besides in the study, it was used a larger height model (25×25 m). This model was calculated from the topographic height curves. Its average accuracy was 2 m.

General soil map (1:200,000) was available in all study plots (Table 3). For the determination of the location of the plots was created a systematic point network (50×50 m) by a "Create a fishnet" tool of the ArcGis program. More than a ten hectares of harvesting site the network density was reduced to 100 meters. Points were established on the plots so that the plot was to be measured to the nearest strip road. Plots were established on the 240 ones (total 3.5 ha). Also the height raster (25×25 m) would have been available in all study plots, but it was used in the calculation of the depth of the groundwater table and in the calculation of the variation of the internal height of the harvesting site just there, where the specific height material (2×2 m) was not available.

Table 3: The number of the study plots (N) of geographical information.

Data source	N
Raster of the length of the stand	96
Density raster	85
Potassium raster	179
General soil map (1:200,000)	240
Height raster (2×2 m)	96
Height raster (25×25 m)	144

2.2. Harvesting conditions in the study stands

The study stands located in the regions of South-Karelia, North-Karelia, South-Savonia, North-Savonia and Northern Ostrobothnia in Finland. The tree volume per hectare, harvesting method and removal per hectare were collected from the stands. Tree volume in prior harvesting operation was an average of 150 m^3 ha^{-1} (variation range: 19–265 m^3 ha^{-1}). The average forest haulage distances and the distances between ditches was established on the map.

The depth of the groundwater table was measured by digging a pit close to the plot in each study stand. The digging place was chosen from deepest place of the stand. The thickness of peat layer was measured by peat sampler in the middle of each plot. The thickness of the peat frequency distribution was almost normally distributed. The model, the number of wheels and tracks used in harvesting machinery were examined. Three different harvester models and six different forwarder model were used in the study stands (Table 4).

Table 4: The model and the number of wheels used in harvesting machinery of the study, as wells as the number of plots in the study. Type: H = Harvester; F = Forwarder.

Machine unit	Type	Wheel	Plot
John Deere 1070D	H	6	77
Ponsse Beaver	H	6	14
Ponsse HS10	H	8	124
John Deere 1010D	F	8	14
John Deere 810D	F	8	57
Ponsse Elk	F	8	6
Ponsse S10	F	8	100
Ponsse Wisent	F	8	14
Ponsse Gazelle	HF	8	62
Valmet 840 + pulling trailer	F	12	24

2.3. Harvesting result data from the study stands

The harvesting result data were collected from the stands where wood harvesting operations had carried out during the summers of 2011 and 2012. From the middle of the plot six meters of strip road in both directions was measured. The length of rut formation was determined from this trip (i.e. 12 m). The percentage of rut formation was calculated by means of the length of rut formation according to the guidelines of harvesting result in thinnings (2003) drawn up by Metsäteho. The rut formation was interpreted as more than 10 cm deep and more than 50 cm long ruts if it was on one of tracks. Besides, the deepest rut point (i.e. maximum rut depth) on the tracks in the study stand was measured, as well as the average rut depth in the stand was estimated.

The percentage of rut formation of total strip road length was 12.2% in the study. Respectively, the maximum rut depth was, on the average, 10.8 cm and the average rut depth was 3.8 cm. The highest percentage of formatted rut in the study stand was 56.3% (std: 23.3%). Correspondingly, the biggest average maximum rut depth was 11.2 cm and the highest average rut depth was 5.2 cm in the study stands.

The width of strip road was measured in each study plots. A single observation of the width of strip road was measured by determining the distance to the nearest tree of strip road edge on both sides of the central line, and by summing up these distances together. Furthermore, the length of stumps was determined from the tracks of study plots. If the length of one stump crossed from a root neck 10 cm, it was interpreted as the length for a long stump. Otherwise, the length of the stumps was interpreted as normal. If the plot on the way there were no stumps, it was interpreted as resulting, not stumps.

2.4. Methods

The coordinates of each study plot were stored in the terrain using the Trimble GeoExplorer 2005 GPS device. The locations of the plots were stored in ArcMap 10 programme. The location of the values of the spatial data sets corresponding to the locations of the study plots were picked up by the "extract values to point to the" function to the study plot database, from which they could be exported to Microsoft Office Excel. The harvesting results collected from study stands was saved in the Microsoft Office Excel. Statistical analyses were performed using a SPSS Statistics 19.0 programme.

The factors that predicted the percentage of rut formation and the maximum depth of the rut were not normally distributed (Kolmogorov-Smirnov test). Therefore the nonparametric tests of Kruskal-Wallis and Mann-Whitney were applied to test the effect of these factors on rut forming. Before the tests, Spearman's rho was used to measure the relationship between two items, for example, rut forming and an indicator (i.e., independent variables that affected rut forming in ground carrying capacity classes of the harvesting machinery used). The goal was to see if a change in the independent item will result in a change in the dependent item (the rut formation percentage, the max-depth of the rut). This information increases our understanding about the indicator's predictive abilities. A regression was modeled for the maximum rut depth formed by forwarder in gound carrying capacity two.

3. Results

Both variables of rut formation (i.e. rut formation percentage and maximum rut depth) correlated negatively with the depth to the groundwater table, the height variation (2×2 m) of stand, as well as the density of laser pulse reflecting from the vegetation. Moreover, there was a negative correlation between the values of potassium and rut formation percentage (Table 5). Both rut formation variables correlated positively with the thickness of peat layer and the value describing the tree height in the stand.

The explanation degree of maximum rut depth regression model was 0.514 (Table 6). On the basis of the standardized regression coefficients, the type of harvesting system (i.e. harwarder vs. two-machine harvesting systems with harvester and forwarder) explained the best rut formation. The type of harvesting system and the thickness of peat layer were statistically highly significant. Forest haulage distance and the depth to the groundwater table were statistically almost significant explanatory variables. When the thickness of peat layer and the forwarding distance grew, the maximum rut depth increased. In addition to this, when the depth to the groundwater table lowered, the maximum rut depth reduced.

According to the analysis of variance, a model agreed to statistically very significant. The frequency distribution of standardized residuals formed a little to the right of the entire panoply of distribution (Figure 1). According to the Kolmogorov-Smirnov test, the residuals were almost normally distributed. The standard deviation of the residuals of the model was around zero on both sides when the maximum rut depth was less than 15 cm (Figure 2). With this larger depth of ruts, the model gives the higher values than realistic values for the maximum rut depth. In this respect, it can be observed in the graph of residuals.

Table 5: The correlations between the rut formation and independent variables. Rmax = maximum rut depth, R% = rut formation percentage.

	Thickness of peat layer		**Height raster (2×2 m)**		**Depth to groundwater table**		**Density of tree volume**		**Height of stand**		**Forest haulage distance**		**Potassium**	
	Rmax	R%	Rmax	R%	Rmax	R%	Rmax	R%	Rmax	R%	Rmax	R%	Rmax	R%
C	.32 (***	.40 (***	-.34 (**	-.28 (**	-.44 (***	-.33 (***	-.26 (*	-.29 (**	.32 (**	.29 (**	.30 (**	.28 (**	-.20 -	-.29 (*
N	115	115	96	96	113	113	85	85	96	96	115	115	54	54

Table 6: An explanatory model for the maximum rut depth of strip road network.

$y = a + b_1k_1 + b_2x_1 + b_3x_2 + b_4x_3$

where

y = maximum rut depth, cm

k_1 = dummy variable: 1 = harwarder, 2 = two-machine system (i.e. harvester & forwarder)

x_1 = thickness of peat layer, cm

x_2 = forest haulage distance, m

x_3 = depth to the groundwater table, cm

a = constant

b_1, b_2, b_3, b_4 = coefficients of the variables

Variable	**Parameter estimate**	**Standard error**	**Standardized regression coefficient**	**t value**	**p value**
a	-10.047	3.252		-3.089	.003
b_1	9.250	1.690	0.472	5.474	.000
b_2	0.121	0.029	0.306	4.212	.000
b_3	0.031	0.015	0.156	2.046	.044
b_4	-3.040	1.553	-0.166	-1.958	.053
N	**R**	**R^2**	**Adjusted R^2**	**Mean error of estimate**	**Kolmogorov-Smirnov**
95	.731	.535	.514	6.863	.049
	Sum of squares	**Degree of freedom**	**Mean square**	**F value**	**p value**
Regression	4866.911	4	1216.728	25.836	.000
Residual	4238.520	90	47.095		
Total	9105.432	94			

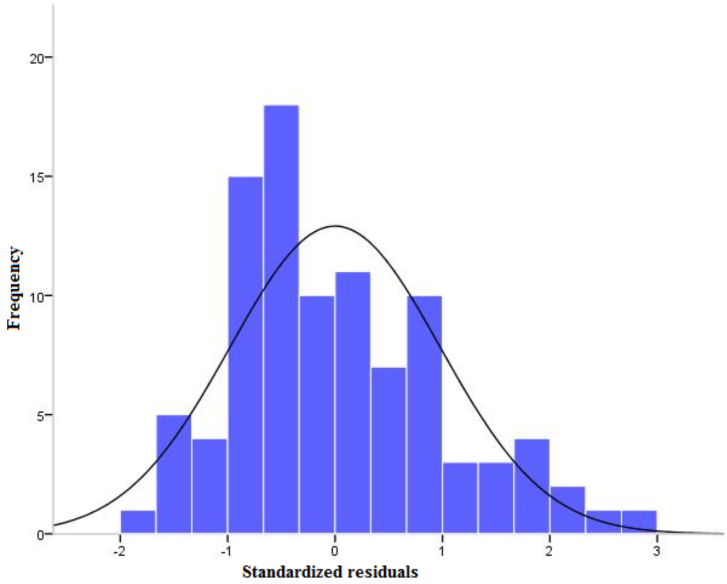

Figure 1: The distribution of the standardized residuals of the regression model.

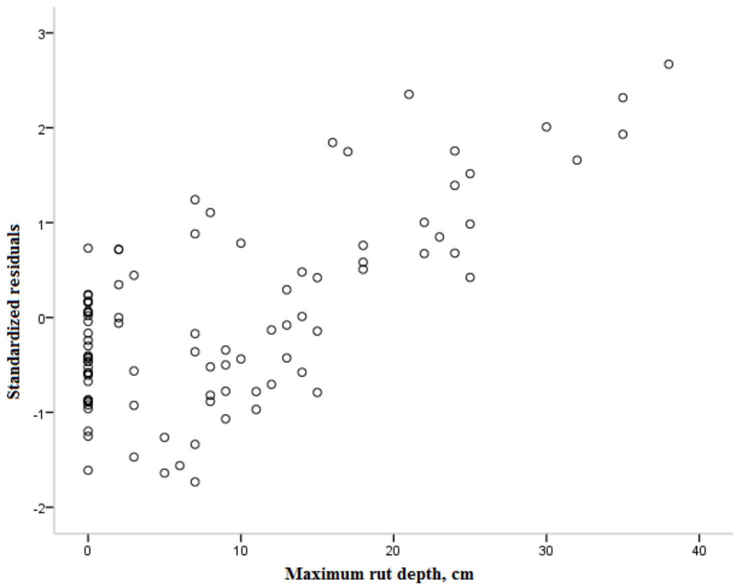

Figure 2: The residuals of the regression model of maximum rut depth.

4. Discussion

The thickness of peat layer, forwarding distance and the depth to the groundwater table were found as the statistically significant independent variables in the linear regression model of the maximum rut depth. The thickness of peat layer and the depth of the groundwater table (field measurement) were also included in the regression models of the rut depth by Lindeman (2010). In this study, the conversation was made by combining terrestrial high model (2* 2 m) and groundwater table. Another GIS variables which describe the spatial variation in stands, were also tried to include the rut depth model. On the basis of the correlation analysis, the density value of laser scanner reflected back from the vegetation would have been statistically significant variable, but on the basis of the findings measured, the model drawn up had a lower explanation degree than that of the model presented in this study (Table 6).

The best explanation degree of the regression model was quite good in the study (R^2 = 51.4%). From the perspective of operational planning of harvesting operations, the model was able to describe the rut up to the maximum depth of 15 cm with a sufficient degree of certainty, even if the residuals of the model range were quite large. The model gave too high values, while the maximum depth of the rut was more than 15 cm. In so deep ruts it exceeded the criterion value (<10 cm) permitted by law. Hence the model works with a sufficient degree of certainty in an acceptable operating range. It can be used for selection of stands for summertime wood harvesting, in which the maximum value of the rut depth is less than or equal to 10 cm. On the basis of this criterion, from research data 33 study plots located in the stands, which should have been harvested during wintertime.

In the study, the better explanation degree was given to the maximum rut depth than rut formation percentage.

The current regulatory success factors set out for the harvesting result of wood harvesting on peatlands are based on the rut formation percentage, which on basis of this analysis, is from the point of view of practical wood harvesting more vague meter than the maximum rut depth. As the subject of further investigation it would be interesting to find out whether these variables may be combined into one more robust independent variables of rut formation. The linearity of the residual variation can contribute to be due to this reason, although the most likely reason is the difficulty of measuring the maximum rut depth in really deep ruts.

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Mechanized processing of big broadleaved crowns an operational reality

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Abstract: For the French State Forest Service, identifying efficient, cost-effective mechanized logging solutions to secure the processing of big crowns in mature broadleaved stands is a challenge. In the east of France, about 17500 ha/year are concerned. Less and less motor-manual workforce is available to perform such relatively dangerous operations and the demand for biomass is increasing. Moreover, in some oak stands, motor manual processing is increasingly difficult for the operator, due to the invasion of irritating caterpillars. Two logging systems, using a grapple saw mounted (i) on a forwarder (single machine system) and (ii) on an excavator which processes the crowns for a forwarder (two machines system), were studied respectively on 5 and 2 sites (2013/2015). Results on productivity and observed efficiency in terms of technical and economic aspects, led to the elaboration of operational recommendations. Hence, the promotion of the best performing systems is now possible towards forest enterprises and forest managers.

Keywords: crowns, broadleaves, mechanization, grapple saw, biomass

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1. Introduction

1.1. The problem and the context

Identifying efficient, cost-effective mechanized logging solutions for the processing of big crowns in mature broadleaved stands is a challenge that ONF, the State Forest Service in France, has to take up.

Less and less motor-manual workforce is, indeed, available to perform such relatively dangerous operations and the demand for biomass is increasing. Round firewood and pulpwood are the traditional products made out of the big crowns removed in mature oak and beech stands. The demand for such products is steady, but the market chips is still growing. In such a context, crowns represent, with the first thinnings in broadleaves stands, the largest potential source of additional biomass.

The surface area, where such resource can be harvested, is relative high. An assessment performed in 3 of ONF's 9 metropolitan districts (Burgundy-Champagne-Ardenne, Lorraine, Franche-Comté) concluded on an estimated surface of 17 500 ha/year for the period 2012-2017. Those interventions would correspond to a potential volume from 247 000 to 411 000 m^3/year (Burban, 2012). The operations concerned are the two last thinnings and all the regeneration cuttings (in general 3 progressive regeneration cuttings before the final regeneration clearcutting) in high forests and coppice with standards.

Moreover, in the department of Moselle (Region Lorraine), motor manual processing is nowadays increasingly difficult to do, due to the invasion of irritating caterpillars (*Thaumetopoea processionnea*) in oak stands. The tiny allergenic hairs of these caterpillars are carried by the wind, and they are responsible for important human health problems: edema, ocular defects, dizziness… These effects occur not only when the caterpillars are present, but also during several months and even one to two years after, because of the persistence of allergenic hairs in the remains of winter nests (Département de la Santé des Forêts, 2006).

1.2. An applied research project

In order to feed its strategy regarding mechanized harvesting of big broadleaved crowns in oak and beech stands with the finding of efficient and acceptable mechanized logging solutions, ONF launched a dedicated study in 2012. Technical experts, field practitioners and researchers from FCBA were gathered in a working group. After a field trip visit in each district of the north east of France, specifications towards the harvesting system, to be used in the different stands, were agreed upon (Burban, 2012):

- Products adapted to the morphology of the crowns
  Oak and beech crowns are made of several relative sinuous strong branches with narrow insertion angles. These characteristics are a real handicap for mechanized processing with traditional harvester heads (Cacot, 2008) for the production of roundwood. However, since the production of chips is done at the roadside in France, long curved branches just need to be cross-cut to facilitate the extraction.
- Length of the extracted products adapted for the preservation of the trees
  The length of the extracted products should not exceed 9 m to preserve the remaining trees in the last thinnings. For the regeneration cuttings, as inter-space between standing trees increases, longer parts can be extracted even the whole crown, however by paying attention to the regeneration.
- Circulation on permanent corridors
  Soil preservation against compaction and rutting, is very important for the forest managers. The definition of perennial lanes, within a forest stand, is the first answer to the problem. The recommended spacing is 16 to 24 m (Pischedda, coord. 2009). Traffic is concentrated on such skid-trails in order not to burden the rest of the soil.

Finally, specifications for the machines of the logging system were defined as follow:

- capable of handling all the crowns from the permanent corridors, while preserving the remaining trees,

the regeneration and creating the minimum impact on the soil;
- efficient, reliable and cost-effective, when producing short logs for the energy market;
- operated from an enclosed cab, for the operator to be safe when working in caterpillar infested areas.

Then, efforts were invested in collecting enough data and convincing experience to identify satisfying solutions in terms of logging machinery and systems for mechanized harvesting operations of big broadleaved crowns. As far as methodology is concerned, the choice was to organize case studies, which consisted in testing different logging systems in real conditions.

Two logging systems, both using a grapple were pre-selected. In the 1st system a grapple saw is mounted on a forwarder with long crane (10 m) (single machine system). In the 2nd one, an excavator processes the crown for a conventional forwarder (two machines system). In 2013/2014, the single machine system was studied on 5 sites. In 2015, the focus was put on the “two machines system” on 2 sites.

This paper presents the results on productivity and then compares the effectiveness of both systems on technical and economic aspects.

2. Material and methods

2.1 The machines tested during the case studies

➢ the single machine system : a forwarder equipped with a chainsaw grapple mounted on a long crane

The tests of this system were performed with 2 entrepreneurs working for ONF in the Lorraine region, particularly in oak stands infested by caterpillars. They worked on separate logging sites. The characteristics of the machines are listed in table 1. Although they are quite similar, two important differences have to be mentioned:

- the owner of the HSM forwarder built a compactor for his machine in order to load more volume. This special equipment was mounted by the entrepreneur on his forwarder on 2 sites. The machine is named F12_C in the following article, whereas the traditional version with stub stakes is F12_S;
- the Valmet Combi is equipped with a rotating cab and has a more powerful crane.

Table 1: Description of the logging machines tested as single machine system (Each machine works alone on its logging site)

	HSM 208F 12T		**Valmet COMBI 801**
Original function	8*8 Forwarder		8*8 Harwarder
Engine power	Iveco 6-cylinder, 238 hp		Sisu 6-cylinder, 190 hp
Crane (length, lifting capacity)	10 m; 125 kNm		10,6 m; 139 kNm
Grapple	Hultdins SuperGrip II 420S (2,05 m width)		Hultdins SuperGrip II 360S (1,90 m width)
Saw	Hultdins SuperSaw 550 S		Hultdins SuperSaw 550 S
Weight (empty without tracks, manufacturer data)	16,5 t		19,8 t
Load capacity	12 t		13 t
Load space	Stub stakes	Compactor	Stub stakes
	Area: 11,4 m^2	Area: 16 m^2, after compressing 9 m^2	Area: 10,7 m^2
	Length: 4,65 m	Length: 3,90 m	Length: 4,30 m
Case study	FEN-P054	FEN-P083 FEN-P191	SAN-P194 FEN-P076

Table 2: Description of the logging machines tested in the 2 machines system.

	Machine n°1 Terex TC125	**Machine n°2 Ponsse Gazelle**
Original function	Excavator	8*8 Forwarder
Engine power	Deutz 4-cylinder, 116 hp	Mercedes Benz, 175 hp
Crane (length, lifting capacity)	5,9 m; 125 kNm	10 m; 106 kNm
Grapple	Intermercato (1,37 m width)	1,90 m width
Saw	Intermercato saw 60 cm	-
Weight (empty without tracks, manufacturer data)	16,5 t	14 t
Load capacity	-	10 t
Load space	-	Stub stakes, Area: 9,9 m^2 Length: 4,20 m
Case study	RAN-P5 CHA-P185	

The organization set up is the same on all study sites and for both entrepreneurs. The machine always remains on the permanent corridors. The driver, using the grapple saw, gradually dismantles the crown. He only cross cuts branches which are too long (more than 6 to 8 m) or too curved. He loads them progressively and he only lays on the ground small strands, to form a larger load. When the forwarder is full, the timber is brought to the landing area and unloaded. The driver leaves his cab only for maintenance and repair. No crown is processed manually.

- ➢ the two machines system : an excavator with grapple saw and a conventional forwarder

Tests were performed with one entrepreneur working in the Franche-Comté. Due to delicate operating conditions on soils sensitive to compaction during a long part of the year, the company chose an 12.5 T excavator, perceived as compact and responsible for low ground pressure (less than 500 g/cm^2), and a Ponsse Gazelle forwarder (see table 2). The excavator processes the crowns with its grapple saw and stacks the products along the corridor lane. In such configuration, processing and forwarding can be separated in time. In case of unfavorable skidding conditions, the excavator can continue to work, prepare the crowns and stack according to a pattern which will facilitate the forwarder's work in the future.

2.2 Content of the 7 case studies

The field trials were carried out over the period 2013-2015:

- 5 sites for the single machine system, all in oak stands: 3 last thinnings (FEN-076, FEN-083 and FEN-P191) and 2 regeneration cuttings (FEN-P054 and P194);
- 2 sites for the 2 machines system: 1 last thinning in a mixed oak-beech stand (RAN-P5) and 1 in a regeneration cutting of oak (CHA-P185).

On all sites, the trees were felled motor manually and the logs extracted by skidders, except FEN-P083 where trees were extracted with cable-yarder. No specific instruction had been given to the teams regarding crowns. The main characteristics of the case studies are shown in table 3.

For each site, an area was identified in which crowns were measured (diameter at the crown basis, total length and distance crown-corridor). Additional data were recorded concerning the work organization, the corridors (width and inter-space), the stand (density, species), the machine and the operator's experience.

An AIR3-CT94-2097 compatible protocol, was followed during the time studies performed on this sample of crowns and the corresponding processing-forwarding cycles. Within each cycle, the work step was recorded every 15 seconds according to the Instant Observations method and all saw cuts were accounted. The following five main functional work steps were identified for each cycle:

- Moving empty, from the landing area to the first crown (all forwarders),
- Processing, comprising several sub-steps such as moving out the boom, preparation of the crown, crosscutting (all machines equipped with a grapple saw),
- Loading the crowns (all forwarders) and moving from one crown to another (all machines),
- On load moving, back to the landing area (all forwarders),
- Unloading comprising also several sub-steps such as boom loaded, boom empty, moving (all forwarders).

As the volume is not easily measurable, the machines were equipped with a boom scale to determine the fresh weight loaded for each cycle (from 5 to 18 forwarding cycles by site). These boom scales were calibrated daily with field standards.

2.3 Characteristics of the 7 logging sites

Each machine was tested at least in a last thinning stand and in a regeneration stand (see figure 1).

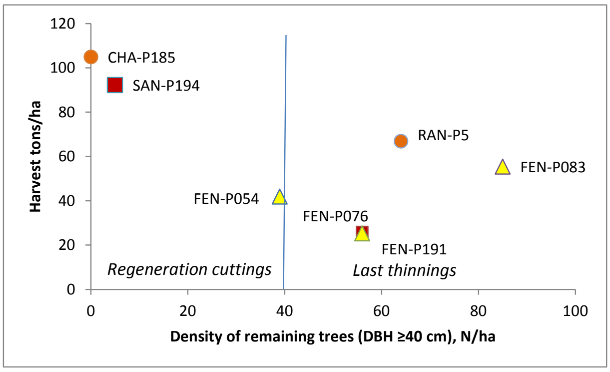

Figure 1: Position of the case studies. Triangles = HSM, Scares = Valmet, Circles = 2 machines system. Fresh tons.

Removals of crowns and co-products in gross tons/ha range from 25 to 67 tons/ha for the last thinnings (RAN-P5, FEN-P076, FEN-P083 and FEN-P191) and for the progressive regeneration cutting (FEN-P054). The average mass of crowns is about 1 to 1.5 tons. In the final regeneration clearcuttings (SAN-P194 and CHA-P185), the removals are about 100 tons/ha higher (see figure 1). Average weights of 2 to 2.5 tons/crown were recorded. It should be noted that other types of wood are harvested at the same time: whole trees previously felled by loggers, but not further processed because of their smaller size, ridges, branches and also pieces of dead wood. The share of these "co-products" is more important in the thinnings (see figure 2). On site RAN-P5, they represent 75% of the products (in number of pieces) for 55% of the whole extracted weight.

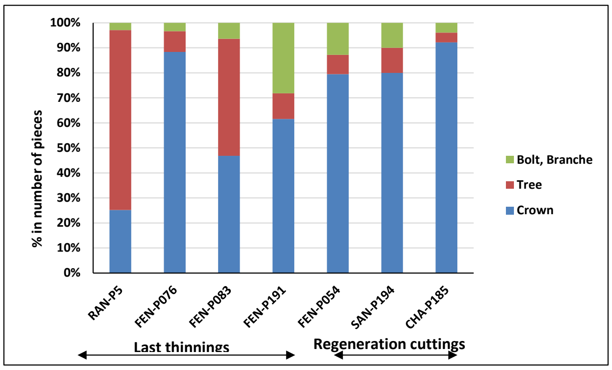

Figure 2: Distribution between crowns, trees, bolts and isolated branches.

The plots showed no particular difficulty of exploitation (flat land, no obstacles). The only significant differences in regard to productivity (see table 3) were:

- The forwarding distances, usually quite short, except for CHA-P185;
- The inter-space between the corridor lanes, sometimes variables within the same plot. At RAN-P5, the spacing of 37.5 m required more time for the excavator to extract the wood. At FEN-P083, despite a large spacing, the crowns were beside the corridor lane, as a result of the former cable yarding of the logs.

On all these sites, 268 crowns were measured precisely (see figure 3). An analysis of variance, followed by a mean comparison test (Student-Newman-Keuls), was performed to compare the average crown characteristics of the 7 sites.

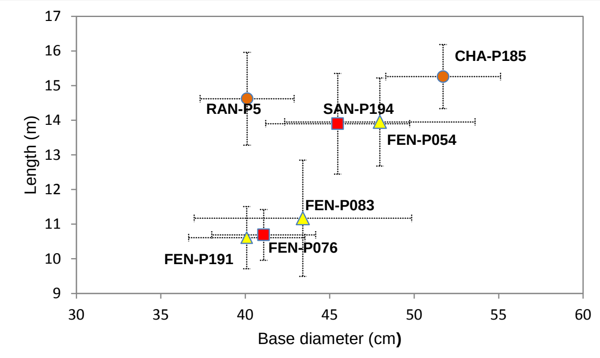

Figure 3: Diameter at the base and length of the crowns (mean and confidence interval of 95%).

On the lengths, 2 groups are statistically different:

- a first group of 4 sites (CHA-P185, RAN-P5, SAN-P194 and P054-FEN) with average lengths between 13.90 and 15.30 m, these are the 2 logging sites of Franche-Comté and all the regeneration cuttings;
- a second group of 3 sites (FEN-P083, FEN-P076 and FEN-P191) with average lengths between 10.60 and 11.20 m, all are last thinnings sites of Lorraine.

On the diameters, differences between sites are lower. Besides, they are not statistically different except CHA-P185, which can be considered as having an average diameter greater than the 4 sites with the lowest diameters (FEN-P191, P076-FEN, RAN-P5 and FEN-P076). The average diameters are of about 40-55 cm (40-45 for the last thinnings and 45-55 for the regeneration cuttings). The largest diameter found on the monitored areas is 90 cm.

3. Results and discussion

The whole study (7 case studies) concerned 73 forwarding cycles, 276 crowns of oak and beech corresponding to 522 fresh tons (see table 3).

Table 3: Main characteristics and results of each case study.

	Single machine system					**2 machines system**	
Case study	**SAN-P194**	**FEN-P076**	**FEN-P054**	**FEN-P083**	**FEN-P191**	**RAN-P5**	**CHA-P185**
Crop of crowns and co-products (tons/ha)	92.2	25.8	41.9	55.4	25.3	30	105
Silvicultural logging operation	Final felling	Thinning	Secondary felling	Thinning	Thinning	Thinning	Final felling
Machine 1	Forwarder Combi + grapple saw	Forwarder Combi + grapple saw	Forwarder HSM + grapple saw	Forwarder HSM + grapple saw	Forwarder HSM + grapple saw	Excavator + grapple saw	Excavator + grapple saw
Machine 2						Forwarder	Forwarder
Load space	Stub stakes	Stub stakes	Stub stakes	Compactor	Compactor	Stub stakes	Stub stakes
Theoretical load capacity (kg)	13 000	13 000	12 000	12 000	12 000	10 000	10 000
Nb of cycles observed	10	9	9	5	5	17	18
Total harvest (kg)	73 532	61 116	64 804	62 121	50 493	88 422	121 673
Mean load with crowns and co-products (kg)	7 353	7 203	7 200	14 266	10 099	5 797	7 051
Loading rate (%) *(mean load / theoretical load capacity)*	57%	55%	60%	119%	84%	58%	71%
Maximum load (kg)	8297	8564	8581	16048	11381	8090	8372
Maximum load rate (%)	64%	66%	72%	134%	95%	81%	84%
Mean forwarding distance (m)	**255**	**228**	**358**	**140**	**163**	**161**	**591**
Distance between corridors (m)	20 m	23 and 45 m	20 m	41 m	28 m	37.5 m	15 and 26 m
Mean distance crown-corridor (m)	2.4	3.0	5.8	3.5	2.1	8.9	3.5
Productivity in kg/pmh (productive machine hour)							
Processing	**17 846**	**15 480**	**9 711**	**15 371**	**11 259**	**7 372**	**10 372**
Forwarding						**17 504**	**15 503**
Global (kg/hmp)	**17 846**	**15 480**	**9 711**	**15 371**	**11 259**	**5 182**	**6 205**
Yield (min/ton)	**3.4**	**3.9**	**6.2**	**3.9**	**5.3**	**11.6**	**9.7**
Mean cross cuttings (nb/tons)	1.7	2.4	2.1	1.3	1.8	11.3	6.6

3.1 Machines suited for the processing of the crowns, when they are reachable

Lesson 1: The first and the most important result is that the machines equipped with grapple saw, were able to process all the crowns on all sites, whatever the size of the crown. On all sites, no crown had to be abandoned or processed.

Lesson 2: The distance between the corridor lanes and the crane's capacity are key factors. The 10 m crane from the forwarder (single machine system) allows to work in plots with inter-space up to 18 m. Beyond this distance, it is not possible to process the crowns from the corridor lane (FEN-P083 and FEN-P076 both stands with some 40 m spacing). For the 2 machines system, the crane of the 12.5 T excavator is much shorter, hence forcing the machine driver to drive out of the corridor lane when the crowns are distant by more than 5 m. Larger excavators (22 T) can reach further away with their 7 m crane, but are still limited in comparison with the forwarder's capacity. To avoid traffic out of the corridor lane, it might be possible to winch the remote crowns with the skidder, when logs are being extracted after felling. But this solution is not always suitable, due to the risk of potential damage on trees or seedlings.

Lesson 3: Using a crane preserves the remaining trees and / or the regeneration. Working with crane equipment reduces damages on remaining trees and seedlings. The dexterity of the driver is therefore fundamental.

3.2 The main factors determining productivity

Lesson 4: The forwarding distance influences forwarder's productivity. Although this might sound self-explanatory for skidding and forwarding, results on the distance-productivity correlation are confirmed to be significant on three sites: FEN-P054 ($p = 0.0142$), FEN-P076 ($p=0.047$) and CHA-P185 ($p=0.096$). These are sites with a sufficient number of cycles and a range of fairly large distance (see figure 4). But distance is not the only criteria.

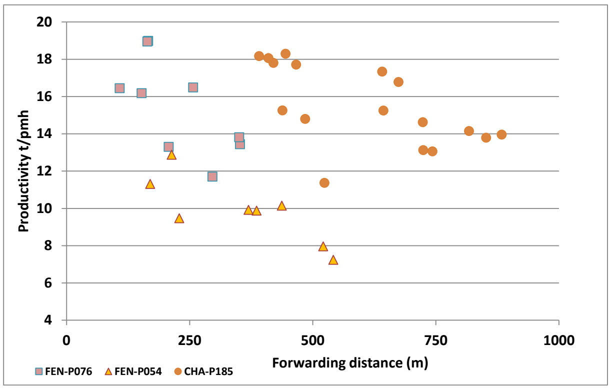

Figure 4: Forwarder's productivity and forwarding distance (for the single machine system, productivity includes also crown processing).

Lesson 5: the high expansion rate of crowns hinders the overall transported tonnage, whereas the compactor increases loading rate. With stub stakes, the loading rate (mean load/theoretical load capacity) range between 55 and 60% on 4 of 5 case studies. On the fifth case study, (final clear cut CHA-P185), this rate was sharply higher due to the absence of obstacles and the fact that the timber was well prepared by the excavator driver. Indeed, the bolts are cut shorter (mean length 4.30 m compared to 7 m for the single machine system) and so they are slightly straighter. Thus, loading rate over 80% were only observed for the 2 machines system for some cycles (see figure 5), but this preparation is time consuming. Another result is that the compactor considerably increases the loading rate: 84% for FEN-P191 and even over 119% with optimal forwarding conditions (large corridor, high crop per corridor in FEN-P083).

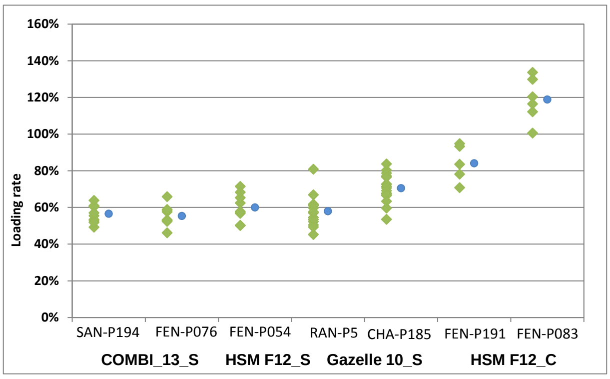

Figure 5: Forwarders' loading rates. (Results per cycle in green and mean in blue, S stub stakes and C compactor).

Lesson 6: time consumption for processing crowns is the lowest for the single machine system. The analysis was made on the productive time to process one fresh ton, expressed in seconds/ton (see figure 6).

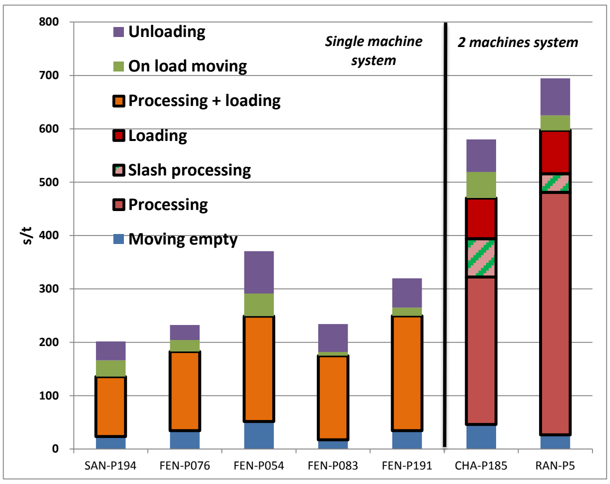

Figure 6: Productive time for processing and forwarding a fresh ton.

This time includes:

- For the single machine system all working phases, namely moving empty from the landing area to the first crown, processing and loading all crowns from the cycle, on load moving back to the landing area and unloading,
- For the 2 machines system, the full excavator working time is in the processing phase, however the time spent for processing the tiny branches (slash processing) left on the field has been separated. This latter phase was only present for this system (CHA-P185 and RAN-P5). All the other phases concern the forwarder.

The productive time required to process one ton of crown is very different between the two systems:

- 200 to almost 400 seconds/ton for the single machine system, corresponding to a productivity of 9.7 tons/pmh

(forwarder with stub stakes, mean forwarding distance 358 m, crop 42 tons/ha) up to 17.8 tons/pmh (forwarder Combi, crop 92 tons/ha; mean forwarding distance 255 m); the best performances are obtained by the Combi (crane kinematics better suited) and the forwarder with the compactor;
- about 600 to 700 seconds/ton for the 2 machines system, corresponding to a global productivity of the whole system of 5.1 v. 6.2 tons/pmh.

Moving times (empty and loaded) are difficult to compare because the forwarding distances and payloads are different. The unloading time depends more of the machine and configuration of the landing place, so analysis is focused on the phases that consume the most time (processing and loading) and differentiate the two systems. It appears that excavator's productive time (processing on figure 6, without slash processing), is 275 seconds/ton for CHA-P185 and 454 seconds/ton for RAN-P5. Whatever case study, it's higher than the processing and loading times of the forwarders equipped with a grapple saw (from 113 seconds/ton for SAN-P194 to 216 seconds/ton for FEN-P191). The driver of the excavator tries to optimize the work of the forwarder by stacking the wood very well. Indeed loading time of the forwarder in the 2 machines system is lower, about 85 seconds/ton. But the combination of both machines is very penalizing in terms of global time and of course also on the cost of the operation. Thus, for sites with similar conditions (crop per hectare, size of crowns), the single machine system is about three time faster on "processing and loading" (final clear cuttings: SAN-P194 versus CHA-P185 and last thinnings: FEN-076, FEN-P083 versus RAN-P5 (see also table 3).

Lesson 7: productive working time is proportional to number of saw cuts. Indeed, another feature is the close relationship (statistically significant) between the processing time and the number of saw cuts (see Figure 7).

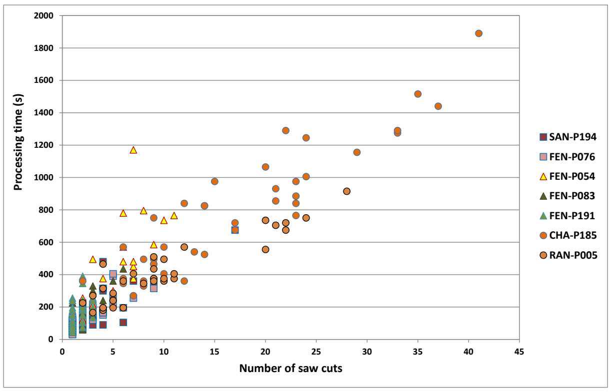

Figure 7: Processing time (for the single machine system loading is included) and number of saw cuts. Correlation coefficient (Pearson, r) = 0.92; $p < 0.0001$.

On sites of the 2 machines system, the excavator processed crowns in relatively short lengths (about 4.30 m), and left the small branches with leaves on the ground. Differences in number of saw cuts per ton between the 2 sets of sites are, therefore, very important: 1.3 to 2.4 for the single machine system and 6.6 to 8.9 for the 2 machines system and respectively 16% and 24% due to the small branches (see Table 3). Thus, increasing bolt lengths (up to 7-8 m) should be considered as a solution for improving excavator's productivity by reducing the number of saw cuts, but its impact should also be studied on the forwarder's activity especially due to a probable modification of the loading rate.

Lesson 8: Additional processing of the slash hinders productivity. The latter results shows clearly, that if you have to leave the small branches on the ground (e.g. to avoid loss of fertility, or to improve the quality of the chips), there will be an impact on the time consumption. It represents 7% of the working time for RAN-P5 and up to 21% for CHA-P185 where the excavator driver decided to put the small branches in the corridor lanes to avoid soil compaction.

Lesson 9: the higher the crop per ha, the better the productivity of the operation. 1 to 1 comparison were done for 2 couple of sites where the main difference was the crown volume recovered per ha. Results from the analysis of variance and the mean comparison test (Student-Newman-Keuls) show that the productivity is significantly different:

- for the Combi SAN-P194 (final clear cutting, crop 92 t/ha) and FEN-P076 (last thinnings, crop 26 t/ha): F=5.38, p = 0.0323;
- for the HSM with compactor FEN-P083 (last thinnings, crop 55 t/ha) and FEN-P191 (last thinnings, crop 25 t/ha): F=22.36, p=0.0008.

3.3 Extracting costs

Technical costs per ton are determined according to the hourly technical cost of the machine (95 €/h for a forwarder with long crane and grapple saw, 84 €/h for a 10 T forwarder and 64 €/h for the excavator), and the average productivity in ton per hour machine. The latter is lower than the productivity in ton per productive machine hour because it takes into account all the operating time of the machine (travel, maintenance...). For all forwarders, average productivity was estimated to be between 60 and 80% of productivity of productive machine hour observed on the logging sites. Thus for the single machine system, the technical costs vary between 7.6 and 14 €/ton (see figure 8), the lowest cost being obtained on site with the most favorable operating conditions (high crop per hectare, low forwarding distance and no constraints due to remaining trees, SAN-P194).

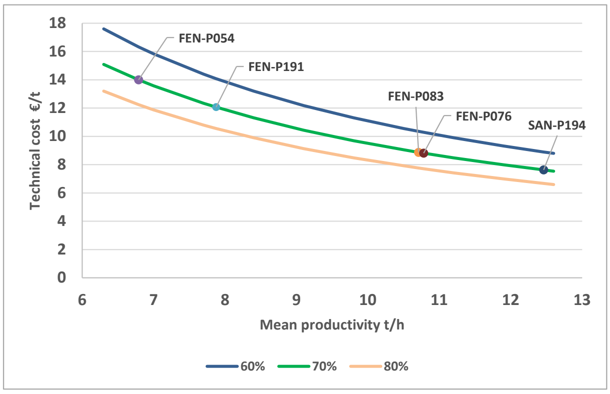

Figure 8: Technical costs for the single machine system.

Although the excavator has a lower hourly technical cost than the forwarder equipped with a grapple-saw, his low productivity heavily influences the technical cost of mobilization. For a mean productivity from 4 to 5 tons/hour (about 50% of the productivity in ton per productive machine hour on both sites), the technical cost of the excavator varies from 12.8 to 16 €/ton. The time saved for the forwarder by the excavator is on average 85 seconds/ton (see result 6), corresponding to 2 €/ton. That means, if both systems were equivalent, the average productivity of the excavator should be of 32 tons per hour to lower the excavator's costs down to 2 €/ton!

On both sites (RAN-P5 and CHA-P185), forwarder's technical costs are about 7.3 €/ton and thus, for the 2 machines system, technical costs vary from 20.1 €/ton to 23.3 €/ton.

4. Conclusion

The full mechanization of large broadleaved crowns is an operational reality and has been facilitated by the development of wood energy. Indeed, wood being chipped on the roadside does not need to be as properly calibrated (length and rectitude) as solid wood does. Through the case studies, the grapple saw has proven to be an efficient and easy to use tool, in addition to being a small investment for the entrepreneur (about 15,000 €). On all sites, all crowns were processed easily. The only exceptions were crowns located too far from the corridor lane, out of reach for the crane, or not visible from the cab.

The single machine system, a forwarder equipped with a saw grapple, is the best performing system because the handlings are limited. However, it solicits more mechanically the forwarder, especially when the machine pulls big crowns towards the corridor lane. This should be followed over time and practice, in particular how quickly the crane will age. Of the 5 case studies followed in this configuration, the Combi and the forwarder with compactor were the best performers, compared to traditional forwarder.

An asset of the 2 machines system (excavator with grapple saw and forwarder) is the capacity to separate the operations in time. This can be interesting in terms of organisation when the soil conditions are deteriorating, but it is much less efficient in terms of productivity and from an economic point of view.

This study contributed to highlighting the various factors which influence the productivity of the systems, in particular the type of equipment and the forwarder's load capacity, the forwarding distance, the site characteristics (crops associated with the type of cutting), the length of the products and the treatment of the small branches.

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Long range cable systems in Japan: succession and continuous development to overcome terrain and cost balance

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Abstract: Cable systems with long span and immovable yarder are still mainly used in mountainous areas in Japan. The most popular method of such cable systems is Endless-Tyler system accompanied with an additional lateral yarding cable which enlarges the available logging area mainly for clear cutting. A modification of Endless-Tyler system, Collector system, is used for thinning operation. The system has a device on the carriage that limits the movement of lateral yarding cable in order to prevent damage to residual stands. The other modified system oriented for thinning is H-type system of which two sets of Endless-Tyler system are rigged parallel and their two loading blocks are connected together to realize vertical lifting of cut trees over a wide logging area. The present paper describes the characteristics of two systems as well as analysis of operational efficiency and cost balance. Some trials for renovations on yarders and equipment follow.

Keywords: Logging cable system, thinning, mountainous forest, operational efficiency, cost balance

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1. Introduction

During recent decades, mobile tower yarders and ground based logging machines are gradually increasing in number to enhance logging productivity in Japan. However, cable systems with long span and immovable yarder are still mainly used in Japanese mountainous forests. In the present paper the authors at first describes the role of cable logging systems compared with other logging systems in relation to terrain and status of road network development. Historical background of Japanese forestry is also considered. In the era of clear cutting and expanding plantations, the most popular logging cable system was the Endless-Tyler system, which is currently one of the most popular rigging methods too. Because the system is basically for clear cut operations, there have emerged some modifications of the Endless-Tyler system in order to fit thinning operations. Secondly two of such modified systems are overviewed; the Collector system and the H-type system. Then operational efficiency and cost balance of the systems are analyzed, followed with insight of possible developments.

2. Material and Methods

The first part of "**3 Results and Discussion**" section, **3.1**, reviews the development and the role of logging cable systems in Japan. This part is based on reference information. In the following parts, **3.2** and **3.3**, overview of the selected cable systems is summarized through both references and original data obtained from field studies and related logging contractors. Finally in the last part, **3.4**, the method of Setiawan et al. (2013) and Suzuki et al. (2015) is used for cost balance analysis. The method employs a graph in which resultant operation cost z (Currency/m^3) is expressed as equivalent straight lines, $z = x/y$, over x-y coordinates where x is hourly cost of the system including labor and machine (Currency/crew-hour) and y is operational efficiency of the system (m^3/crew-hour). Three cases are employed for the analysis and then the total cost of each case is estimated and discussed.

3. Results and Discussion

3.1. Role of logging cable systems in Japan

Recently Nakagawa (2016) precisely reviewed researches on and history of logging systems in Japan. He classified the era after the World War II into three periods. The first period starts from late 1940's and early 1950's. It is defined as "Recovery after War," followed with the period of "Mass plantation." Mass plantation was conducted all over Japan under a national policy in order to fulfill emerging demand of timber. Price of logs much increased during this period (Figure 1). A vast area of natural forest was clear cut and then converted to new plantations of coniferous trees, mainly Sugi (Japanese cedar; *Cryptomeria japonica*) and Hinoki (Japanese cypress; *Chamaecyparis obtusa*). In this period, clear cut forests were logged mostly by logging cable systems with a long span because there were only few forest roads among mountainous area.

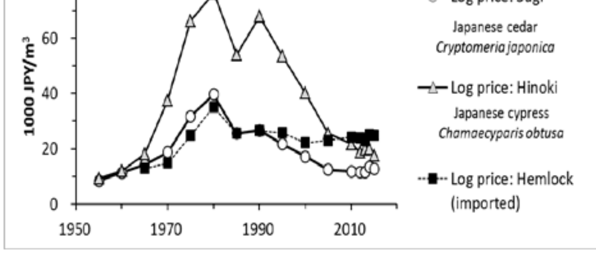

Figure 1: Trend of log price in Japan.
Note: Period is defined by Nakagawa (2016).

From late 1970's, imported logs made domestic log price lowered, accompanied with decline of logging industry. Nakagawa (2016) defined the period from early 1980's as the era of "Commercial thinning" when mass created plantations reached the age of first commercial thinning. From then a number of fine road networks have been constructed in forest areas, even on mountainous areas. In the period, short span logging cable systems have been started to be used. Such systems include tower yarders and Japanese style swing yarders. The swing yarders are mainly modified excavators equipped with two winch drums to operate running skyline system of up to ca. 100 m of span (Figure 2).

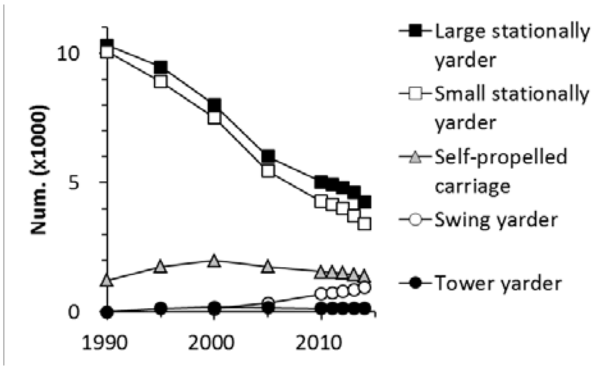

Figure 2: Number of cable logging machines in Japan
Note: Note: Data obtained from Forestry Agency (2016).

As shown in Figure 2, number of yarders for logging cable systems has been decreased over the recent decades. However a considerable proportion of forest areas in Japan are on so steep terrain where cable systems or long range cable systems are only feasible options. In earlier stage of Forest Engineering studies in Japan, Hori (1965) classified suitable logging systems based on the terrain index *I*, which is closely coincide with slope gradient (Sakai, 2000). Table 1 summarizes the classification and proportion of corresponding forest areas.

In the current stage of Forest Engineering studies in Japan, Gotou (2011; as a part of repots in Ishibashi, 2011) renovated the classification. He classified appropriate current logging systems in relation to both terrain and road density, and also proposed a new classification for coming new systems (Table 2; Suzuki et al. 2015). Here tower yarders are supposed to be used up to 300-500 m of span whereas conventional cable systems for over 500 m of span. Recently he has estimated the proportion of mountainous forest area, on which cable system should be used, to be 22.8% (Gotou, 2016).

Table 1: Road network status and selction of operation system.

Classifi-cation	Gentle	Medium	Steep	Very steep	Total
Gradient	<20%	20-40%	40-70%	70% <	
Suitable logging system	Truck	Tractor	Cable system	Long range cable system	
Area (10^3 ha)	3,731	9,852	10.305	1,14	25,026
Proportion (%)	14.9	39.4	41.2	4.6	100.0

Note: Classification and suitable looging system from Hori (1965), area and proportion from Sakai (2000)

3.2. Overview: Endless-Tyler system and Collector system

Rigging methods of logging cable systems in Japan was well listed and classified by Koshinaka (1964), Konuma and Shibata (1976), and Okawara (1991). In the early stage of "Mass plantation" period (Figure 1), Tyler system (Konuma and Shibata, 1976; Samset 1985) was one of the most popular rigging methods, which is suitable for downhill yarding. The Endless-Tyler system is a modification of Tyler system having an endless line for terrain-independent movement of the carriage (Figure 3) so that it can be used for uphill yarding.

Table 2: Road network status and selction of operation system.

Road network status			Conventional system				New system			
			Average slope gradient (within a circle of main-road-distance diameter)							
Distance between main roads (m) [Roundab out rate]	Road density (m/ha)	Fine road network	Gentle (less than 15deg.)	Medium (15-30 deg.)	Steep (30-35 deg.)	Very steep (more than 35 deg.)	Gentle (less than 15deg.)	Medium (15-30 deg.)	Steep (30-35 deg.)	Very steep (more than 35 deg.)
Truck road 1000 [2.6]	c.a. 25	Yes	Swing yarder Middle size (base machine bucket capacity $0.45m^3$)		Middle range cable system Self-propelled carriage	Long range conventional cable system	Tractor-Winch Middle sized		Tower yarder Middle sized	Conventional cable system
		No								
Truck road 500 [2.2]	c.a. 50	Yes								
		No	Tractor-Winch		Swing yarder Small sized				Tower yarder Middle sized	
Truck road 250 [1.7	c.a. 75	Yes								
		No								
Forwarder road 120 [1.4]	c.a. 100-150	Yes	Grapple-Forwarder Middle sized (base machine bucket capacity $0.45m^3$)		Grapple-2t-Truck (base machine bucket capacity $0.25m^3$)		Harvester Middle sized		Tractor-Winch Small sized	Tower yarder Large sized
		No								
Forwarder road 60 [1.2]	c.a. 200	Yes								
		No	Harvwster				Harvester Large sized			

Note: The original table was proposed in Suzuki et al. (2015)

In the Endless-Tyler system, a haul back line is also applied for lateral yarding in order to enlarge logging area. A cost for rigging up and down is required for cable system. One efficient way to reduce the cost is enlarge the logging area per one rigging up (Okawara, 1991). Therefore availability of lateral yarding is one of most essential points on development of cable logging systems in Japan. However, as Okawara (1991) pointed out, the haul back line of Endless-Tyler system sweeps over the logging area during loaded movement of the carriage. If there remain residual trees, they will be damaged via the haul back line. This is the reason why the Endless-Tyler system is normally applied for clear cut sites.

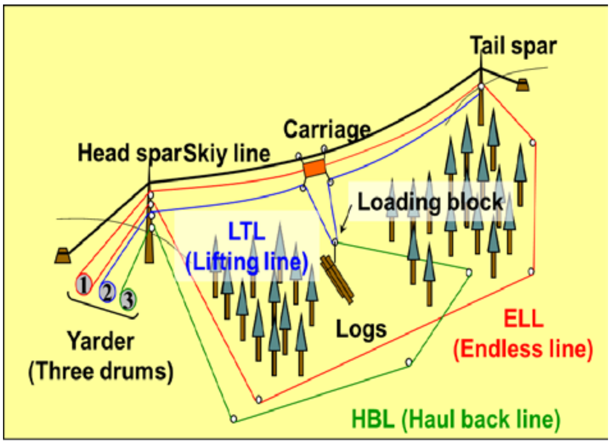

Figure 3: Endless-Tyler system.

The Collector system is one of modifications of Endless-Tyler system oriented for thinning operation (Figure 4). The system has a device named "Collector block" on the endless line that limits movement of the haul back line within a linear area during lateral yarding. A similar system was introduced probably early 1970's in Japan. It can be said from the fact that a Tyler-modified system that enables the same function as the Collector system was illustrated as "branched cutting strip yarding" in Konuma and Shibata (1976) and Samset (1985). The name "Collector" is a product name of the rigging equipment. Rigging cases of such complex rigging methods have been declined after "Mass plantation" era. However from the late 2000's some logging contractors in Kochi Prefecture, which located on Shikoku Island in south western Japan with much mountainous areas, started to use the system for thinning operations (Suzuki and Omachi, 2005; Suzuki et al. 2011).

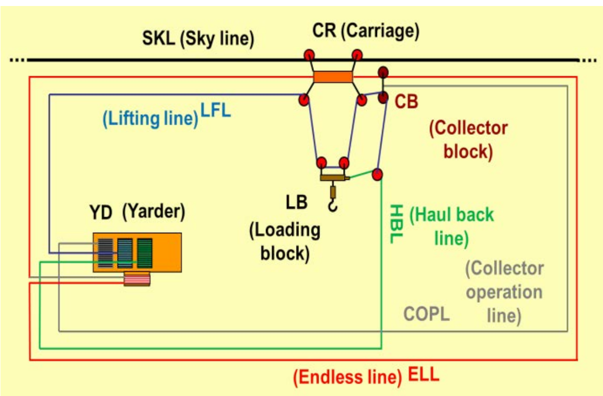

Figure 4: Collector system.

3.3. Overview: H-type system

The other modified system is H-type system of which two sets of cable system are combined to accomplish plane and wide logging area. An example is illustrated in Figure 5, where two sets of Endless-Tyler system with no haul back line are rigged parallel and two loading blocks are combined together.

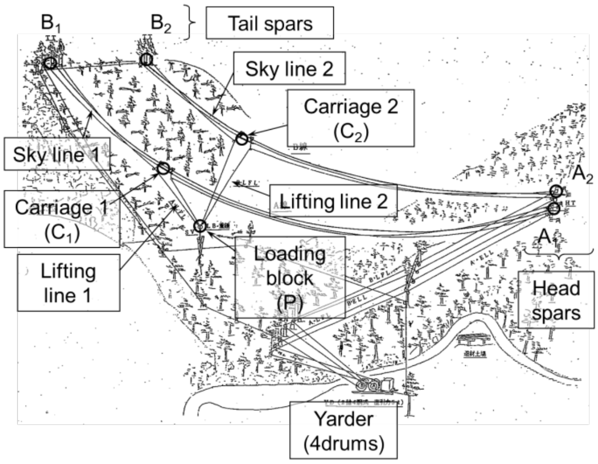

Figure 5: H-type logging cable system.
The original figure was from Reihoku Forestry Office, Kochi Prefecture (1998).

Around 1970's the first rigging up of H-type system was tried in the national forests in Japan. Konuma and Shibata (1976) reported earlier versions of H-type system with two sets of running skyline system or Tyler system. Although there existed many versions of H-system, currently the most operative one is that of two sets of Endless-Tyler system (Suzuki et al. 1999; Kondo et al. 2005; Suzuki et al., 2005; Kondo 2006; Kondo and Kobayashi 2006). There are a few logging contractors that operate H-type system in Shikoku Island, mainly in Kochi Prefecture. A set of rigging requires two fold of devices, time, and labor than that of normal cable system. However, consecutive setting up over adjacent area enables lower expense of rigging cost per set. In such an arrangement, effective planning of road network over the total harvesting area is necessary. One of the contractors which continuously operates H-type system achieved a total efficiency of 7.53m^3 per person-day, including road construction, which is more than twice of average achievement of Japanese logging contractors.

The H-type system requires a large vertical distance between skylines and the canopy surface. That is because there are two types of deflection in the H-type system. That is, deflection of the skylines and deflection of the lifting lines. At maximum total deflection reaches to 100-150 m (Kondo, 2006). Furthermore, when the system is applied to thinning operation, a length of sling rope under the loading block should be longer than the heights of residual trees. In order to fully hang up the cut trees, which are in a shape of full trees in most of the cases, much more deflection is necessary. The H-type system is well applied over such an area on mountains that have deep valleys. Average spans are around 1000 m or more (Kondo et al. 2005; Suzuki et al., 2005). In order to reduce required deflection height, some logging contractors have started to use a self-propelled carriage as a loading block, where the self-propelled carriage just functions as a winch equipped remote-controlled carriage. Requirements for yarders of H-type system are four drums, two for two sets of endless lines and two for two sets of lifting lines. While until recently the contractors employed 4-durm conventional yarders for H-type system rigging, there has been started a renovation project to develop special yarder for H-type system use.

3.4. Operational efficiency and cost analysis

At first let us discuss on operational efficiency of logging and processing operation. The data of Collector system was obtained from a case reported by Suzuki et al (2011) where a system of 500m span was rigged up over 6 ha of plantation forests. While the felling operation was done in advance, the logging operation and the processing operation were performed simultaneously. The crew was consisted of 3 persons, one yarder operator, one processor operator at the landing, and one hocking person at the felling site who uses one chainsaw. Hourly cost of the yarder, the processor, and the chainsaw were 935, 4303, 346 JPY (Japanese yen; 1 USD = 110 JPY)/hour, respectively. The hourly cost of yarder was low because it was used beyond normal depreciation years, so only maintenance and repair cost is required. Including the labor cost of 2725 JPY/hour (Setiawan et al., 2013; Suzuki et al., 2015), hourly cost of the crew and the machines was summed up to 14,216 JPY/crew-hour. This hourly cost includes depreciation cost of rigging equipment, 458 JPY/crew-hour. Note that the depreciation cost of rigging equipment is originally assessed as 256 JPY/m^3; the cost was adjusted concerning total production of log volumes over the logging sites. Productivity of the logging and processing operation was 1.79 m^3/crew-hour. Such low operational efficiency was due to the time required for lateral logging. While the Collector system can prevent or reduce damage to residual trees, its productivity tends to be lower than the other systems. Then resultant cost of the operation (z; JPY/m^3) is calculated by hourly cost (x = 14216 JPY/crew-hour) divided with productivity (y = 1.79 m^3/crew-hour) (Setiawan et al., 2013), i.e., 7940 JPY/m^3 (Figure 6).

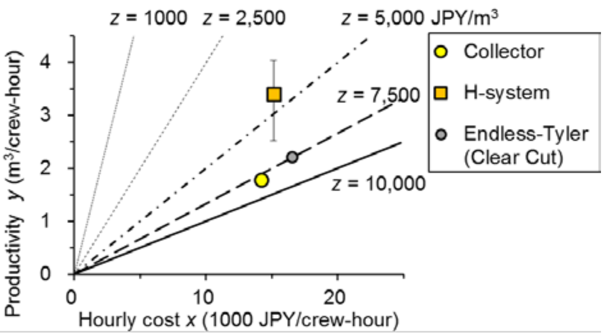

Figure 6: Relationship between Productivity (y), houly cost (x), and reultant cost (z).
Note: Resultant cost z (JPY/m^3) = [Hourly cost x (JPY/crew-hour)] / [Productivity y (m^3/crew-hour)]. Error bars indicate Max. and Min.

For the cases of H-system, a series of data were obtained from a logging contractor. By picking up and summarizing the data, average productivity of the logging and processing operation was 3.40 m^3/crew-hour, while the minimum and the maximum ones were 2.52 and 4.03 m^3/crew-hour, respectively. Average span was 1058m. The number of crew was same as that of the case of Collector system. The hourly cost of chainsaw and labor was set to the same as that of the Collector system case. Those of yarder and processor were 763 and 4013 JPY/hour, respectively. Total hourly cost including the crew and machines was 15138 JPY/crew-hour in which depreciation cost of rigging equipment 1842 JPY/crew-hour was added (the original depreciation cost of rigging equipment was 542 JPY/m^3). Then the resultant cost is calculated 4454 JPY/m^3 for the average productivity (Figure 6).

In Figure 6, a case of Endless-Tyler system is also plotted; however the case was of clear cutting of broad leaved tree forests for woody biomass utilization (Suzuki et al., 2016). Whole trees were logged, processed to logs and twigs, and both were shipped to a woody biomass power generation plant. The span was 603 m. Number of the crew was four; two for hocking and chasing, one for yarder, and one for grapple and motor-manual bucking at the landing. Most of the hourly cost elements were the same as those of the Collector system case and the H-type system case except for that of a grapple, 4329 JPY/hour. The total hourly cost was 16510 JPY/crew-hour, the productivity of logging and processing was 2.21 m^3/crew-hour, and the resultant cost was calculated as 7713 JPY/m^3.

By comparing the three cases, it is obvious that the productivity of H-type system is higher than the other system although its span is the largest. Among many factors that affect productivity of cable systems, logging distance is the most important one (Cavalli, 2012; Lindroos and Cavalli, R., 2016). In the cases of Collector and Endless-Tyler systems, each landing was located at not so far from the head spar. However, in the case of H-type system, multiple landings were prepared over the large logging area. A contactor designs a project over more than 100 ha of area with 3-5 sets of H-type systems in average. Such a project area should have a sufficient road network even if its density is not so high. Multiple landings, more than one for each set of H-system, are placed on the road network so that logging distance is fairly short.

Total costs, including not only logging and processing but also rigging, felling, and transportation, of the above mentioned systems were calculated from the obtained data (Figure 7). Although rigging cost linearly correlates with span in normal (Umeda et al., 1982), rigging cost of the H-type system is lowest in these cases even if a set of H-type system requires two sets of rigging up. This is because logging contractors design multiple sets of H-type systems over a large project area, 4.2 sets in average for the data obtained. Such 4.2 sets of H-type systems need rigging up and down of 5.2 single cable systems if the sets are arranged consecutively, because a new set can use one single cable system of the former set. Then requirement of rigging up and down of a set of H-type system reduces to 5.2 / 4.2 = 1.24 fold of a single cable system.

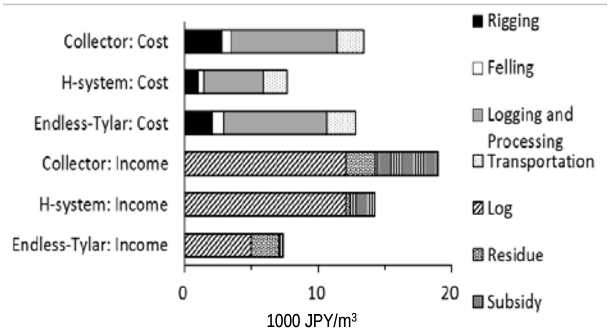

Figure 7: Cost balance of the three cases.
Note: Commercial thinning operation except for the Endless-Tylar case. Data obtained and modified from Suzuki et al. (2011 and 2015).

Also it should be noted that H-type system uses no haul back line. As already shown in Figure 6, logging and processing cost is lowest for H-type system because of higher operational efficiency, even if it is for thinning. In Figure 7, Transportation cost is almost the same among the three cases, 1800 - 2000 JPY/m^3.

In order to inspect cost balance, income from logged products is shown in Figure 7 as well. Log price is assumed as average of Japanese cedar (*Cryptomeria japonica*), 12700 JPY/m^3 (Figure 1; Forestry Agency, 2016). Here charge at timber market, 5% of log price, is discounted. In the case of Collector system, logging residue was sold to a cement production company for co-firing of power generation. The price was 4000 JPY/t, which was converted to 2191 JPY/timber-log-m^3. In the case of H-type system, a woody biomass power generation plant purchased logging residue slash. The price was 2500 JPY/t excluding transportation cost. In the case of Endless-Tyler system, all logged timbers and slash were purchased by the other woody biomass power generation plant and the same cement production company. The woody biomass power generation plant is located in the west part of Kochi prefecture. Purchase price of the plant differs from 1500 to 7400 JPY/t depending on shape and water content of logs and slash.

Comparing the cost and income, income from log and residue not always compensate the cost. There exist subsidy programs offered by a local government. One of such subsidies is for thinning. When the thinning rate is more than 30%, a constant subsidy of 180000 to 300000 JPY/ha is provided to corresponding forest owner. This was applied to the cases of Collector system and H-type system. For clear cutting, a subsidy for rigging can be paid for a cable system, if its span is longer than 500 m, with 400 JPY/span-m. It was applied to the case of Endless-Tyler system. In the case of Collector system, total cost exceeded the income from logs. However, by adding income from residue and thinning subsidy, the deficit balance was compensated.

4. Conclusions

Logging cable systems have been important logging methods in Japan, especially in mountainous areas. The function of lateral logging is essential in order to reduce the costs of rigging up and down costs per logged volume. Among many rigging methods, the Endless-Tyler system is most popular while it is mainly applied to clear cut. In the present paper two modifications of Endless-Tyler system were discussed: the Collector system and the H-type system. The Collector system is used for thinning operations. Although its lower productivity often increases total cost, additional income from residue and subsidy would compensate the deficit. A set of H-system rigging up and down needs almost two fold of work as well as cost compared to normal Endless-Tyler system. However, a well-designed logging project reduces the burden of rigging cost as well as total cost, and also increases logging efficiency.

A current problem to be solved for cable logging operation is development of yarders. As shown in Figure 2, number of yarders has been declined. There is almost no forest machinery company that can provide new yarders. Most of logging contractors have no choice other than continuously keeping to use old yarders applying repair and heavy maintenance. Recently national projects for renovating development of yarders have started. It is also important for experienced cable logging engineers to hand over their prominent skills required for long range cable systems toward the next generation.

5. Acknowledgement

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* The titles are tentative translations from original Japanese by the authors.

The impact of road geometry and surface roughness on fuel consumption and travelling speed for Swedish logging trucks

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Abstract: Transport accounts for more than 25% of the Swedish forest industries' roundwood procurement cost at mill gate (exclusive stumpage). Fuel and wages each account for 1/3 of truck transport costs, so for further cost reduction and productivity increase it is important to better understand the impact of the transport environment on driving speed and fuel consumption. This study of a conventional 60-ton logging truck examined the correlations between speed and fuel consumption with independent variables such as gradient, curvature, road surface roughness, integrated gradient and functional road class. Functional road class captured many of these associated independent variables. Further analysis will focus on developing complete empirical models for the purpose of improved transport planning and pricing of logging truck transport as well as further refinement of the route selection system Calibrated Route Finder.

Keywords: logging truck, fuel consumption, speed, road geometry, gravel road

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1. Introduction

Transport accounts for more than 25% of the Swedish forest industries' roundwood procurement cost at mill gate (exclusive stumpage). Fuel and wages each accounted for more than 1/3 of truck transport costs (Brunberg 2012, Statistics Sweden 2014). Given that the current trends for increasing transport costs are expected to continue in the future, further R&D investments in fuel- and timesaving measures are necessary.

There have been numerous international studies of fuel consumption and travelling speed for heavy truck transport, but there is a need for studies covering forestry-specific conditions with typical road characteristics for logging trucks. This paper presents and discusses the results from a study focused on the impact of road geometry and surface roughness on fuel consumption (Svenson and Fjeld 2016) and travelling speed for a conventional Swedish 60-ton self-loading logging truck.

2. Material and Methods

In order to capture sufficient variation in the independent variables (gradient, curvature and road surface roughness), a 320 km long test track on both public and forest road was assembled in Värmland county in south-western Sweden. Studies of vehicle fuel consumption and speed were conducted for wet autumn conditions during November 2010 and for dry summer conditions during July, 2011. Each study was started with an empty truck (ca. 23 tons), followed by half loaded (ca. 43 tons) and finally with fully loaded truck (ca. 60 tons).

Data collection included two dependent variables – vehicle speed (Sp, m/s) and fuel consumption (Fc, l/100 km), and four independent variables – curvature (Cu, m^{-1}), surface roughness (Rsr, mm/m), gradient (Gr, %) and integrated gradient (Ig, %). Measures of curvature were derived by dividing 1000 by the curvature radius. Measures of surface roughness used the common measure IRI (International Roughness Index). Integrated gradient measures the additional vertical gain beyond average gradient in order to better describe the total vertical work done by the truck over a distance in undulating topography.

The study of vehicle speed and fuel consumption used a conventional 22 m, self-loading logging truck with a maximum allowed GVW of 60 tons. Vehicle speed and fuel consumption data was collected with equipment developed by VDI Innovation, (Drivec AB) which inductively reads and interprets the CAN-bus communication in the truck. Road geometry and surface roughness was measured with a Vectura P45 Profilograph; a high speed profilometer equipped with lasers, inertial sensors and GPS, figure 1 (Ahlin, Granlund et al. 2004). Each segment was also classified in terms of functional road class (Rc), where classes 1-6 and 7-9 most often are public roads and private forest roads respectively (Swedish Road Administration 2008).

Figure 1: The Vectura P45 Profilograph was used to for accurate measurement of road geometry and surface roughness.

The data from the two sources (Truck/CAN-bus and Profilograph) was merged meter by meter using the Spatial Join function in ArcMap10 (ESRI 2011). The 320 km route was cut into road sections of different lengths. One-thousand-meter road sections were used in the analysis, giving approximately 1700 observations. The resulting distribution of observations per functional road class is shown in figure 2. Analysis of the data was done in the statistical programme R (R Development Core Team 2014). The average, minimum, maximum and standard deviation for individual road characteristics are shown in table 1.

Table 1: Average values, range and standard deviation for gradient (Gr), curvature (Cu), surface roughness (Rsr) and integrated gradient (Ig).

Variable	Average	Min - Max	Standard deviation
Gr (%)	0.09	-7.79 – 7.85	1.75
Cu (m^{-1})	2.93	0.00 – 11.67	2.06
Rsr (mm/m)	3.98	0.89 – 17.31	2.36
Ig (%)	0.69	0.00 – 2.86	0.47

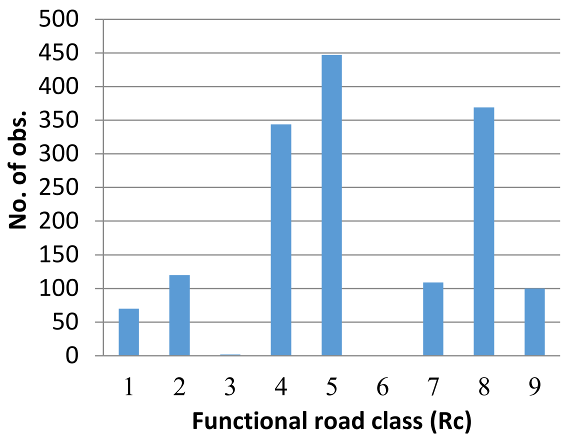

Figure 2: Distribution of 1000 m road sections per functional road class (Rc).

3. Results

The average fuel consumption and speed for the study was 71.4 litres/100 km and 14.6 m/s, respectively. Both fuel consumption and speed varied with GVW. Fuel consumption was 48.8 litres/100 km for 23 tons and 90.8 litres/100 km for 60 tons. Speed was 15.5 m/s for 23 tons and 13.5 m/s for 60 tons.

A Pearson correlation test showed that both fuel consumption and speed were correlated to the independent variables, gradient, curvature, road surface roughness, truck weight, integrated gradient and functional road class, table 2.

3.1. Fuel consumption

Examining the effect of gradient, fuel consumption increased more with increasing gradient than the corresponding decrease when driving down-hill, figure 3.

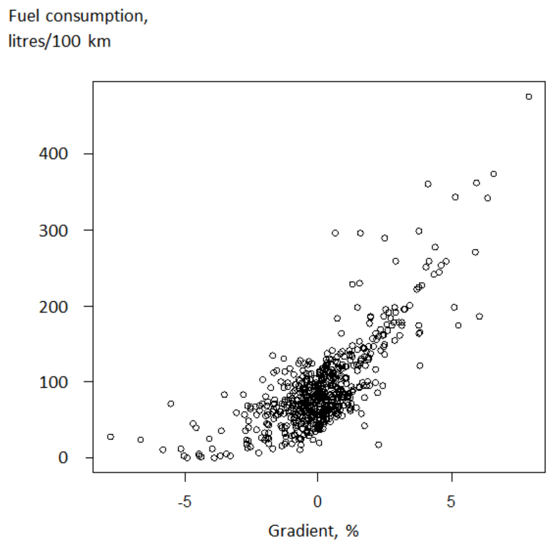

Figure 3: A scatter plot of fuel consumption (litres/100 km) and road gradient (%).

The increase in fuel consumption when leaving the better road classes (1-5) for forest roads (7-9) is attributed to the increased curvature and road surface roughness, figure 4.

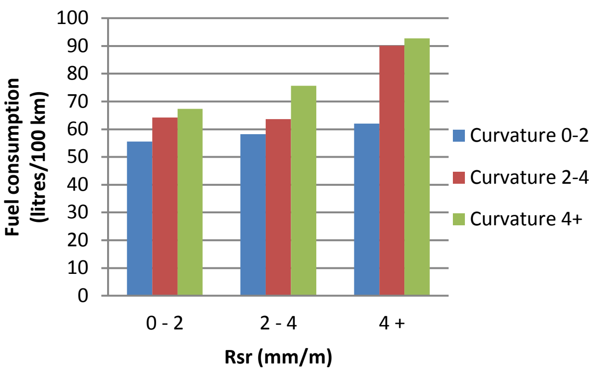

Figure 4: Average fuel consumption (litres/100 km) for different classes of road surface roughness (Rsr, mm/m) and curvature (m^{-1}).

Table 2: Pearson correlation matrix between speed (Sp), fuel consumption (Fc), gradient (Gr), curvature (Cu), surface roughness (Rsr), truck weight (Wt), integrated gradient (Ig) and road class (Rc) measured in the study.

	Sp	Gr	Cu	Rsr	Wt	Ig	Rc
Fc	- 0,52***	0,68***	0,27***	0,38***	0,37***	0,06**	0,27***
Sp	1	- 0,06*	- 0,69***	- 0,73***	- 0,19***	- 0,39***	- 0,70***
Gr		1	- 0,03	0,00	0,01	- 0,11***	- 0,02
Cu			1	0,52***	0,02	0,34***	0,40***
Rsr				1	0,04	0,38***	0,69***
Wt					1	0,01	0,02
Ig						1	0,38***
Rc							1

3.2. Speed

Regarding the effect of curvature on speed, the effect was greater on private than public roads (Figure 5, top row). Given the correlation between curvature and surface roughness, figure 5 (bottom row) also shows the effect of curvature for two groups of surface roughness (IRI<=2 mm/m and IRI>=7 mm/m). Low road values of surface roughness dominated on roads with low curvature and speed was correspondingly higher for these.

While speed was generally higher on public than on private roads, the effect of gradient was different depending on whether driving uphill or downhill (Figure 6). When driving uphill, speed decreased for both public and private roads, but driving downhill, speed increased on public roads and decreased on private roads.

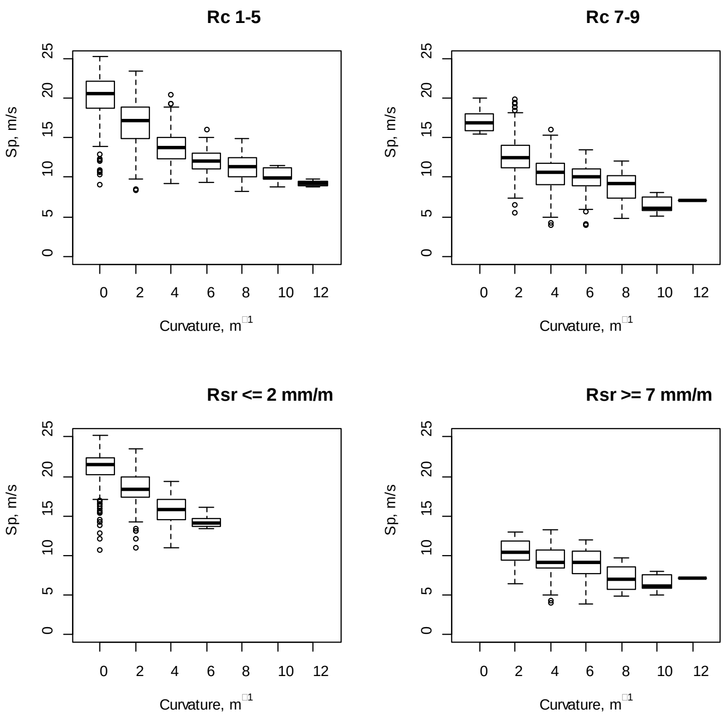

Figure 5: Boxplots of speed (Sp, m/s) versus curvature (Cu, m^{-1}). The top row left represents public roads (Rc 0-5) and top row right private roads (Rc 7-9). The bottom row left represents low surface roughness (IRI<=2) and bottom row right high surface roughness (IRI>=7).

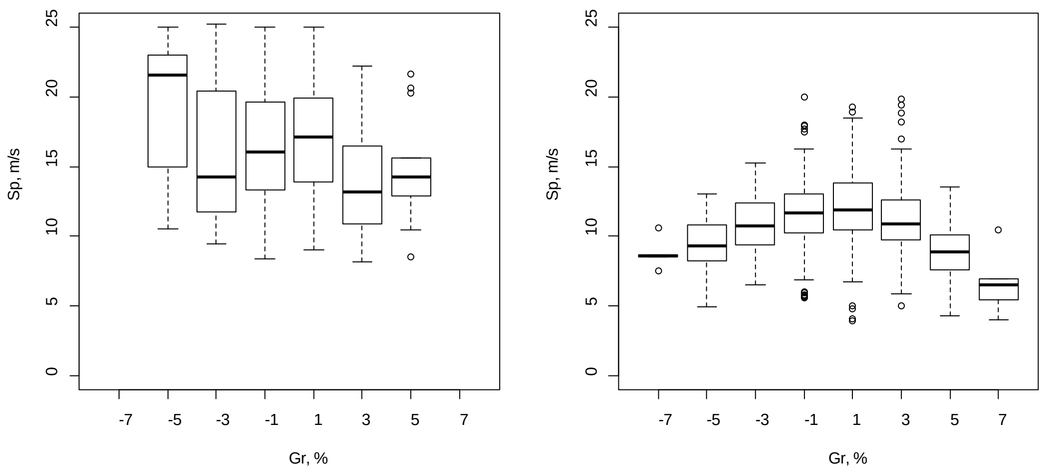

Figure 6: Boxplot of speed (Sp, m/s) versus gradient (Gr, %). The left picture represents public roads (Rc 0-5) and right picture private roads (Rc 7-9).

4. Discussion

The objective of this study was to quantify the influence of road characteristics on fuel consumption and travelling speed for a conventional 60-ton logging truck. The average fuel consumption was 71.4 litres/100 km and speed 14.5 m/s, respectively. The difference between the best public roads and the forest roads was substantial; fuel consumption varied between 62.6 litres/100 km and 129.8 litres/100 km, and speed 15.5 m/s and 13.5 m/s, respectively. The higher fuel consumption and lower travelling speed on the forest roads was attributed to the tighter curves, rougher road surfaces and increased undulation. This latter road feature was captured by introducing the variable integrated gradient (Ig). Integrated gradient, unlike gradient which describes the average inclination between the starting and ending point of a road section, measures the total vertical gain not already described by grade.

The results show that fuel consumption is mainly determined by gross vehicle weight and road gradient. However, both curvature and surface roughness were important to capture when modeling fuel consumption. Regarding travelling speed curvature and surface roughness had the greatest impact. In contrast to fuel consumption, gradient and integrated gradient played a smaller role for travelling speed.

For the study area used, there were strong correlations between the curvature, surface roughness, functional road class and integrated gradient. In this case functional road class captures the correlated variation in a number of road characteristics. This is similar to results shown earlier by Forsberg (Forsberg, Löfroth et al. 2002). Functional road class is, however, a subjective measure, aiming to describe the roads function in a road network and does not directly describe the typical transport environment for a logging truck with tighter curves and rougher road surfaces. In other areas of Sweden, functional road class will have another distribution of gradients and curvature and the general influence of road class may therefore vary. This requires that future studies should build on a broader sample of road networks.

A better prediction of the impact of road geometry and surface roughness on travelling speed provides a basis for more accurately modeling transport costs under varying transport environments. Better prediction will also improve road investment and maintenance calculations. Further analysis of the data will focus on complete empirical models describing the impact of the identified variables on fuel consumption and travelling speed, as well as the interactions between these variables. The final models will be useful for improved forestry transport planning, the development of transport tariffs which better reflect regional conditions and in the further refinement of the route selection system Calibrated Route Finder used by the forestry sector in Sweden.

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Wood yard design methodology for improved supply chain performance

Marta Trzcianowska*, Daniel Beaudoin, Luc LeBel

Abstract: Wood yard requirements are directly influenced by the operations happening upstream and downstream of its location within the forest supply chain. The performance of wood yard operations is closely related to its design. Despite the importance of wood yard design, this problem has attracted little attention in the scientific community. Most of the existing documents deal with specific sub-problems with no or little consideration of the inherent interactions. We hypothesize that a global analysis is indispensable to properly address the issue of wood yard performance. We also propose that a methodology specific to wood yard design is required. To this end, this paper introduces a description of current practice in wood yard design in the province of Quebec based on the results obtained through a survey. Current performance levels are presented and discussed along with performance criteria best suited for wood yard design evaluation.

Keywords: wood yards, warehouse design, performance indicators

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1. Why care about wood yards?

Wood yards fulfill an important role in the wood industry. Depending on their position in the wood supply chain, wood yards serve many purposes: accumulation of wood inventory, reloading point, log sorting, pre-processing of raw material, and feed the mill (Dramm, 2002). They are often a decoupling point in separating raw material and semi-products flows from forecast-driven production to customer order-driven production. In the context of the pulp and paper industry fiber supply, different sets of materials (e.g. logs, wood chips, recycled fiber bales) are processed and stored at the wood yard, according to adopted strategy of production (Lehoux et al., 2012). Moreover, wood yards functioning as a distribution and production warehouse, contribute to effectively manage the variability of raw material and supply the appropriate material. To respond adequately to production demand in terms of quality (freshness and humidity) and quantity of raw material, wood yards are operated according to one or several different strategies of inventory management: FIFO (First in First out), seasonal freshness wood management, truck turn-around time, JIT (just-in-time wood supply). The adopted strategies of wood yard inventory management depend on wood supply chain conditions, including implementation of JIT strategy (which allows unloading directly at the mill in-feed with a minimal on-site wood inventory) requires wood storage in other locations (forest site, satellite yards).

In order to fulfill their multiple roles, wood yards require significant capital investments and generate operational expenses: investment for land, building and equipment handling, holding and processing operating costs, site maintenance (e.g. drainage) and residues disposal. Material losses related to handling operations and wood deterioration due to long storage must also be considered. Based on the literature review, it is difficult to establish the total costs due to the wood yard design and operations. Myers and Richards (2003) provide a holding costs concept based on four harvesting scenarios. Favreau (2001) introduces the wood inventory costs model (O*pti-Stock*) in function of storage duration. Sinclair and Wellburn (1984) present a financial analysis (return on required investment). Moreover, they presented operational costs, but only on separate comparisons of equipment selections. Thus these costs do not represent all operational expenses. Based on the literature available and empirical observations, we believed that wood yards generate significant costs within the wood supply chain.

On the other hand, a wood yard can contribute to value creation if it is well integrated within the wood supply chain network, by pre-processing, sorting and trading of raw material between mills. The *Site Vallières* in La Tuque, Quebec, Canada is an example of such a value creation center where stems are sorted, cut to specified length (based on the mill's specifications), classified based on value and end-use (high value for peeled veneer, medium value for sawing, and lower value for chipping). The sorted logs are stored according to their destination in dedicated storage area, and then transported to the proper process mill (Gagnon, 2015).

Efficient wood yard operations that maximize the value of each log and minimize the costs requires specific design considerations. The performance of a wood yard operations is closely related to its design. The following are symptoms of problems that can be associated with a poor design: long truck queues to unload, long distances travelled by equipment to feed the mills, numerous equipment cross-flows, unused space.

For long established mills, most wood yards are the result of evolution over time in order to improve or maintain the yard performance under specific conditions. Wood yards must be adapted to a changing wood product market requirements. Common adaptations are expansion of the occupied area, leasing of unused storage area, addition of handling equipment. However, considering the design problems mentioned above, wood yard design adaptation over time seems insufficient to ensure global performance. Interviews with yard managers have revealed that current performance level at wood yards does not seem to be closely monitored.

Table 1: The main problems of wood yard design. Adapted from Gu et al. (2007).

General structure determination	Selection of operation strategy	Equipment selection	Layout determination	Sizing and dimensioning
Wood flow selection	Reception and expedition strategy	Equipment selection for unloading operation	Number, length, width and direction of aisles	Size of wood yard
Departments identification	Storage strategy	Equipment selection for handling operation	Entry location	Size and dimensions of departments
Relative location of departments	Order-picking strategy	Level of automation	Product allocation	

In order to examine the issue of wood yard design performance, it is necessary to consider all wood yard design decisions, their sub-problems and the interactions between them under the influence of the regional wood supply conditions. Table 1 presents the main decisions of the wood yard design and their sub-problems formulated according to a framework proposed by Gu et al. (2007) for warehouse design problems. Each of these decisions and their sub-problems interact with others (e.g. the raw material allocation depends on the order-picking strategy and available space; the aisle determination depends on equipment characteristics and size of departments). They also affect operational-level sub-problems, such as equipment assignment or sequence of order-picking, to mention a few (Gu et al., 2010; 2007; Rouwenhorst et al., 2000).

Wood yard can be seen as a specific case of the general warehouse design methodology. As such, its design must encompass the key specifications associated with the wood supply chain. Those include raw material properties (deterioration, breakage), transport specifications (seasonality of wood supply, truck arrival frequency, average load), and divergent processes. Wood yard design is also influenced by environmental limits associated with location and specific maintenance conditions (snow removal, debris disposal, sprinkling against dust). Managing such a complex problem requires a systematic method that allows to dynamically evaluate warehouse design and operation performance (Gu et al., 2010; 2007; Baker and Canessa, 2009; Goetschallckx et al., 2002; Rouwenhorst et al., 2000).

Despite the importance of warehouse design evaluation in dynamic environment, this problem has attracted little attention in the scientific community. Most of existing documents deal with separated specific sub-problems: loader-to-truck allocation strategies (Beaudoin et al., 2012), equipment productivity depending on yard distances (Tran, 2009), optimum storage space of unified and various products cases (Goh et al., 2001), storage strategy comparisons (Kulturel et al., 1999), order-picking policies examination for different types of order (Lin and Lu, 1999). The impact of supply chain characteristics on warehouse design and operations has not been thoroughly researched. However, it is important to mention two wood yard design methods proposed in the early 1980s (Sinclair and Wellburn, 1984; Hampton, 1981). While it is a significant contribution to the practitioners interested in improving their yard operations, they do not address the question of how to evaluate the wood yard performance in dynamic wood supply conditions.

In northern climate, wood yard operations are greatly impacted by the seasonality of wood supply. Strict restriction on transport in the form of weight limit or complete interdiction of heavy loads trucks are imposed in the spring (from the end of March to early June). Important accumulation of raw material in the wood yard before the thaw is required to avoid production shortage. Wood yard storage and equipment capacity must be adapted to these seasonal fluctuations. The difference in terms of wood yard inventory in March can be almost tenfold the volume in June. This volume must be efficiently handled by wood yard equipment under increased truck arrival frequency. As decisions concerning wood yard storage and equipment capacity are of strategic importance in wood yard design planning, they cannot be perfectly adapted to each seasonal variation. In this context, wood yard capacity decision must be made on volume estimation of high or low season with several considerations on how to manage the equipment over- or under capacity, and product space allocation during the year. Neither Sinclair and Wellburn (1984), nor Hampton (1981) addressed that important issue. Their methods are best applied in a stable wood supply setting.

There is an evident gap in research for creating a method to design a wood yard considering the seasonal wood supply variations. Therefore, the main objective of our research is to develop the wood yard design methodology that allows to establish the dependencies between all design decisions and their sub-problems. The proposed design methodology should account for wood yard performance evaluation under seasonal fluctuations of wood supply.

We propose a global analysis as a first step to properly address the issue of wood yard performance. To achieve this goal, we have determined two specific objectives to be pursued:

1) Document the current industrial practices in wood yard operations, management and design in order to highlight best practices.
2) Determine the key performance indicators that can serve to evaluate different wood yard designs.

This paper is organized in four sections. Subsequent to the introduction in Section 1, Section 2 describes the methods and materials applied for this study. Section 3 presents our initial results in our attempts to draw a general description of current wood yard practices (design and performance indicators). A conclusion and future work perspectives follows in Section 4.

2. Materials and methods

To establish a general portrait of wood yard design, management and operations, the data of resource utilization, volume handled and stored, inventory characteristics and operational rules were required. Based on a literature review on yard performance evaluation (Robichaud et al., 2014; Gu et al., 2010; Sinclair and Wellburn , 1984; Hampton, 1981) we classified required data in 6 categories:

1) Site (Inventory localization, yard departments area, site coating)
2) Wood supply characteristics (raw material and transport characteristics: supply periods, inventory levels in the yard during the year, trucks rate arrivals, truck

cycle time (in&out) and waiting time in the wood yard, high and low season)
3) Resources (personnel and equipment)
4) Design (storage strategy, measurement technology and environmental constraints that influence the design)
5) Management (inventory control and validation)
6) Performance (how the managers consider the performance of their wood yard, the indicators they use).

Empirical data was limited to the province of Quebec, Canada. As softwood constitute 73% of total harvest in Quebec, we chose that species group for our research. Our project is focused more specifically on the wood yard associated with softwood sawmills. We obtained a list of 78 Quebec Fir-Spruce-Pine-Larch sawmills with production capacity from 2 200 m^3 to 980 000 m^3. In order to comprehensively determine the degree of heterogeneity of wood yard resources, supply and design, we have added the criteria of production capacity exceeding 100 000 m^3. This constraint allowed us to select 61 mill yards. From this group, we discovered that 2 were not operating anymore. The final survey list contained 59 mill yards currently in operation.

We collected the data by means of a photogrammetric analysis (determination of wood yard departments and estimation of their area by the means of *Google Earth Pro*) and mail survey. Our wood yard survey was divided in 6 sections (presented above), and was validated in two ways:

I. Verification of the relevance of information to be collected (internally, with a researcher from FPInnovations, with representatives from two wood yard equipment companies)
II. Verification of the validity of information (with one-yard manager from the sample).

After minor adjustments following this validation phase, we sent the survey in a paper version to the 59 wood yards. Two reminders were made: by e-mails and telephone at monthly intervals (twice).

3. Results and discussion

We have received so far 32 completed surveys from sawmills located in 13 regions of Quebec (Figure 1). The following paragraphs present the general description of wood yards in Quebec based on results from this sample. Wood yard performance is then discussed.

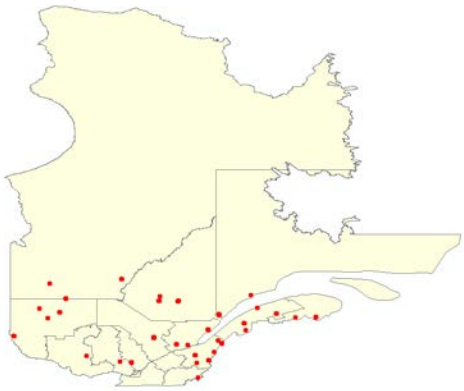

Figure 1: Location of participating wood yards.

3.1. Wood yard general portrait

The surveyed wood yards are varied in regards to resources, raw material characteristics and supply conditions. The volume handled annually varies from 60 000 m^3 to 950 000 m^3. The wood yards occupy an area ranging from 1.7 ha to 58.0 ha (11% to 87% of their total sites area). This is where the raw material is handled, pre-processed and stored. The coating of wood yards is mostly of beaten earth (47%) or gravel (41%); a small surface is of asphalt (8%) and of concrete (4%). According to respondents, the beaten earth surface influences wood yard performance by decreasing the speed of wheeled equipment or even by precluding the access of some parts of the storage area at certain times.

In our sample, the maximum volume is stored during March, whereas the minimum is in June (the average with the thick line on Figure 2), this is coherent with Quebec' seasonality and thaw period. At the peak season the average inventory level is four times the volume of the low season. The exchange of logs with other mills is performed by 25% of sites. The survey indicates that 30% of examined sites store wood for at least another mill, and this wood occupy on average 15% of their area.

Our survey indicated that on average wood yards use 5 sorts based on species, length, diameter, quality and provenance (public forest - 54%; private forests – 26%; Import [mostly USA] – 20%). The duration of raw material storage depends on the strategy adopted for inventory management. The average storage length is 3 months. Inventory control is mostly performed monthly (54% responses) or weekly (33%). The majority (88%) of wood yard managers consider their knowledge of inventory level and quality to be sufficient.

In order to handle logs and stem in inventory, wood yards use from 1 to 8 primary machines. Only 8% of these machines are shared between the wood yard and the lumber yard. The managers of 70% of examined wood yard reported being capable of adjusting the handling capacity of the wood yard on short notice (according to a weekly variation) and 65% of them for the duration of a season.

Among the wood yard design constraints that were reported, four stand out: residue management, site drainage, available space, discharge wastewater conditions (Figure 3). The other constraints include: weather conditions, inventory turnover, space conflict with finished products and wood reception variations. The managers of wood yards consider their sites efficient (67%). Performance is assessed in most cases by operational costs, average truck cycle time in the yard and wood freshness of wood.

3.2. Wood yard performance level

Current wood yard performance level is discussed based on a sub-sample of 8 yards with different levels for selected indicators. The four chosen indicators are: volume to the wood yard area ratio, storage density, average truck cycle time in wood yard, and operational costs. Volume to area ratio and storage density allow to establish the utilization rate of wood yard area, one of the most important warehouse resources. Average truck cycle time in the wood yard reflects equipment capacity adaptation, a key issue of wood yard design. Finally, in order to evaluate the wood yard performance, it is necessary to discuss operational costs. Moreover, operational costs and average truck cycle time in the yard for delivery trucks are mostly used by practitioners to evaluate their site performance (70% and 56% respectively from the surveys returned). Each of these four indicators will be discussed in the following sections.

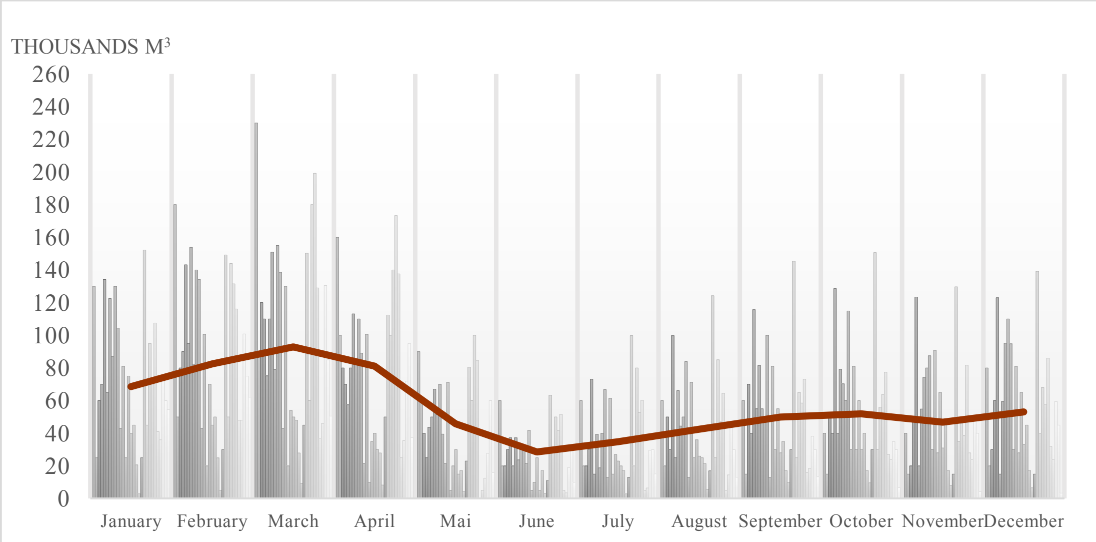

Figure 2: Monthly inventory level variations.

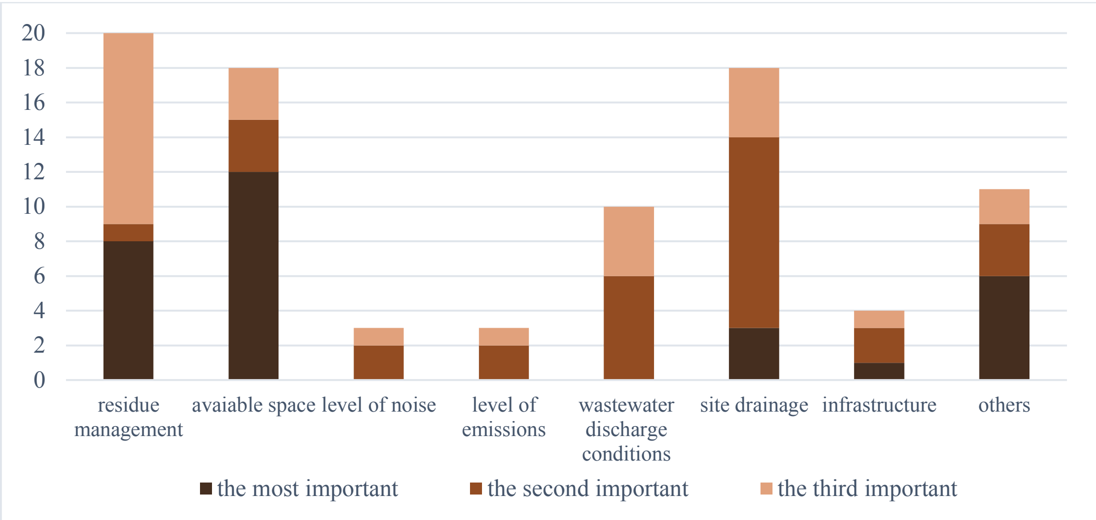

Figure 3: The most important constraints on wood yard design according to the wood yard managers.

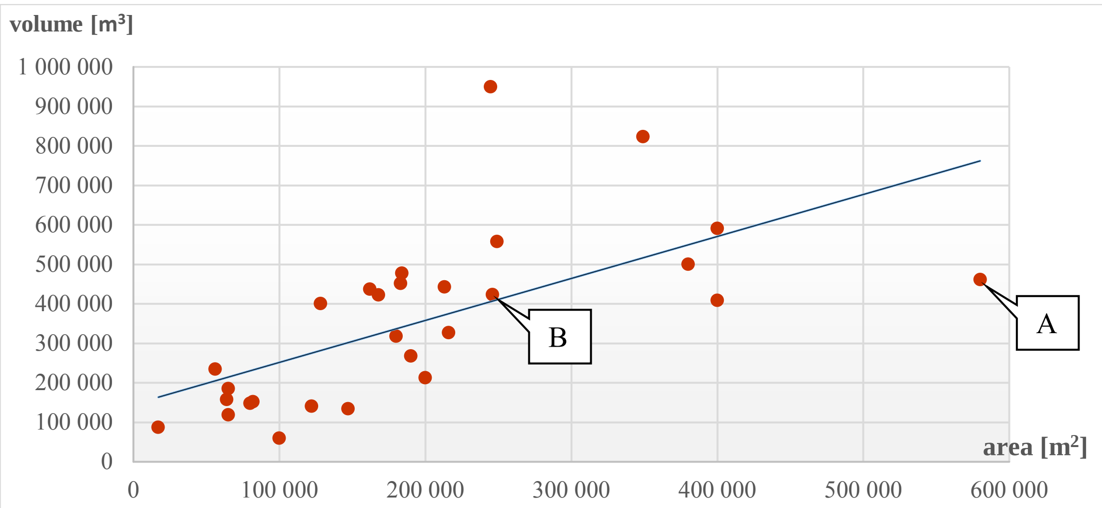

Figure 4: Average of volume handled from 2011 to 2015 to the wood yard area.

3.2.1. Volume to wood yard area ratio

We computed the average volume handled annually in relation to the wood yard surface area. In Figure 4, we can distinguish the wood yards with the biggest volume to surface area ratio. However, it is necessary to consider the wood supply context before presuming of their performance level. We chose two wood yards with similar volume (A: 461 664 m^3 and B: 423 000 m^3) and compared their area (A: 58.00 ha; 24.60 ha). Obviously mill B uses much less space to handle a similar volume as A. However, their supply chain context or strategy is quite different; mill B adopted a just-in-time supply strategy and the core of its inventory is placed in satellites yards. Our current data and information does not allow to judge of the appropriateness of this strategy. It indicates however the risk of a narrow focus on a specific performance indicator to benchmark wood yard against each other.

3.2.2. Storage density

This indicator was calculated in two ways: on maximum inventory reached during the peak season and on minimum inventory in spring/summer season. The maximum storage density in our sampled wood yards ranges from 0.30 to 2.37 m^3/m^2. The minimum ranges from 0 to 0.76 m^3/m^2. The storage density variations indicate the wood yard flexibility. However, this indicator is influenced by the raw material characteristics.

Table 2: Storage density evaluation (m^3/m^2).

	Wood yard C	Wood yard D
Maximum inventory (m^3)	50 000	50 000
Minimum inventory (m^3)	15 825	11 000
Storage area (m^2)	22 632	55 100
Maximum storage density	**2,21**	**0,91**
Minimum storage density	**0,70**	**0,20**
Number of log sort	**2**	**9**

In the Table 2 we consider the number of log sorts in storage density evaluation. The inventory of wood yard C is stored in two sorts, whereas the storage area of wood yard D includes 9 different log sorts. Fewer storage areas can explain higher density for wood yard C.

3.2.3. Average truck cycle time (in&out)

The average truck waiting time was also considered in relation to the two main transport seasons in Quebec: winter peak and spring restrictions.

Table 3: The average truck waiting time [min] consideration.

	Wood yard E		Wood yard F	
	Winter	Spring	Winter	Spring
Truck arrival frequency per day	80	20	85	15
Number of primary unloading equipment	4		1	
Number of spare unloading equipment used in peak season	2		0	
Average truck cycle time (min)	**30**	**9**	**50**	**20**

To analyze properly the performance of wood yard design based on this indicator, we must encompass the truck arrival frequency and unloading equipment capacity and flexibility - capacity to adjust equipment capacity of the wood yard in response to wood supply variations (Table 3).

3.2.4. Operational costs

The operational costs that were considered include unloading, measurement, stacking, maintenance and feeding the mill. Total cost ranges from 0,80 to 10,55 $\$/m^3$ with an average of 3 $\$/m^3$. As for previous indicators, the investigation of wood supply context is a critical aspect of performance evaluation as it dictates the wood yard operation strategy and thus the type and number of wood yard handling and processing operations which influence directly the operational costs. The cut-to-length logs sorted in the forest can be unloaded directly at dedicated storage area or at mill deck. Therefore, the operations of slashing and sorting are not performed at mill and the operational costs are lower in comparison to wood yards that receive non-sorted stem-length products. Another specification is the application of just-in-time inventory strategy. This setup allows to avoid the costs associated with double handling in the mill yard.

To present this concept we chose two wood yards with different wood supply context (Table 4). Wood yard G, with an operational cost of 1,50 $\$/m^3$ is paired with a satellite yard. Since the satellite yard operations are not considered by our survey, the main yard is credited with low operating costs. On the other hand, wood yard H with 6 $\$/m^3$ of operational costs applies a concept of maximizing the value of each log through several activities (measurement, classification, slashing, sorting). Therefore, we cannot measure global wood yard performance based on operational costs without a thorough context evaluation.

Table 4: Operational costs consideration ($/m3).

	Wood yard G	Wood yard H
Storage location	Satellite yard, mill yard	Mill yard
Received raw material	100% cut-to-length logs	Unsorted logs and stems
Included operations	Unloading, sorting, transport to the mill deck (if unloaded at the storage area)	Unloading, measurement, classification, slashing, sorting, transport (to the storage area and to the mill deck)
Operational costs ($\$/m^3$)	**1,50**	**6**

The operational costs of wood yards represent a non-negligible part of total wood supply costs. According to Del Degan and al. (2016), the average transformation costs for the Fir-Spruce-Pine-Larch sawmills in the Province of Quebec is 37,52$\$/m^3$. Therefore, wood yard average operational costs in our, represents almost 8% of total sawmill costs. Wood yard performance analysis is therefore indispensable to address the wood supply chain efficiency. Especially considering that only 32% of the surveyed wood yard designs have been systematically evaluated and improved over the last 15 years. A majority of current wood yard designs have simply evolved over time without specific design considerations. From their answers we believe that wood yard managers do understand the potential of design improvements: infrastructure enhancements, storage space optimization, optimization of material allocation (storage area to sawmill distance), precision of inventory control and validation, stock rotation, formation of equipment operators. That list confirms why it is necessary to investigate the wood yard design methodology in order to improve the performance of their activities and its integration with the wood supply chain it operates in.

4. Conclusions and future work

Properly addressing the wood yard performance level, requires to consider global wood supply conditions and combination with specific criteria analysis. Benchmarking of wood yard operations should be performed with close consideration of yard activities and supply chain context.

The general portrait of Quebec's wood yards presented in this paper will be completed with direct observations during site visits. We have selected sites to visit according to their current performance level, and wood supply conditions. The interviews with managers and operational staff will also serve to establish the major problems associated with the wood yard design. This database of wood yard characteristics will provide data to benchmark performance and highlight best practices of wood yard design, management and operations.

The next step required to develop a wood yard design methodology is to establish the dependencies between design and operation decisions. This information will then be compared with the yard design method proposed by Hampton (1981). The end results should be an extended method that proposes a systematic design and evaluation methodology for wood yards. Finally, the methodology will be applied to a sample of yards.

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Modelling knottiness of scots pines prior to or concurrently with logging operation

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Abstract: The forest industry is aware of dimensional and qualitative differences existing in the forest and is more willing to incorporate information about forest composition and potential markets into its production planning. Scots pines growing in Finland are known to possess huge quality and value differences. It is therefore of greatest importance that the quality differences could be taken into account when trees are crosscut at forest. The paper presents preliminary results of a study aiming at creating models that could be utilized in practical operations to increase value recovery of the final sawing products.

Keywords: wood quality, wood supply chain management

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1. Introduction

The quality and accompanying value of Scots pine (*Pinus sylvestris L.)* is known to have huge between-stand and within-stand variation (Heiskanen, 1954; Kärkkäinen, 1980; Uusitalo, 1996). The growth process of Scots pine and the characteristics affecting the knottiness of Scots pine is rather well-known (Mäkinen and Song 2002). Beside genetic factors, growth rate at the early stage of growth process correlates strongly with the size of knots at the lowest parts of the stem (Heiskanen, 1954; Heiskanen, 1965; Moberg, 2000; Uusitalo and Isotalo, 2005). The faster the young stem develops the thicker the branches tend to be. Thinn branches self-prune earlier than thick branches. Accordingly, the dead branch height (the distance from the stump height to the first dead branch) is widely proved and adopted characteristics to predict knottiness of Scots pines (Kärkkäinen, 1980; Uusitalo, 1997). Uusitalo and Isotalo (2005) states that among these two main characteristics, early growth rate seems to be more appropriate in predicting between-stand variation and on the other hand dead branch height is more appropriate for predicting within-stand variation.

Even if the correlation between the main characteristics and quality of pine is widely known, we are still lacking suitable methods to fit information on pine quality into stem pricing and quality bucking procedures. Hence, huge amount of income is lost every day in sawmilling business. The paper presents preliminary results of a study aiming at creating models that could be utilized in practical operations to increase value recovery of the final sawing products.

2. Materials and methods

The study material comprised eight stands from southern Finland, situated in the municipalities of Hämeenlinna, Orimattila and Myrskylä. The sites were grove-like (OMT), mesic (MT) and dryish (VT) heath. The forests were dominated by Scots pine (*Pinus sylvestris*) or Norway spruce (*Picea abies*) and were roughly 90 to 120 years in age.

Prior to forest operations, 30 sample trees were selected. The sample trees were numbered and marked with colored ribbons to allow easy detection during harvesting. These trees were measured for diameter at breast height (Dbh), tree height (H_t), dead branch height (H_{dbr}) and crown height (H_c) while still standing. Dead branch height was defined as the distance from stump height to the first dead branch having minimum size at least 15 mm. The crown base was defined to be the lowest whorl having at least one living branch with green needles and that is separated from other living whorls above it by one dead whorl at most.

The study stands were clear-cut during autumn 2014 with three harvesters: two manufactured by John Deere and one by Komatsu. In tree bucking the long log bucking method applied by the Koskisen Oy were applied. It means that only one long saw log from 8 to 20 meters having minimum small end diameter 15 cm is cut in forest and remaining stem part is processed as pulp wood logs and/or energy wood logs. While processing, tree taper data for each commercial tree was registered in the STM-format (StandForD 1997).

The long logs were hauled to Koskisen Oy sawmill where the long logs were scanned and bucked to 4 to 6 meter long saw logs at the bucking terminal. Prior to scanning the bottom face of each sample log was photographed. The sample logs were scanned with X-ray apparatus at the bucking terminal. We applied factor 1.12 to convert scanned knot sizes to knot sizes at boards.

Images of the bottoms of the logs were analyzed with an image analyses tool. The scale of image was proportioned to true scale by proportioning the diameter of the bottom face of the log in the image to the big end diameter of each log. The following characteristics were derived from the images: tree age (AGE) (number of year rings at stump height), early growth rate ($RW_{11\text{-}20}$)(radial growth rate (mm/y) at the age of 11 to 20). Due to different problems in linking the information and detection of tree numbers, the whole study material comprise 204 long logs.

All knots detected and converted to knots sizes on “virtual boards” were compared to knot size of 28 mm. This refers to the maximum A-quality dead knot of 50 x 175-225 size sawn good (the Nordic Timber grading rules). A new stem characteristics, height of the B-grade dead knot, for each log was derived. This refers to the distance from stump height to the point where the first B-grade dead knot is found. X-ray cannot detect whether the knot is dead or not. However in this comparison all knots were regarded as dead knots since earlier studies has shown that below 7-8 meters dead knot is the primary criteria that lowers the quality from A to B (Uusitalo et al., 2004; Uusitalo and Isotalo, 2005). Taking into account the character of natural variation of knottiness and tree bucking procedures, it was decided that the mixed logistic regression technique was the most appropriate way to model this phenomenon. The occurrence of the B-grade knot was formed as a binary variable for three different cross-cutting points (370, 490 and 610 cm); whether the first B-grade knot has already shown up or not.

3. Results

It was noticed that dead branch height is the best single stem characteristics in predicting quality of standing trees prior to logging operations. The logistic model including dead branch height as the main stem characteristics predicts correct quality at each crosscutting point in success of 64…67 % of all cases.

The models including early growth rate and dbh as the main predictors provides even more accurate predictions for the occurrence of B-grade knot at various cross-cutting points. They provide predicts correct quality at each crosscutting point in the success of 67…71% of all cases.

4. Discussion

Results are in accordance with earlier investigations in regard to the correlations of early growth rate, dead branch height and knottiness of Scots pine (Heiskanen, 1954; Kärkkäinen 1980, Uusitalo, 1996; Uusitalo and Song, 2002). Dead branch height is measured for standing trees. According to Uusitalo and Kivinen (1998) trustworthy prediction of bivariate dbh – dead branch height distribution within a typical forest stand requires measurement of 20-30 trees. Until now, pre-harvest sampling prior to harvesting has however been regarded as too expensive to carry out in practice. Novel technical solutions may however bring inexpensive solution to collect quality data prior to logging operations. Emerging machine vision solutions, such as Terrestrial laser scanning (TLS) or modern digital camera applications offers an effective method to collect high-detail information on forest attributes. It might be that in the future measurement of quality attributes prior to logging operations is carried out routinely in all forest stands.

Early growth rate seems to be even better predictor than dead branch height. Early growth rate can be detected at moment harvester fells the tree. Assuming suitable image analyses application can be developed, early growth rate can be scanned and analyzed with a camera assembled at the harvested head. As a result, information on early growth rate can be linked with bucking procedures of modern harvesters.

5. Acknowledgements

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Chapter 2. Bioenergy and quality improvement

Fuel quality changes and dry matter losses during the storage of wood chips - Part 2: container trials to examine the effects of fuel screening

Theresa Mendel*, Daniel Kuptz, Hans Hartmann

Abstract: Biological degradation during storage may cause high dry matter losses and a decline in fuel quality. This process might increase with a higher amount of fines in the fuel. Therefore, the aim of this study was to monitor dry matter losses and fuel quality changes of screened (particle diameter > 8 mm) and unscreened (as received) wood chips. These two variants were observed for five different raw materials of fresh wood chips. Samples were filled in containers (0.6 m³) with perforated bottoms and were stored in an outdoor shelter for five months. After 23 weeks of storage, the average decrease in moisture content was 21.5 w-% (± 4.2 w-% SD). Average dry matter losses were 8.6 w-% (± 6.1 w-% SD). Screening of wood chips led to a positive drying effect and also dry matter losses were smaller compared to unscreened samples. Accordingly, temperature difference between wood chips and ambient air increased significantly with higher amount of fines. Moreover, the results on drying and dry matter losses during the trials with container storage reached similar levels compared to field trials under practical conditions. Therefore, small scale container trials can be a simple method to assess storage behavior of wood chips on larger scales

Keywords: wood chips, fuel quality, storage, dry matter losses, screening

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1. Introduction

Wood chips quality varies largely due to different raw materials and processing techniques. However, biomass boilers and biomass heating plants require homogeneous fuel qualities to operate efficiently (Noll & Jirjis, 2012; Thörnqvist, 1984), as fuel quality influences boiler operation and emission behavior during combustion. Especially small boilers rely on homogeneous and high quality fuels (Kuptz & Hartmann, 2014). High quality wood chips are characterized e.g. by low and homogeneous moisture contents, low ash contents and a small amount of green biomass, bark and fines (Neuhof *et al*., 2012).

Storage of fresh wood chips is an important step of the biomass supply chain as it is used to compensate for temporal and spatial differences in fuel supply and demand. Moreover, wood chips are frequently stored for drying. The rate of drying however depends on numerous factors. Physical factors of wood chips such as particle size and amount of fines have an influence on drying, but also external factors like air temperature, relative humidity, wind exposure and precipitation are important for natural drying (Pettersson & Nordfjell, 2006). Drying in wood chip piles follows the principle of natural convection (Neuhof *et al*., 2012). Thereby, due to self-heating processes, cold ambient air streams into the pile take up moist and warm air and transport it to the surface of the pile.

At the same time, biological degradation processes during storage may cause high dry matter losses and a decline in fuel quality. These processes might even be enhanced by a large amount of fines. Small particles like needles, small twigs and leaves not only offer a large surface area but are also rich in macro-and microelements and build an additional source for microbial colonization (Noll & Jirjis, 2012). Furthermore, free water molecules enhance the biological degradation (Scholz *et al*., 2004; Hartmann, 2016). Optimal moisture contents for fungal growth are between 30 and 50 w-%. Below a moisture content of 20 w-% no further growth is to be expected. Air temperature is one of the most important external factors affecting not only the rate of drying but also the rate of decomposition. Mesophilic fungi show optimal growth in a range between 20 and 35 °C and tolerate temperatures up to 40 °C, whereas thermophilic fungi show optimal growth rates within a temperature range between 35 and 55 °C (Scholz *et al.*, 2004).

Storage trials to examine the effects of different wood chip properties on dry matter losses are usually done in large field trials. However, such trials consume time and labor and are very cost intensive. Thus, for the current study, container trials were conducted to determine the effect of fine particles on dry matter losses and drying effects. To test the validity of this procedure for future studies, container trials were performed in parallel to field trials (see Hofmann *et al.,* 2016, i. e. part 1 of this study).

2. Material and Methods

In total, five different raw materials of wood chips were stored, i.e. wood chips from forest residues (FRC) of deciduous and coniferous trees, wood chips from energy roundwood (ERC) of Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*) and wood chips from short rotation coppice (SRC) of European poplar (*Poplar spp.*) (Fig. 1). Each raw material was stored in two variants: screened (particle diameter > 8 mm) and unscreened (as received). Screening was done with a custom built drum screen (hole diameter = 8 mm). Wood chips were filled into 0.6 m³ containers (Fig. 1). Container bottoms were perforated with holes (2 cm diameter) to ensure natural aeration. To prevent small particles from falling through the holes, a net was placed on top. To insure a microclimate similar to large storage piles, all side walls of the containers were insulated (Fig. 1).

Storage was performed over 23 weeks starting in May 2015. The storage took place in a rain and wind protected outdoor shelter to minimize influencing factors on the drying rate such as wind speed and precipitation. Each container was equipped with a temperature sensor in the middle of the container to constantly monitor wood chip temperature. Furthermore, air temperature and relative humidity were recorded in 30 min intervals during the storage period. Moisture content (in w-%) of each type of wood chips was determined before (n=6) and after storage (n=6) according to EN 14774-2 (DIN, 2010a). To compare the effect of particle size and, especially of the fine fraction, particle size distribution was determined according to EN 15149-1 (DIN, 2010b). To monitor mass changes during storage, containers were weighted every third week. Moisture content could only be analyzed before and after the full storage period. Otherwise, storage conditions within the containers would have been disturbed. Accordingly, dry matter losses were calculated by the dry weight before and after storage.

Figure 1: Five raw materials of wood chips used and containers in outdoor shelter (Energy roundwood chips of Norway spruce (1) and European Beech (2), Forest residue chips from deciduous trees (3) and conifer trees (5) and wood chips from short rotation coppice of poplar (4)).

3. Results and discussion

3.1. Particle size distribution and wood chip temperature

Unscreened wood chips of all types could be classified as P31 according to ISO 17225-1 (DIN, 2014a). The only exception was forest residue chips from deciduous trees (P45, see Tab. 1). For three of five assortments, screening had a positive effect on particle size distribution as screened wood chips could now be classified as one of the 'S-classes' according to ISO 17225-4 (DIN, 2014b). Hence, these wood chips could now be recommended for small-scale applications after screening due to higher fuel qualities. In one case, screening had an adverse effect. Due to the loss of the fine fraction, wood chips could neither be classified according to Part 1 nor to Part 4 of the ISO standard. Table 1 shows that approximately 10 to 30 w-% of fine material (particles ≤ 3.15 mm and ≤ 8 mm) were lost due to the screening process.

Table 1: Particle size distribution of wood chips and percentage of particles < 3.15 and 8 mm.

Wood chip type	Particle size class (according to ISO 17225-1/-4)	Particles <3.15 mm [w-%]	Particles <8 mm [w-%]
FRC coniferous trees [unscreened]	P31 / n.c.*	15.1	34.6
FRC coniferous trees [screened]	P31 / P31S	0.8	14.7
ERC spruce [unscreened]	P31 / P31S	7.5	17.8
ERC spruce [screened]	P31 / P31S	0.2	6.5
FRC deciduous trees [unscreened]	P31 / n.c.*	17.4	33.6
FRC deciduous trees [screened]	P45 / P45S	1.2	6.0
ERC beech [unscreened]	P31 / n.c.*	14.5	30.5
ERC beech [screened]	P300 / n.c.*	0.1	1.6
SRC poplar chips [unscreened]	P31 / n.c.*	11.5	34.5
SRC poplar chips [screened]	P31 / P31S	2.0	13.4

*n.c. = non classifiable according to ISO 17225 (Part 1 or Part 4)

Temperature measurements within the containers of unscreened wood chips showed on average higher temperatures compared to air temperature (Tab. 2). Thereby, temperature was higher compared to the respective screened variant. After two days of storage, ERC of beech reached an overall maximum of 39.1 °C. The FRC of deciduous trees also showed peak temperatures during the first days, whereas all other variants reached maximum temperatures during the hot and dry summer months. The reason for the different temperature development might be explained by the different moisture contents at the beginning of storage. The moisture content of FRC of deciduous trees and ERC of spruce had moisture contents between 33 and 40 w-% which is within the optimal range for fungal growth (Scholz *et al.*, 2004; Hartmann, 2016). Storage of all other variants started at higher moisture contents, therefore they had to dry first in order to reach optimal fungi growth rates.

Interestingly, temperature increase in the small storage containers was lower compared to temperature increase in larger storage piles (see Hofmann *et al.*, 2016, i. e. part 1 of this study). Thörnqvist (1985) made similar observations in his study. Due to their small storage volume, temperature in small piles (< 120 m³) usually follows ambient air temperature.

The temperature difference (Δ) between ambient air and wood chip temperature positively correlated with the amount of fines ($p \leq 0.05$, Pearson correlation; Fig. 2). The larger the fine fraction (particles ≤ 3.15 mm), the higher was the temperature development in wood chips. A large amount of fine particles can lead to a decrease in aeration, causing a heat accumulation within storage containers. Moreover, they display a larger surface for microbial infection and usually they also provide a larger share of easily available nutrients for microbial communities enhancing their growth and thus, enhancing self-heating of storage piles. This effect was distinct for the amount of particles ≤ 8 mm.

3.2. Metereological data and weight losses

During the storage period, mean air temperature from May until October was 19.0 °C and relative humidity was 65.2 %. Temperatures during this storage period were on average 3 °C warmer than during the previous 10 years (DWD, 2016). Especially, during July and August temperatures were high (ø 24.0 °C) and relative humidity was low (ø 57.9 %). Due to a warm and dry climate, saturation deficits of the air were high (9.1 hPa). This lead to weight losses of wood chips ranging from 21 to 53 w-% after 23 weeks of storage. Weight measurements did not show significant differences between unscreened and screened variants. On average, wood chips lost approximately 1.7 w-% per week. Thereby, mean weight losses within this period significantly correlated with saturation deficits of ambient air ($p \leq 0.05$, Pearson correlation). Hence, the higher the saturation deficits, the higher the weight losses observed.

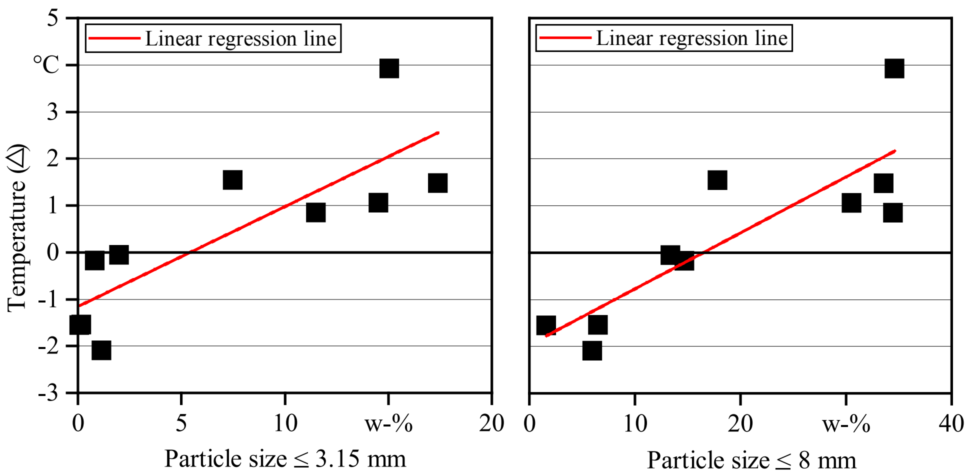

Figure 2: Correlation of the share of particles having a particle size ≤ 3.15 mm (left figure) and a particle size ≤ 8 mm (right figure) and temperature (Δ = difference in wood chip and ambient temperature) of all wood chip types and variants.

Table 2: Moisture contents before and after storage (Δabs: difference absolute), average temperature increases in containers and dry matter losses.

Raw material [unscreened/screened]	Moisture content [w-%] 0 weeks	23 weeks (Δabs)	Average temperature (Δ*) [°C]	Dry matter losses [w-%]
FRC coniferous trees [unscreened]	49.6	25.9 (-23.7)	22.9 (+3.9)	11.6
FRC coniferous trees [screened]	46.3	19.3 (-27.0)	18.8 (-0.2)	7.5
ERC spruce [unscreened]	51.2	30.4 (-20.8)	20.5 (+1.5)	8.7
ERC spruce [screened]	51.7	27.9 (-23.8)	17.4 (-1.5)	4.2
FRC deciduous trees [unscreened]	33.2	19.7 (-13.5)	20.0 (+1.1)	4.2
FRC deciduous trees [screened]	32.7	16.1 (-16.6)	17.4 (-1.6)	1.7
ERC beech [unscreened]	39.4	19.3 (-20.2)	20.4 (+1.5)	7.0
ERC beec [screened]	39.3	16.2 (-23.1)	16.9 (-2.1)	4.0
SRC poplar chips [unscreened]	68.9	49.1 (-19.8)	19.8 (+0.8)	21.7
SRC poplar chips [screened]	67.5	41.3 (-26.2)	18.9 (-0.1)	15.5

3.3. Moisture content and dry matter losses

During 23 weeks of storage, moisture content on average decreased by 21.5 w-% (± 4.2 w-% SD) for all variants. Thereby, screened variants showed significantly smaller moisture contents compared to their unscreened variants ($p \leq 0.05$, Students t-Test). With the exception of wood chips from spruce and poplar and the unscreened forest residues chips of coniferous trees, all variants reached moisture contents < 20 w-% after five months of storage (Tab. 2). Therefore, all these variants could be declared as 'stabile in storage'. In contrast, variants with moisture contents > 20 w-% could be exposed to decomposition due to microbial activity even after five month storage. Therefore, longer storage duration might have caused even higher dry matter losses for poplar and spruce chips and for the unscreened variant of FRC of coniferous trees.

Mean dry matter losses for the five month storage period measured 8.6 w-% (± 6.1 w-% SD). Overall, screened variants showed smaller dry matter losses compared to the respective unscreened variant (Tab. 2). Furthermore, moisture content at the beginning of the storage period strongly correlated with dry matter losses ($p \leq 0.05$, Pearson correlation; Fig. 3). This might be due to the fact that these wood chips were exposed to optimal moisture contents for fungal growth, i.e. 30 – 50 w -%, for a longer period of time.

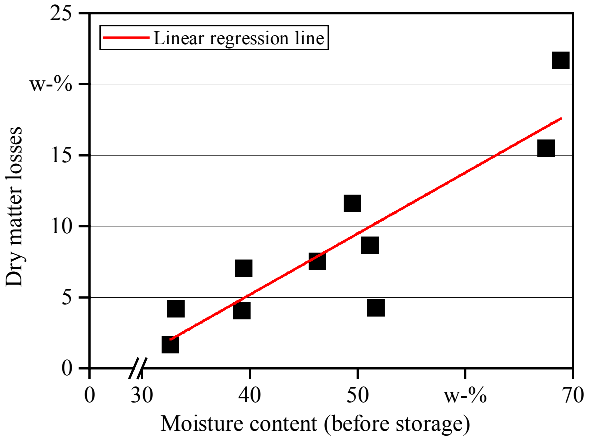

Figure 3: Correlation between moisture content before storage and dry matter losses after storage of wood chips.

In large storage piles (see Hofmann *et al.*, 2016, i. e. part 1 of this study) dry matter losses were 11.1 and 6.9 w-% for forest residue chips and energy roundwood chip pile, respectively; both piles had been arranged with rain protection. Therefore, even if the temperature development in containers was substantially smaller, dry matter losses of the two assortments reached similar levels as in the field.

4. Conclusion

Screening of wood chips not only leads to better drying but also to smaller dry matter losses during storage. The study confirmed that drying and dry matter losses depend on numerous external and physical factors such as the amount of fines or ambient air humidity and that these factors are also interdependent. Thereby, screening of wood chips usually leads to higher fuel quality and a favorable classification according to ISO 17225-4. However, due to the screening process approximately 10 to 30 w-% of wood chips are separated and may be regarded as loss if no commercial use can be found. Higher fuel prices of the screened material may compensate for this loss but profitability of screening might be critical on an economic basis. Hence, there is a need for further investigation concerning the effectiveness and profitability of screening processes on fuel quality and drying of wood chips in large storage piles.

The results on drying and dry matter losses during the trials with container storage had reached similar levels compared to field trials under practical conditions. It may therefore be concluded that trials using small storage containers (0.6 m³) can be an applicable and relevant low cost method to assess storage properties of various fuel treatments and drying stages. But further validation of this finding is needed.

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Variability of energy woodchips and their economic effects

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Abstract: The main aim of the work is to assess physical parameters of forest woodchips and their impact on the prices achieved by the supplier in transactions with a power plant. During fragmentation of logging residue, high content of green matter and contaminants negatively impacts the quality parameters that serve as basis for settlements. The analysis concerns data on the main parameters – water content, fuel value, sulphur and ash content – from 252 days of deliveries of forest chips to a power plant. The deliveries were realised from forested areas on an average about 340 km from the plant. Average water content and the resultant fuel value of forest chips was within 27–47% and 8.7–12.9 $GJ \cdot Mg^{-1}$ (appropriately), respectively. They depend on the month in which they are delivered to the power plant. The threshold values for the above-mentioned parameters are set by the plant at a real level and the suppliers have no problems with meeting them. The parameter that is most frequently exceeded is ash content (11.5% of cases). The settlement system does not differentiate on the basis of the transport distance but gives possibility to lower the settlement price when the quality parameters are not met but provides no reward for deliveries with parameters better than the average ones. On the basis of results obtained, it was calculated that average annual settlement price is lower than the contract price by about 0.20 $PLN \cdot GJ^{-1}$, which in case of the analysed company may translate into an average daily loss of about 700 PLN.

Keywords: forest biomass, transport, fuel value, ash content, forest woodchips, woodchip prices

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1. Introduction

According to the Ordinance of the Minister of Economy, dated 18 October 2012 (Dz. U. 2012, poz. 1229), the renewable energy sources do not include electricity or heat produced from full-value wood. This provision secures the valuable wood resource being used as fuel and, at the same time, results in interest in wood resources that were used to a small extent up to this point. This means that logging residue and biomass are mostly acquired during cutting activities. Creation of chips from such material is, however, burdened by a number of problem. The most crucial problems are the high degree of dispersal of biomass in forests, low yields and high content of green mass. This results in higher acquisition costs for the chips.

As with all types of business activity, also in this case, all the business entities involved in the process of acquisition, transport and burning of the material must achieve an acceptable level of economic gains. Many of the characteristics of this sector results in a situation that not all the entities present in the individual segments of the sector achieve the expected profit. In most cases, this is due to the circumstances beyond the control or any choice of the companies. Such factors include dispersal of material on large areas, low 'density' of the material in the forest, location of power plants, high share of transport costs (large distances) and variability of physical and chemical characteristics of chips (fragment size, water content, ash content, hydrogen content, sulphur content, fuel value).

From the viewpoint of the recipient of the chips – the power plant – the most crucial parameter of the material is the fuel value that is directly related to the water content of the material. The water content, in turn, is dependent on environmental conditions and, to a large extent, on the season in which the chips were acquired. The prices that the power plant is willing to pay is the result of these parameters. But is the supplier able to impact the physical parameters of the material supplied? – The impact is very limited. Therefore, should the supplier bear the costs related to lower parameters of the material that are beyond its control?

This work aims to assess the physical parameters of woodchips during a calendar year and their impact on prices on the industrial market in settlements with a power plant.

2. Materials and Methods

The subject of the analysis was information originating in a period from August 2013 to April 2015 which covered 252 days of chips deliveries by a single company to the power plant. Owing to the maintenance works in the power block fuelled by the biomass, there were no deliveries in July.

Transport from forests to the power plant (average distance of 300 km) was realised using trailer trucks with capacity of 90 m^3 equipped with movable floors.

The procedures used to assess the water content, heat of combustion, fuel value, sulphur content and ash content were based on norms PN-EN 13183-1:2004, PN-ISO 1928:2002, PN-G-04584:2001, PN-EN 15289:2011, PN-EN ISO 16994:2015 and PN-ISO 1171:2002.

The distance between the forests and the power plant (accuracy ±1 km) was analysed based on the data from the vehicle fleet database of one of the chips suppliers and the analysis of parameters of chips was based on the data agreed and signed in the contract between the supplier and the energy company.

3. Results add discussion

On basis of analysis of randomly chosen 186 deliveries of chips, it was established that the average transport distance was 341.25 km (SD=65.12) and was between 188 and 499 km.

Average water content and the resultant fuel value of the chips supplied to the power plant is directly related to the atmospheric conditions and the month of delivery. The lowest average water content (27.74%; SD=3.00) and the highest fuel value (12.94 $GJ \cdot Mg^{-1}$) were observed in case of chips supplied to the power plant in September. Owing to the fact that timber harvesting took place a few months before chipping, the forest biomass in form of branches and treetops rested on the ground during the summer season and decreased its water content naturally. From October onward, the water content increased – lower temperature, rainfall and snowfall – down to the maximum water content in February, 47.12% (SD=4.47). From March to September (spring/summer), the water content decreased and the fuel value increased. The fuel value of chips delivered to the power plant was similar to the values determined by, amongst others, Gendek and Zychowicz (2014), Günther et al. (2012) or Phanphanich and Mani (2009), which at low humidity (5–7%) may achieve about 18 $GJ \cdot Mg^{-1}$.

Another important parameters controlled by the power plant are the content of sulphur and ash. The average sulphur content in individual months was between 0.016% and 0.022% (minimum 0.01; maximum 0.027) and did not exceed the upper threshold value of 0.3%, which corresponds to biomass sulphur content of 0.02%, determined by Komorowicz et al. (2009).

An important parameter from the viewpoint of the supplier, which results in decrease in price for exceeding the threshold values is the ash content. The average ash content in the analysed chips, in most cases, was about 3–4%. This is about 1 percentage point above the values present in the literature for branch chips (Phanphanich M., Mani S. 2011) and about 1–2 percentage points above the values given for chips acquired from whole trees. In the analysed period, there were 29 days (11.5% of all deliveries) of deliveries where the value exceeded the threshold. The highest values were recorded during the summer months (June and August), whereas the average ash content in June was above 5% and close to that value in August. During the above-mentioned months, the largest diversity of measured values was observed.

Taking into consideration the contractual and the measured parameters of chips supplied to the power plant after accounting for the deductions for exceeding the norms, the average settlement price for GJ of energy is calculated. Depending on the month of deliveries, the settlement price is from less than 10 to more than a few dozen groszy (1/100 PLN) worse than the basic price. The largest difference is present in June and August, when the number of deliveries with excessive ash content was the largest. These are, however, summer months where the demand for energy is lower and the daily deliveries are reduced in comparison to other months.

The settlement price is related to daily deliveries and may be corrected only downwards if the required parameters are not met by the supplier. As it was mentioned earlier, there is no award for deliveries of higher quality. This system means that every negative deviation from the set values decreases the settlement price and that there is no mechanism that could increase the said price. In such a case, determination of the settlement price on the basis of average monthly values of quality parameters is not the correct mechanism.

When assessing the settlement system between the suppliers and the recipients of the forest woodchips, we have to state that in many cases, it works to the detriment of the supplier, resulting in the basic price being lowered in all the analysed months.

In the analysed case of a single supplier, the average annual settlement price for 1 GJ of energy was about 0.2 PLN lower than the contract price, which translates into daily loss for the supplier of about 700 PLN and during a month (depending the number of days with deliveries) from a few thousand PLNs to (in some extreme cases) about 14,000 PLN.

4. Conclusions

The settlement system used for the delivered chips is disadvantageous for the suppliers. It allows for the price being lowered if some of the parameters are not met but does not foresee a method for increasing the price.

The analysed method of settlement between the supplier and the recipient of forest chips does not take into consideration the distance between the location where the material is acquired and the location of the recipient. If this is possible, the transport distance should be taken into consideration when setting the basic price.

5. Remarks

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Future need of forest biomass supply chains at the regional level of South Savo in Finland

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Abstract: The future need of harvesting machines and transportation vehicles should be estimated at the regional level of Finland to analyse entrepreneurs´ investment possibilities. Large industrial and energy wood investments are reflected also in the machine investments and job opportunities in the harvesting and transportation sector as a result of the more efficient use of forests. The forest industry's major investments are being realized mainly through centralization, but forest energy potential could generate decentralized opportunities and economic growth also in the regional level, alongside the existing forest industry. The aim of the study was to measure the future need of alternative forest biomass supply chains at the regional level (a province, South Savo in Finland) emphasizing either industrial or energy wood end-use targets by 2020-2030. The study showed the increasing need of machines, vehicles and systems used in forest biomass supply chains but the share and number of alternative machines and vehicles is greatly depended on the regional target and trends. The highest increase would be for energy wood supply chains in the regional level. Subsequently, simulation study methods will be utilized to estimate the needed supply chains in alternative future scenarios to help local entrepreneurs´ decision making in future investments.

Keywords: forest biomass, supply, future, regional

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1. Introduction

The economic advantages brought by the forest based bioeconomy appear to be positive, however, those may be distributed unevenly in the society depending on the forest resources from regional areas and demand potential by user-sites. The need of industrial round wood and energy wood will be increased due to the new investments in the chemical forest industry and energy sector in Finland (Anttila et al. 2014). The aim of the study was to find out the future need of alternative harvesting machines and transportation vehicles at the regional level (a province, South Savo in Finland) to achieve industrial and energy wood targets by 2020-2030. South Savo is situated in eastern Finland (Figure 1).

Statistics of harvesting machines and transportation round wood vehicles are available in national level (Natural Resource Institute Finland) (Figure 2). Usually statistics presents the national information in Finland and focusing on industrial round wood. Regional statistics are missing and may be totally different compared to national statistics especially in the case of energy wood systems. National development of energy wood chipping systems have been collected regularly by Metsäteho. In addition, transportation vehicles for energy wood chips and loose material have been collected twice for analysing transportation development (Karttunen et al. 2012, Föhr et al. 2016), which has showed the increased payload capacity after dimension change in 2013. The future need of harvesting machines and transportation vehicles used in industrial and energy wood supply chains at the regional level may depend at least on three things; (1.) supply and demand of wood, (2.) productivity development of supply chains, (3.) special regional features in supply chains at regional level.

There is a strong aim at increasing industrial round wood and energy wood supply in Finland by 2025 (Figure 3). The harvested domestic volume of industrial wood was 58.5 million m^3 in 2015, whereas the aim is totally 80 million m^3 by 2025 (Ministry of Agriculture and Forestry 2015). In addition, the Finnish national strategy for renewable energy aims to use 13.5 million m^3 (~ 25 TWh) of forest-based chips by 2020 (Finnish Ministry of Employment and the Economy 2010) and 15 million m^3 for 2025 (Ministry of Agriculture and Forestry 2015) (Fig. 1). The current usage of forest fuels is 8.0 million m^3, which was consumed by the heat and power plants (7.3 million m^3) and in small buildings (0.7 million m^3) in 2015 (Ylitalo 2016). Small-diameter trees were the most used forest fuel in 2015 (3.9 million m^3). Forest fuel usage has been rapidly growing since the 2000s whereas the use of industrial wood has been stable by now.

2. Material and Methods

2.1. Study area

Regional area of South Savo is known as one of the most important provinces for forest biomass supply in Finland (share of ~10%) (Natural Resource Institute Finland). However, the use of forest biomass is weak in the area of South Savo, because pulp mills are situated in neighborhood provinces. Over half of the forest biomass is used outside the area. Forest biomass demand of South Savo is 3.0 million m^3 (Figure 4), whereas the harvesting supply was totally 6.4 million m^3 in 2015 (Figure 5). Regional aim (a=aim) is to increase supply for 8 million m^3 (1.5 million m^3 increase) and local demand to 4 million m^3 (1 million m^3 increase) by 2020. Wood demand is expected to be increased according to possible investments to the use of energy wood and pine timber. Previous demand (2000-2015) increase has realized for spruce timber and energy wood at the region of South Savo.

2.2. Supply chain analysis

Supply future trend for round wood was measured by using realized harvesting round wood supply statistics and energy wood was based on demand statistics (Natural Resource Institute Finland). Two ways were used in the study: (1.) Statistics analysis and (2.) Productivity analysis.

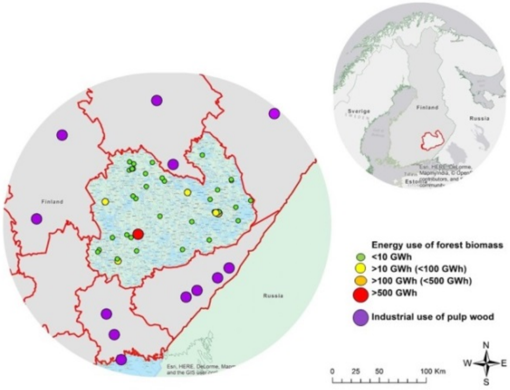

Figure 1: South Savo province is situated in eastern Finland. The decentralized use of energy wood in the region of South Savo compared to industrial use of pulp wood in neighborhood regions.

In statistics analysis (1.) the harvested round wood supply volume per year was divided by the number of each machine to get annual productivity volume. After the regional harvested supply volume at South Savo was divided by annual productivity volume of each machine to get the number of machines used regionally, which was further linearly estimated to the future.

In productivity analysis (2.) needed supply chains at regional level were estimated more precisely as separated for industrial and energy wood. The regional supply aim of 2020 was based on regional forest program targets (Metsäkeskus 2016). Following estimates were used for the share of alternative long-distance truck transportation (Table 1, Table 2). Future estimates of energy wood chipping systems were used as follows (Table 3). The current situation in 2015 was based on earlier studies (Strandström 2016, Föhr et al 2016) in spite of regional differences.

Table 1: The estimated share of long-distance truck transportation of round wood by maximum truck weight in future. Current situation in 2015 (Venäläinen & Poikela 2016).

	2015	2020	2025	2030
76 tn	18 %	20 %	30 %	40 %
68 tn	55 %	60 %	60 %	60 %
60-64 tn	27 %	20 %	10 %	0 %
Total	100 %	100 %	100 %	100 %

The cutting productivities of round wood based on a study of Nurminen (2006), whereas delimbed stemwood, and whole trees by means of the multi-tree processing technique were based on a study by Laitila and Väätäinen (2013). Round wood forwarding productivities based on a study of Nurminen and Heinonen (2007). The effective forwarding productivity for delimbed energy wood was calculated via the model of Kuitto et al. (1994) and the functions of Laitila et al. (2007) were applied for forwarding of whole trees. The total length of the strip-road network at the stands was assumed to be 600 m/ha, based on an average strip-road spacing of 20 m (Niemistö 1992). The forwarding distance was set to 300 m (Kärhä et al. 2009, Laitila 2008, Laitila & Väätäinen 2012). In this study, long distance transportation distance was set to 100 km. Following productivities and annual volumes for alternative machines, vehicles and systems separated between round wood and energy wood assortments were used in the study (Table 4).

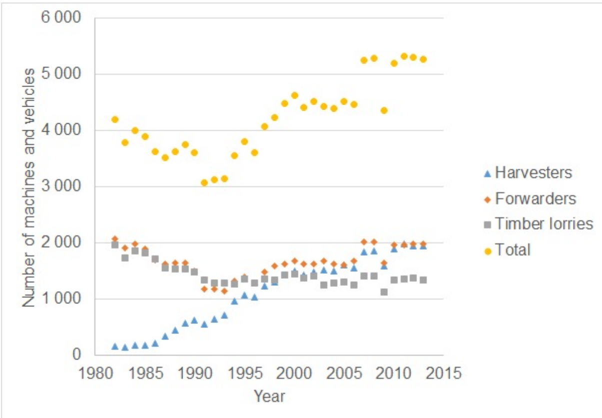

Figure 2: Forestry machines operating in felling, forwarding and transportation of commercial round wood in Finland between 1982 and 2013 (Natural Resource Institute Finland).

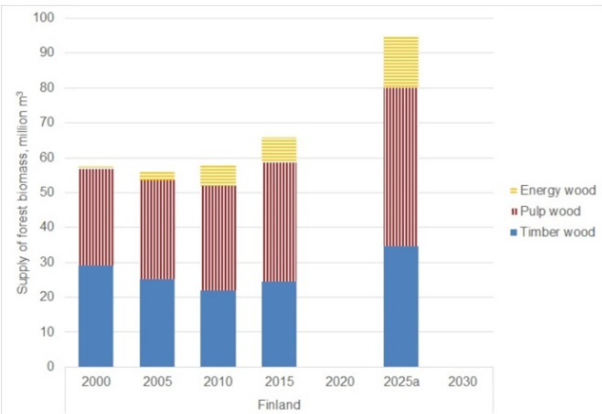

Figure 3: Supply of forest biomass (domestic round wood harvesting volumes and use of energy wood) for the past (2000-2015) and future aim (2025a) in Finland (a= aim) (Natural Resource Institute Finland).

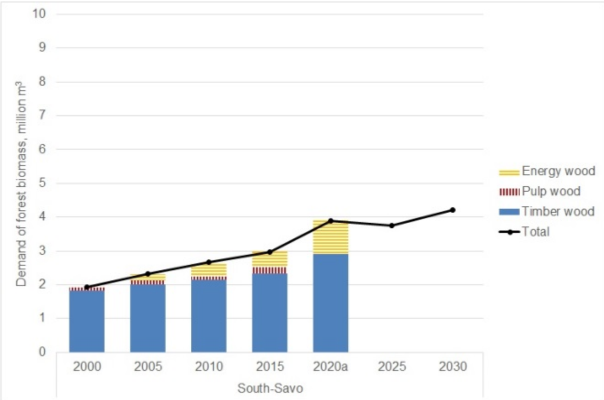

Figure 4: Demand for forest biomass (domestic) for the past, current and future situation in South Savo (2000-2030) (a=aim) (Natural Resource Institute Finland). Total curve presents the trendline development by 2030.

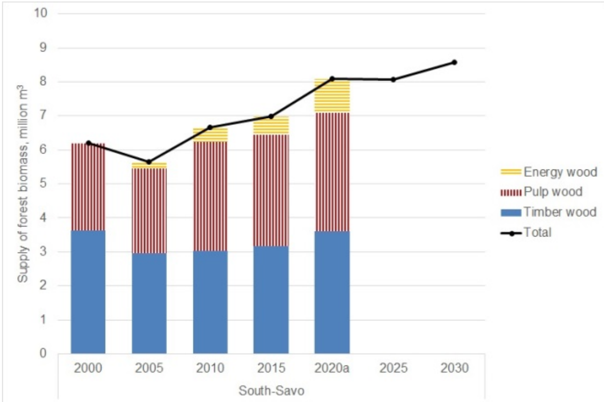

Figure 5: Supply of forest biomass (domestic round wood harvesting volumes and use of energy wood) for the past, current and future situation in South Savo (2000-2030) (a=aim) (Natural Resource Institute Finland). Total curve presents the trendline development by 2030.

Table 2: The estimated share of long-distance truck transportation by chip or loose material in future. Current situation in 2015 (Föhr et al 2016).

		2015	**2020**	**2025**	**2030**
Chips	1.Small diameter trees	53 %	50 %	40 %	30 %
	2.Logging residues	77 %	70 %	60 %	50 %
	3.Stumps	24 %	25 %	25 %	25 %
Loose residues	1.Small diameter trees	46 %	50 %	60 %	70 %
	2.Logging residues	23 %	30 %	40 %	50 %
	3.Stumps	75 %	75 %	75 %	75 %
Total (Chips + Loose residues)	1. / 2. / 3.	100 %	100 %	100 %	100 %

Table 3: The estimated share of energy wood chipping systems. Current situation in 2015 (Strandström 2016).

		2015	**2020**	**2025**	**2030**
1.Roadside chipping system	1.Small diameter trees	53 %	50 %	40 %	30 %
	2.Logging residues	77 %	70 %	60 %	50 %
	3.Stumps	24 %	25 %	25 %	25 %
2.Terminal chipping system	1.Small diameter trees	33 %	40 %	40 %	40 %
	2.Logging residues	12 %	20 %	20 %	20 %
	3.Stumps	46 %	65 %	55 %	45 %
3.Stationary chipping system	1.Small diameter trees	13 %	10 %	20 %	30 %
	2.Logging residues	11 %	10 %	20 %	30 %
	3.Stumps	29 %	10 %	20 %	30 %
Total (1.+2.+3.)	1./2./3.	100 %	100%	100 %	100 %

Table 4: Following average productivities (m^3/h, E15) and annual volumes (m^3/a) of round wood and energy wood supply chains were used in the study. “Sdw”= Small-diameter wood including both stemwood “Sw” and whole trees “Wt”, “Sw”=Stemwood, “Wt”=Whole trees, “Lr”=Logging residues, “S”=Stumps.

				m^3/h	**m^3/a**
Round wood	Cutting	First thinning		8.2	21320
		Other thinnings		16.7	43461
		Final cutting		26.4	68764
	Forwarding	Thinnings		9.8	25384
		Final cutting		20.5	53328
	Transportation	Timber wood	76 tn	11.5	39231
			68 tn	9.6	32636
			60-64 tn	7.8	26663
		Pulp wood	76 tn	10.5	35799
			68 tn	8.8	29907
			60-64 tn	7.2	24387
Energy wood	Cutting	“Sw”		7.5	19411
		“Wt”		8.5	22208
		“S”		6.8	17680
	Forwarding	“Sw”		12.5	32468
		“Wt”		9.0	23341
		“Lr”		11.5	29900
		“S”		7.5	19500
	Transportation	Roadside chipping, chips	“Sdw”	6.9	23489
			“Lr”	6.4	21716
			“S”	6.4	21716
		Terminal/Stationary chipping, loose	“Sw”	9.9	33761
			“Wt”	5.3	17910
			“Lr”	5.3	17910
			“S”	4.6	15737
		Terminal chipping, chips		6.9	22799
	Chipping	Roadside chipping	“Sdw”	30	60000
			“Lr”	26	52000
			“S”	26	52000
		Terminal chipping	“Sdw”	46	92300
			“Lr”	40	80800
			“S”	40	80800
		Stationary chipping	“Sdw”	77	199300
			“Lr”	67	174400
			“S”	67	174400

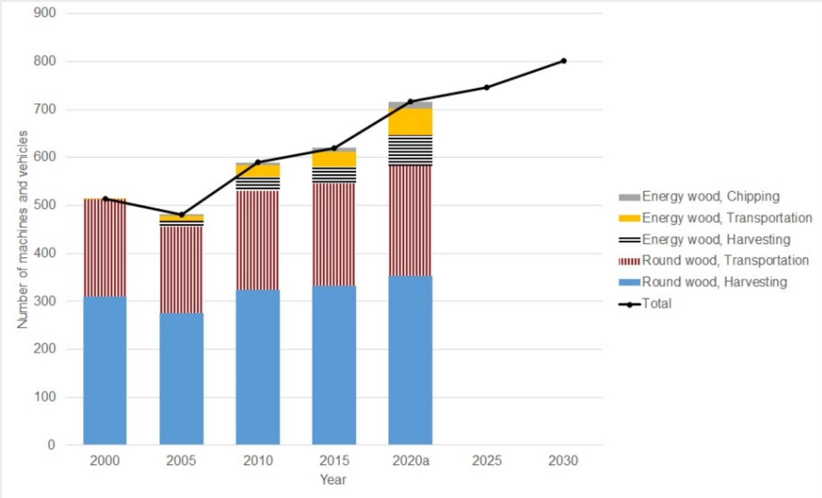

Figure 6: Estimated number of harvesting machines, transportation vehicles and chipping systems needed for the past, current and future situation in South Savo (a= aim). Total curve presents the trendline development by 2030.

3. Results

3.1. Needed supply chains at the regional level

The average increase in harvesting machines, transportation vehicles and chipping systems would totally be 96 pieces more (16%) from the current situtation (620 pieces, 2015) to 2020 (716 pieces) in the region of South Savo (Figure 6). Energy wood harvesting machines, transportation vehicles and chipping systems would be needed 58 pieces (78%) more in 2020. The needed increase would be smaller (38 pieces, 7 %) for industrial round wood supply chains. The future trend by 2030 shows a strong increase (181 pieces, 29%) compared to the current situation in 2015. The highest increase will be for energy wood supply chains (109 pieces, 146%), whereas the increase in round wood supply chains would be smaller (72 pieces, 13%) according to the trendline analysis.

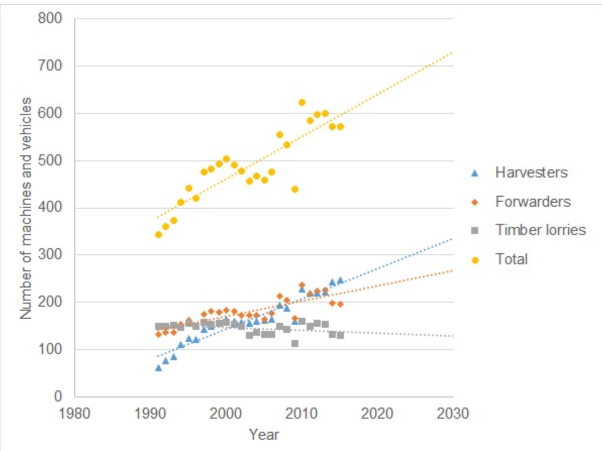

Figure 7: Forestry machines operating in felling, forwarding and transportation of commercial round wood in South Savo was estimated from national statistics (1982–2013) (Natural Resource Institute Finland).

The average statistics analysis for round wood supply chains shows the total increase to be 69 pieces (12%) from year 2015 to 2020 (Figure 7). The total increase would be 159 pieces (28%) from year 2015 to 2030. There were differences in needed round wood supply chains between statistics analysis (Figure 7) and productivity analysis (Figure 6) in the study.

4. Discussion

The study presented the need of harvesting machines, transportation vehicles and chipping systems on the regional level of South Savo in eastern Finland by 2020-2030. The study was implemented as a part of regional project because regional statistics and analysis are missing, especially for energy wood. There is a strong aim at increasing forest biomass supply in Finland, which has effect on the alternative machines, vehicles and systems needed. Study showed that the highest increase will be for energy wood harvesting machines, transportation vehicles and chipping systems in regional level of South Savo according to the future aim and trends. On the other hand, regional demand of energy wood is still uncertain and new large-scale investments is needed to reach the aim by 2020. Study presented both statistics and productivity analysis to estimate the future need of regional supply chains for round wood. Statistics analysis presented higher estimates than productivity analysis.

The study will be continued by using forest growth simulation to measure future supply potential with alternative forest management regimes at the regional area of South Savo. In addition, site-dependent information on supply and demand points can be utilized with agent-based simulation method for alternative regional future scenarios. Combined simulation methods can be used for more precise analysis when describing future supply and demand potential that can be used in local entrepreneurs´ decision-making of future investments in their operational area.

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Comparison of rapid moisture content determination methods for wood chips

Theresa Mendel*, Andreas Überreiter, Daniel Kuptz, Hans Hartmann

Abstract: Rapid determination of moisture content of wood chips is crucial at critical points during production. Thereby, new gravimetric or electric methods may be suitable alternatives to provide a fast and accurate moisture content determination. In total, nine different rapid determination devices were selected for testing including two infrared dryers, four dielectric instruments, two conductivity methods and one time-domain-reflectometry method. Oven drying according to ISO 18134-2 was used as reference. Testing was carried out on different raw materials of wood chips and at different levels of moisture content. The high accuracy of the oven drying method could not be reached by any of the tested devices. However, by using a high amount of samples the average moisture content of all measurements approximated the reference value. On average, the mean measuring deviation from the reference value ranged from -2.6 w-% (± 1.7 w-% SD) to 3.8 w-% (± 4.7 w-% SD). Thereby, best results were obtained with the infrared dryer MA35 for a large range of different moisture contents. In contrast, the electric methods were less accurate but allowed for larger sample sizes. Furthermore, the instrument's accuracy strongly increased with decreasing moisture content. Overall, some instruments can be recommended for quality assurance during wood chip production.

Keywords: wood chip, moisture content, quality measurements

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1. Introduction

1.1. General

Moisture content (MC in w-%) is the most important fuel quality parameter of wood chips as it influences the net calorific value, fuel combustion behavior and the storability of the biofuels (Hartmann, 2016). Varying MC may present a challenge for wood chip producers, fuel distributors and boiler operators. Hence, correct and on-time MC determination is crucial at many points during production and distribution. However, the standardized method for MC determination, i. e. oven drying according to ISO 18134-2 (DIN, 2015a), consumes both time and labor. Moreover, the heterogeneity of wood chips often requires a large number of samples, often exceeding the capacity of drying cabinets. Newly developed gravimetric or electric methods may be suitable alternatives to provide a rapid and accurate MC determination.

1.2. Measuring principles for moisture contents

Common methods to determine MC of solid biofuels can be divided into direct methods such as thermogravimetric measurements and indirect methods such as electric measurements. Thermogravimetric methods determine MC by weight difference of a medium before and after drying to constant mass (DIN, 2015a). The most common direct method is oven drying according to EN ISO 18134-2. This method uses cabinets for drying of the medium at 105 ± 2 °C (DIN, 2015a). Oven drying is independent of other fuel properties such as bulk density or varying environmental conditions (Daugbjerg-Jensen *et al*, 2006). Another thermogravimetric method facilitates infrared radiation for drying. Such infrared dryers determine MC more rapidly compared to the oven dry method and allow for smaller sample sizes (Böhm, 2006). Indirect methods work nondestructively. In contrast to the thermogravimetric methods, they do not change fuel properties of a medium (Böhm, 2006). In most cases, MC is determined in only a few seconds. Dielectric methods, conductivity methods and TDR (time domain reflectometry) methods are the most common electric methods.

2. Material and Methods

2.1. Selected measuring instruments

In total, nine different measuring instruments were selected for rapid MC testing according to their availability, price, handiness and field of application. The selection included two infrared dryers, four dielectric methods, two conductivity methods and one TDR method (Fig. 1).

The two infrared dryers were MA35 (Sartorius AG) and UX3081 (A&P Instruments). The sample sizes measured on average 15 g for MA35 and 35 g for UX3081. The dielectric methods were humimeter BMA (Schaller GmbH), humimeter BL2 (Schaller GmbH), AD22-CMS22 (Doser Messtechnik GmbH Co. KG) and Almemo FH A696-GF1 (Ahlborn Mess- und Regelungstechnik GmbH) (Fig. 1). Schaller GmbH offers the calibration curves according to the particle size and the amount of fines (i.e. particle Ø < 3.15 mm) of wood chips. The humimeter BMA also offers the option to measure bulk density. In contrast, Almemo and AD22-CMS22 work with only one calibration curve. However, for AD22-CMS22 a user-defined calibration is possible. The two conductivity methods were GMH 3851 (Gann Mess- und Regeltechnik GmbH) and Hydromette HT85T (Greisinger electronic GmbH). Both devices work with more than one calibration curve. The calibration of the instrument HT85T categorizes according to wood species. GMH 3851 offers a curve for wood chips in particular. The only TDR method HD2-Sono M1 (IMKO GmbH) offered three calibration curves. These curves were not particularly calibrated for biofuels. This method is mainly used in soil moisture determination, but it also allows for a user-defined calibration curve.

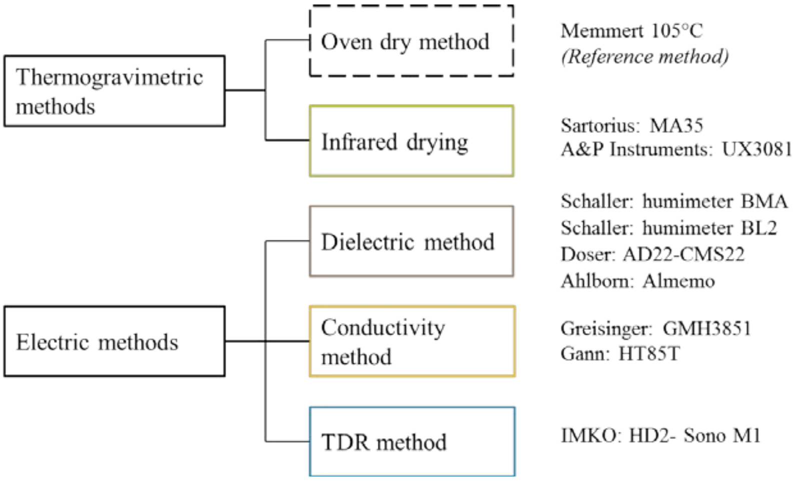

Figure 1: Measuring methods of selected rapid moisture content determination methods.

Figure 2: Measuring procedure: (a) wooden boxes for wood chip drying, (b) air-tight plastic bags, (c) sample preparation: homogenization and mass reduction, (d) barrel used for measurements with lances

2.2. Fuel samples and moisture contents

Testing was carried out on five different types of wood chips; on wood chips from energy roundwood of Norway spruce (*Picea abies*) (ERC-spruce) and European beech (*Fagus sylvatica*) (ERC-beech), from forest residue of conifer trees (FRC-conifer) and deciduous trees (FRC-deciduous) and from short rotation coppice chips of European poplar (*Poplar spp.*) (SRC-poplar). Based on fuel specifications for wood chips according to ISO 17225-4 (DIN, 2015b), testing was done at five different MC levels, i. e. at the moisture content of fresh material 'as received', at 35 w-%, at 25 w-%, at 15 w-% and at 10 w-%.

At delivery, fresh wood chip types were tested for bulk density according to ISO 17828 (DIN, 2016). At a MC of 15 w-% chips were analyzed for particle size distribution according to ISO 17827-1 (DIN, 2015c).

2.3. Moisture content determination

First MC testing was done at a MC 'as received'. To reach lower MC levels, wood chips were dried naturally by spreading whole samples in wooden boxes on the floor (max. height 10 cm, Fig. 2a).

Wood chips were mixed frequently to ensure homogeneous drying. At target MC levels, chips were filled in air-tight plastic bags (Fig. 2b) and stored at 4 °C for a minimum of 24 h. The air-tight storage enabled equilibrium of MC of individual wood particles to the whole sample and, thus, further increased homogeneity. After storage and homogenization, sample mass for individual MC measurements was reduced according to EN 14780 (DIN, 2011) (Fig. 2c). For each fuel type and MC level a series of MC measurements was performed with the test devices always following the same procedure. First, rapid testing was carried out with the two infrared dryers. For each infrared dryer three samples were analyzed (n = 3). Then wood chips were transferred into a 220 l cylindrical barrel (Fig. 2d) and condensed following EN 15103 for bulk density (DIN, 2016). Measurements with lances were performed by inserting the respective lance into the barrel ten times (n = 10). Afterwards, measurements were performed with humimeter BMA (n = 5). Thereby, a 12 l sample was used. Reference MC was determined by oven drying according to EN ISO 18134-2 directly before and after the series of measurements (n = 8).

3. Results and discussion

Due to a small fraction of fines ERC-spruce could be specified as P31S according to ISO 17225-4. All wood chip samples could be classified as P31 according to ISO 17225-1. Therefore, the calibration curve 'wood chips' was valid for all samples tested with both humimeters. Bulk densities (at a constant MC of 15 w-%) varied from 159 kg m^{-3} (SRC-poplar) to 310 kg m^{-3} (FRC-deciduous). MC of samples during testing ranged from 9.5 to 68.0 w-%. Thereby, MC ranges exceeded the ranges for some of the measuring devices according to manufacturer specifications (Tab. 1).

Both infrared dryers allowed for MC determination between 0 and 100 w-%. Overall, infrared dryers provided the smallest standard deviations and smallest interquartile differences (Fig. 3) despite of the very small sample sizes of 15 g and 35 g. Even at higher moisture content levels (> 25 w-%) interquartile differences were small compared to all electric devices (Fig. 4). MA35 displayed overall best results (Fig. 3, Tab. 1). In contrast, MC measured with UX3081 was constantly lower compared to the reference values (-2.6 w-%, see Tab. 1). This might be due to an incomplete infrared drying of the sample during the performed study. Drying temperature of UX3081 was 105°C. By adjusting drying temperatures to > 105°C measurement accuracy could have been improved. However, with increasing temperatures the risk of loosing volatile organic compounds in addition to water increases, leading to higher mass losses and, thus, might bias MC determination (Gaggermeier *et al.*, 2014). A longer drying time could improve results. At 35 w-% the drying time measured 45 minutes and drying times increased with increasing MC. Hence, it is questionable if these instruments could still be seen as rapid testing methods.

Table 1: Measuring range, number of measurements and mean deviation (± standard deviation) of measuring instruments.

Name of instrument	Measuring range [w-%]	*n*	Mean deviation (± SD) [w-%]
Sartorius: MA35	0 – 100	67	-0.7 (± 2.1)
A&P Instruments: UX3081	0 – 100	68	-2.6 (± 1.7)
Schaller: humimeter BMA	5 – 70	120	-0.5 (± 4.0)
Schaller: humimeter BL2	10 – 50	190	3.8 (± 4.7)
Doser: AD22-CMS22	0 – 50	220	-0.7 (± 4.0)
Ahlborn: Almemo	0 – 50	220	1.5 (± 4.2)
Greisinger: GMH3851	5 – 50	190	0.7 (± 4.9)
Gann: HT85T	4 – 50	220	1.9 (± 3.7)
IMKO: HD2-Sono M1	0 – 50	206	-1.6 (± 5.1)

Measuring ranges of dielectric instruments were smaller compared to infrared dryers. Mean deviations from reference values increased with increasing MC (Fig. 3, Fig. 4). Among electric devices, humimeter BMA displayed the lowest mean deviations from reference MC while its measuring range was largest (Tab. 1). On average, mean deviations from reference values were highest for humimeter BL2 (-3.8 w-%), especially at higher moisture contents (Fig. 4). Smallest mean deviations at higher moisture contents (> 25 w-%) were given by Almemo (Fig. 4). Manufacturer instructions of AD22-CMS22 specified a maximal measuring range of 50.0 w-%. However, in contrast to reference values, MC according to the instrument never exceeded of 41.2 w-%. Nevertheless, the AD22-CMS22 also provides the electrical raw values allowing for a customized calibration for each wood chip type.

The accuracy of the conductivity methods was similar compared to the dielectric methods. The Hydromette HT85T showed good results at high MC (Fig. 4). The GMH 3851 displayed error measurements when measuring MC > 38 w-%, although a measuring range up to 50 w-% was stated by manufacturer instructions. However, the mean deviation from reference values was very low when testing was done with wood chips at low MC (Fig. 3). The TDR method HD2 showed large deviations at high moisture contents. These deviations decreased at lower MC. Customized calibration curves for the HD2 could optimize measuring results. On average, all instruments reached best results on forest residues chips of conifer trees. This type of wood chip is with 89 % of wood chips of forest wood the most common in Bavaria (Gaggermeier *et al.*, 2014). SRC-poplar and ERC-spruce had the smaller bulk densities and FRC-deciduous and ERC-beech higher bulk densities compared to FRC-conifer. A strong correlation ($r = 0.94$, $p \leq 0.05$, Pearson correlation) between bulk density and mean deviation was observed for wood chip types. Moisture contents were overestimated for ERC-beech and FRC-deciduous and underestimated for SRC-poplar and ERC-spruce. Hence, customized calibration curves for individual wood chip types should improve measurements.

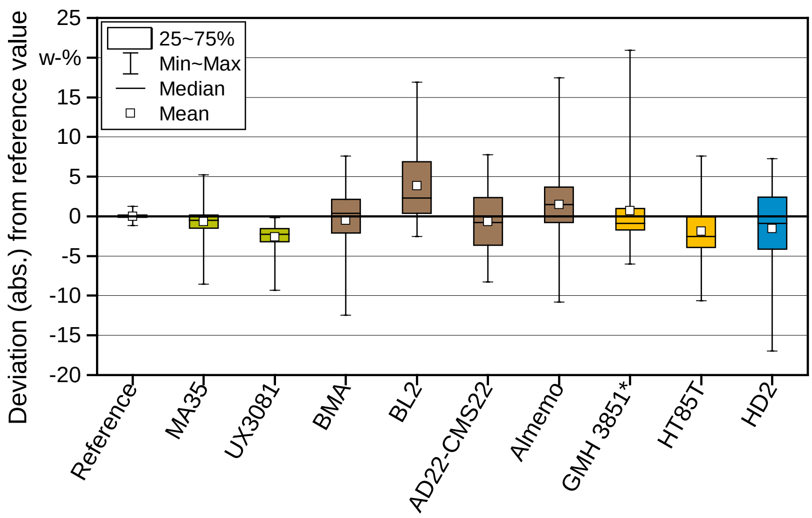

Figure 3: Measuring deviations from the reference value (*error measurements were excluded from the results).

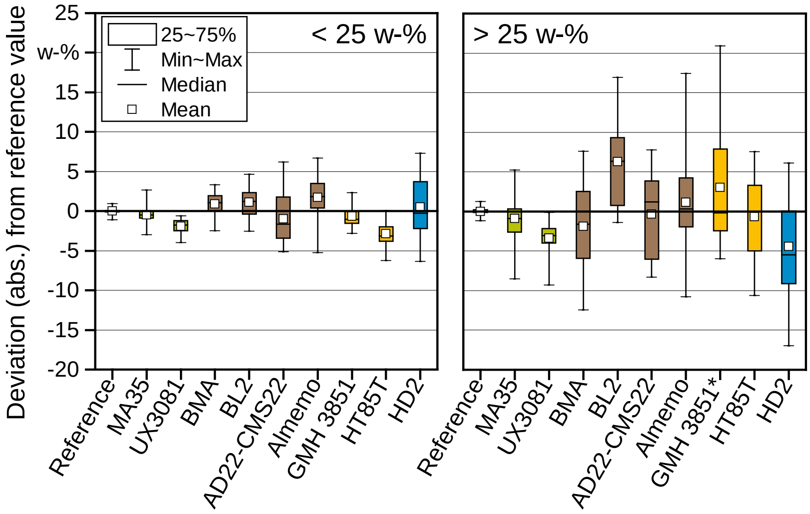

Figure 4: Influence of moisture content levels on the measuring deviation from reference values (*error measurements were excluded from the results).

4. Conclusion

The high accuracy of the oven drying method could not be reached by any of the tested devices. On average, the mean deviation of all rapid determination methods was in a range between +5 and -5 w-%. Some instruments can be recommended for quality assurance during production. The tested electric methods allow for a rapid and in most cases instantaneous MC determination of wood chips. The electric methods showed a decreasing accuracy with increasing MC. However, by using a high amount of samples the average moisture content of all measurements approximated the reference value. The infrared-dryers have the advantage of being independent from the type of wood chips and moisture content level. However, drying times can be long. MA35 scored best results despite of a small sample size and a large measuring range. Nevertheless, the heterogeneity of wood chips should not be disregarded. Representative sampling and accurate sample preparation are thereby fundamental for obtaining high-quality results. Thus, sampling may be considered of higher importance compared to instrument precision.

5. Acknowledgements

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Economic analysis of secondary fuel quality treatment for wood chips from forest residues

Kathrin Schreiber[1]*, Daniel Kuptz[2], Fabian Schulmeyer[1], Hans Hartmann[2], Herbert Borchert[1]

Abstract: For a case study the production costs for high quality wood chips from forest residues including secondary treatment steps were analyzed. With 91.03 €/tODT for chipping, screening and drying a higher marginal return could be achieved than with fresh, untreated wood chips. Furthermore, changes in fuel quality were determined. Using these additional production steps moisture and ash content could be lowered and particle size distribution could be enhanced considerably. This offers the possibility to sell these high quality wood chips profitable.

Keywords: Wood chips, secondary treatment steps, economic efficiency, marginal return

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1. Introduction

In Bavaria, wood chips from forest residues are often used as fuel for regional, small to medium-scale heating plants. Without secondary fuel treatment steps such as drying and screening, these wood chips often incorporate high shares of fines, bark and needles and are thus considered to lead to high gaseous and particular emissions during combustion, especially when they are used in combustion plants with an installed thermal power of up to 100 kW. In January 2015, the second stage of the first German Federal Immission Control Ordinance (1st BImSchV) became effective. As a result, emission thresholds for particulate matter and carbon monoxide (CO) were lowered to 0.02 g/m³ and 0.4 g/m³ for plants ≥ 4 -1 000 kW, respectively. Hence, operators of small to medium combustion plants are forced to pay close attention to meet these values. Decisive for a good operation are not only combustion engineering but also flue gas cleaning and the right fuel quality. Thereby, the composition of moisture content and fines in solid biofuels has an influence especially on particulate matter emissions (HARTMANN, 2016). To identify how to enhance the fuel quality and to determine the cost of secondary treatment steps, the German Federal Ministry of Food and Agriculture (BMEL) funded the Joint Research Project "qualiS".

2. Methods

The project started with gaining more insight into the wood chip production market and secondary fuel treatment processes in Germany. By researching various databases and internet sites, approx. 900 potential wood chip producers could be identified and were asked to participate in an online survey. The main purpose of the survey was to identify typical fuel processing technologies and how these secondary treatment steps are performed when producing high quality wood chips. Therefore, several questions focused on additional production steps such as screening and drying. Afterwards, case studies covering the most frequently named technologies were conducted as best practice examples.

Field studies consisted of three parts:

- work studies and economic analysis of the process chains
- laboratory analysis of changes in quality
- combustion tests of resulting emmissions (data not shown)

During the production process, high shares of individual samples of the raw-material and the enhanced wood chips were taken for analysis in the laboratory and for combustion tests. Moisture content, ash content and particle size distribution were determined following international standard methods and fuel quality was related to ISO 17225-4.

The economic analysis is the main focus of this paper. The production steps at the work yard were closely observed. A defined amount of raw-material was put into the process. Throughout the whole working cycle, the time consumption was recorded and throughput rates of all products such as the wood chips, the fine particles and the overlong particles were measured. This was done by determining the mass of each product at the end of each cycle. Additional data on fuel and electric power consumption and on expenditure of human labor was also gathered. Machine costs for the secondary treatments were calculated. For adjacent production steps, calculations from previous studies were transferred.

3. Results and discussion

In total, 91 companies participated in the online survey. Evaluation showed that mainly wood chips produced for combustion plants < 100 kW (Assortment 1) are screened as well as dried, while fuels for larger plants often are only dried or directly burnt (assortment 2) (Figure 1 and Figure 2).

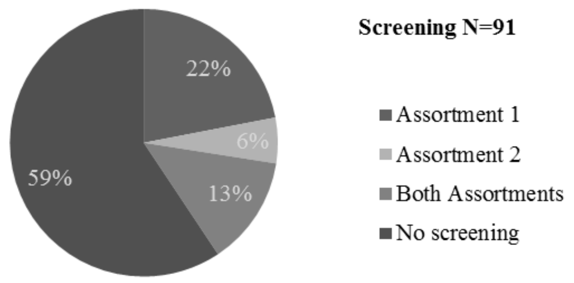

Figure 1: Percentage of screening assortment 1 (for plants < 100 kW) and assortment 2 (for plants > 100 kW).

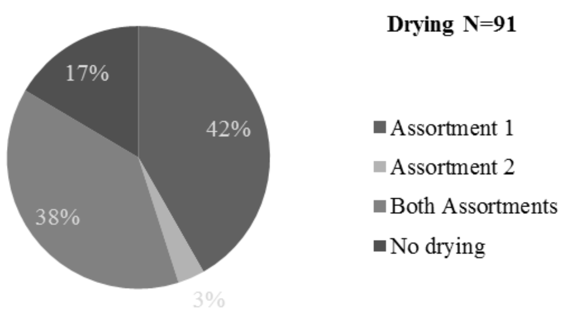

Figure 2: Percentage of drying assortment 1 (for plants < 100 kW) and assortment 2 (for plants > 100 kW).

The results of the online survey are considered as a random sample of the German wood chips market. Based on the most frequently named treatments and technologies, six case studies were chosen as best practice examples. Studies encompassed various screening and drying technologies (Table 1).

Table 1: Conducted case studies.

Case Study No.	Drying Technology	Screening Technology
1	Drum Dryer	Vibration Screen
2	Drying Container	Star Screen
3	Natural drying after chipping	Drum Screen
4	Self-Constructed Batch Dryer	-
5	Natural drying after chipping	Star Screen
6	Belt Dryer	Vibration Screen

While case study number 1, 3 and 5 concern companies which only produce and enhance wood chips, the other three studies were conducted in companies where secondary treatment steps of wood chips from forest residues are an additional branch of the whole business concept.

In the following, only results from case study 2 are presented. The respective operating company is active in both composting and biomass conditioning. The production process of high quality wood chips consisted of two secondary fuel treatment steps (Table 1). The raw material, i. e. forest residues of Norway spruce (*Picea abies*), was bought at forest roadside. Chipping and transport was conducted by the company. At the work yard the fresh wood chips were dried for several days in containers using excess heat from a biogas plant. Later on they were screened with a Komptech Multistar screen machine. Three fractions were separated, i.e. overlong particles, fines and wood chips, which made up around 72.66 w-% of the original material (Figure 4). The fines are sold and overlong particles burnt in larger heating plants. However these two additional assortments were not considered in the calculation of this paper. Afterwards the high quality wood chips are stored in a depot (Figure 3).

After analyzing the samples, results show (Table 2) distinct improvements in quality throughout all fuel quality parameters.

Table 2: Fuel quality of the wood chips before and after processing in case study 2 (mean ± standard deviation).

	Raw Material	Final Product
Moisture content (m-%)	51.0 (± 3.0)	13.1 (± 2.7)
Particle size distribution (ISO 17225-4)	Not classifiable	P45S
Fines (m-%)	17.7 (± 6.6)	2.50 (± 1.9)
Ash Content (dry basis) (m-%)	7.38 (± 4.33)	1.86 (± 0.70)

The moisture content decreased from 51.0 (± 3.0) m-% to 13.1 (±2.7) m-%. Thus, after drying, moisture content was suitable for application in small boilers. Before secondary fuel treatment, the particle size distribution could not be classified due to high shares of fines and overlong particles. Afterwards, wood chips were classified as P45S according to ISO 17225-4. This means that at least 60 w - % were between 3.15 mm and 45 mm. Overlength particles (> 63 mm) had to be ≤ 10 w - %. Fines which are smaller than 3.15 mm also only represented ≤ 8 w - %. Therefore the particle sizes were also suitable for small scale combustion plants, making an undisturbed heating process possible (Deutsches Institut für Normung e.V., 2014).

Most profoundly, screening strongly reduced the amount of fines and the ash content and thus, strongly improved fuel quality. This should lead to overall better combustion performances especially in small furnaces by ensuring failure-free and low emission combustion.

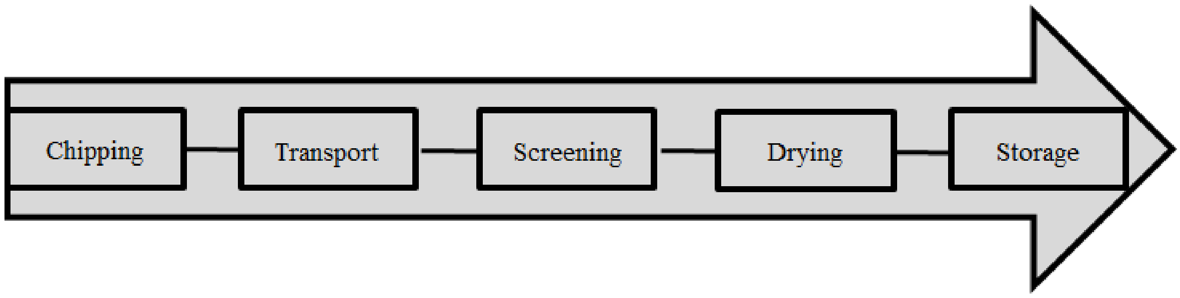

Figure 3: Production process of case study 2.

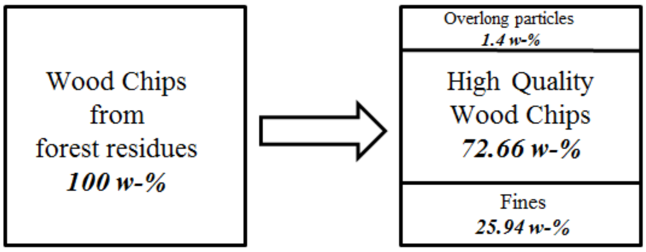

Figure 4: Assortments of wood chips, fines and overlong particles after screening in case study 2.

The major component of the production chain is the star screen. Table 3 shows the most important input parameters for calculating its machine cost.

Table 3: Input parameters for calculating machine costs of the star screen in case study 2.

Operation	Screen	Unit
Investment cost	213,716.21	[€]
Operating hours	1621	[PMH_{15}/year]
Salvage value	53,429.05	[€]
Depreciation	15	[years]
Interest factor	4.00	[%]
Output	114.76	[m^3/PMH_{15}]
Production cost	0.26	[€/m^3]
	1.50	[€/t_{ODT}]

The investment cost of the star screen machine was 213,716.21 €, resulting in a salvage value after 15 years of 53,429.05 €. An interest factor from 4.00 % was presumed. The output reached 114.76 m^3/PMH_{15}. Further parameters considered for the calculation were power consumption, maintenance and repair, as well as insurance and labor cost. Resulting the overall cost for screening is 1.50 €/t_{ODT}.

During a previous project several chipping operations were conducted. Based on Bavarian conditions the typical bulk density for wood chips of Norway spruce forest residues was 170 kg/m³ (dry basis) (KUPTZ ET AL, 2015). For this reason the throughput rate for the screen was calculated at 19.51 t_{ODT}/PMH_{15}.

To calculate the complete production cost for this case study several other parameters were added. Table 4 shows the setup of the calculation.

Table 4: Information and rates of the production process of case study 2.

Process step	Information	Cost [€/m³]	Cost €/t_{ODT}]
Purchase of raw material	Forest residues • Unchipped • forest roadside • Water content 51%	4.50	26.47
Chipping	JENZ HEM 593 • 278 kW drive power • 61.6 m^3/PMH_{15} • 240.36 €/PMH_{15}	3.90	22.94
Transport	Scania R480 with two containers • Average distance 70 km • Revenue load 60 m³ per drive • 1.43 €/km	1.68	9.88
Screening	Komptech • 29.34 €/PMH_{15} • Output 114.76 m^3/PMH_{15}	0.26	1.50
Manipulation by wheel loader	Volvo L110G/2012 • 66.10 €/PMH_{15} • Operating time 0.0036 PMH_{15}/m^3	0.24	1.41
Drying	• Container drying • Outsourced	4.00	23.53
Container	• Drying-container, self-construction • Investment cost 5,500 € • Annual 1,350 m³/ Container	0.71	4.18
Property and buildings	• Bituminized forecourt • Machinery hall for screen • Storage depot wood chips	0.19	1.12
∑		*15.48*	*91.03*

With information provided by the company owner, a prize for 4.50 €/m³ was set for the purchase of the unchipped forest residues. Another 3.90 €/m³ were set for wood chipping. This value also was calculated by a previous study (Kuptz et al., 2015). The drying was outsourced of the company and therefore an all-inclusive prize from 4.00 €/m³ was determined, containing the transportation to and from the biogas plant as well as the drying cost. Table 4 gives an overview of the cost for each step for both €/m³ and €/t_{ODT}. A final production prize of 15.48 €/m³ respectively 91.03 €/t_{ODT} was calculated for the treated wood chips. Production cost for untreated wood chips were 60.41 €/t_{ODT}.

Typical wood chip prices per container (Spring 2016) in Bavaria were 128.63 €/$t_{20m\text{-}\%}$ (Carmen e.V., 2016) or 160.79 €/t_{ODT}, respectively. In the calculation of this paper the transport was already calculated (Table 4). The average delivery distance to the final customer is also 70 km. Thus 9.88€/t_{ODT} are added to the production cost, resulting in total cost of 100.91 €/t_{ODT} for high quality wood chips. Untreated wood chips achieved earnings of 97.06 €/ t_{ODT} during the first half of 2016 according to information provided by the company owner.

Table 5: Marginal return of high quality - and untreated wood chips (case study 2).

€/t_{ODT}	**High quality wood chips**	**Untreated wood chips**
Sales revenue	160.79	97.06
Production cost	100.91	70.29
Marginal return	***59.88***	***26.77***

The expected marginal returns Table 5) are higher for quality wood chips compared to untreated wood chips. Hence the secondary treatment steps were considered economically profitable in case study 2. Moreover, untreated wood chips are not usable for some customers particularly in small heating plants. Thus the conditioning of wood chips by secondary fuel treatment steps can expand the sales market.

4. Conclusion

The study demonstrated that the production of wood chips using secondary fuel treatment steps ensures high quality fuels even for small combustion plants. It showed that secondary treatment steps can improve the quality of the wood chips by reducing the moisture and ash content and enhance the particle size distribution.

Furthermore, the study showed that the marginal return of the quality wood chips is higher than that of wood chips sold right after chipping. Thereby, not only a new market with more costumers can be developed, but the prizes can also be adapted to the demand for high quality wood chips.

The results shown in this paper are only a part of the whole study. Remaining findings are still in development and will be shown in future publications.

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Effects of rough delimbing of coniferous crowns on biomass and nutrient exports and the productivity of the forest wood chip production chain

Fabian Schulmeyer*, Elke Dietz, Birgit Reger, Karl Hüttl, Herbert Borchert

Abstract: Utilisation of forest biomass for power and heat production plays an important role in Bavarian forestry. On sites with low levels of available nutrients, sustainability might be impaired when whole crowns and forest residues are extracted. Harvesting can be adapted by roughly delimbing coniferous crowns, leaving most branches and needles on site. During field trials, biomass exports were reduced by 17 w-%. The additional work needed amounted to 38.4 min/ODT (motor-manual variant) or 4.2 min/ODT (fully mechanised variant). Forwarding productivity was increased and could in favourable conditions (i. e. when driving longer distances) compensate the extra costs. The method can be used as an economically and ecologically feasible alternative for energy wood utilisation on sites with low levels of available nutrients.

Keywords: wood chips, forest residues, nutrient export, delimbing, productivity

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1. Introduction

Today forest biomass plays an important role in power and heat production in Bavaria. Coniferous crowns are the most important raw material for chipping. Growing demand also has led to an increase in biomass and nutrient exports. Depending on the intensity and the intervals of harvesting, sustainability might be impaired on sites with low levels of available nutrients.

Figure 1: Roughly delimbed spindles from a fully mechanised harvesting operation.

In regions of Bavaria with problematic site conditions, practitioners developed an adapted harvesting method. The aim is to reduce the export of nutrient-rich tree parts causing as little extra work as possible. The method is mainly used in final thinnings and final harvests in coniferous stands and can be executed motor-manually or fully mechanised. Crowns are roughly delimbed. Most branches (including green tree parts) are left on site; only saw logs, industrial wood and roughly delimbed spindles are exported from the site. Length, diameter and quality of delimbing may vary considerably between spindles (Figure 1). The spindles are not measured or cut to length. However, a maximum length of 6 to 8 m is desirable for efficient extraction.

In motor-manual operations, delimbing proceeds in one pass. Crowns are not turned around, so a certain number of branches are left on the lower side.

2. Aim

The aims of this research are to quantify the changes in biomass and nutrient exports when roughly delimbing crowns instead of utilising whole crowns and to assess the economic effects of the adapted work method.

To date, field work is completed and analysis of gathered data is ongoing. Complete results of the research project will be published in 2017.

3. Material and Methods

Work studies were conducted during one motor-manual and one fully mechanised harvesting operation in two spruce-dominated stands with low nutrient levels. The stands were divided into comparable blocks. Harvesting was performed alternating blockwise with and without rough delimbing of crowns. Time needed for harvesting and forwarding was recorded in cumulative timing at element level. Samples of the wood chips produced in each variant were gathered for quality assessment.

On each site, 5 to 7 trees were chosen to represent the stand in terms of tree dimensions and competitive position. Tree climbers took down branches and tree tops and collected them one by one on a plastic foil before felling the remaining stem. The biomass of each tree was divided into compartments (stem wood, branches, twigs and needles) and weighed on site. Biomass samples from each compartment in different tree heights were taken for further analysis. The samples were divided into smaller fractions in the laboratory and their proportions and the nutrient concentrations determined.

4. Preliminary results

4.1. Productivity

The motor-manual variant was examined in a 100 years old spruce-dominated (*Picea abies*) stand with 15 % Scots pine (*Pinus sylvestris*) in the Fichtelgebirge in North-Eastern

Bavaria. Felling was executed by two experienced local forest workers with chainsaws. Timber was extracted by forwarder. The study area was 3.5 hectares (ha). Volume removed amounted to 48 m³/ha. Due to a high volume per tree (mean diameter at breast height: 43.5 cm), productivity of felling and bucking reached 4.3 m³/h. Rough delimbing took the workers between 0.5 and 5 min per crown (mean: 1.6 min per crown). Time consumption did not depend directly on DBH or tree height, but on crown length and competitive position. The additional work amounted to 10.9 %. Relating to the volume of wood chips produced, additional work amounted to 6.2 min per bulk cubic metre (bcm) or 38.4 min per oven dry ton (ODT).

Fully mechanised harvesting was analysed during a harvesting operation in a 65 years old spruce stand in the Frankenwald in Northern Bavaria. A Valmet 911.3 harvester and a Pika / Pinox 828 forwarder were employed with experienced local machine operators. With a relatively high volume removed (81 m³/ha), productivity reached 32.2 m³/PMH15. Rough delimbing necessitated additional work of 10.7 % (corresponding to 0.7 min/bcm or 4.2 min/ODT).

In both variants, the load per forwarder cycle was increased when extracting roughly delimbed spindles. The number of required cycles per ha was reduced considerably. Crane work and driving are the main work elements during forwarding. Crane work per oven dry ton (ODT) was higher for delimbed spindles, as less biomass was loaded with each crane movement. When driving longer distances, the extra crane work was overcompensated by the reduced number of driving cycles, leading to an overall gain in efficiency (Figure 2).

4.2. Wood chip quality

In both case studies, the raw materials were chipped with the same mobile drum chipper and the same machine settings. Screen size was 80x80 mm. Wood chips from whole crowns had high proportions of fines and high ash content (Table 1). Quality of wood chips was higher in regard to these parameters when delimbed spindles were chipped.

4.3. Biomass and nutrient exports

In the described field trails, the amount of biomass that was left on site was increased by rough delimbing by 12 to 26 w-% (mean: 17 w-%) relating to the above ground biomass of felled trees. Analysis of nutrient concentrations within the compartments is still in progress. Combining the changes in biomass exports with nutrient data from Göttlein & Weis (2011), we calculated the nutrient exports in both variants for site conditions in a coniferous stand near Roding (Eastern Bavaria). By leaving the additionally separated biomass on site, the export of nutrients could be reduced distinctly by 5.6 to 16.6 w-% (calcium, Ca), 5.5 to 16.5 w-% (iron, Fe), 5.9 to 20.0 w-% (potassium, K) and 7.4 to 25.2 w-% (phosphorus, P).

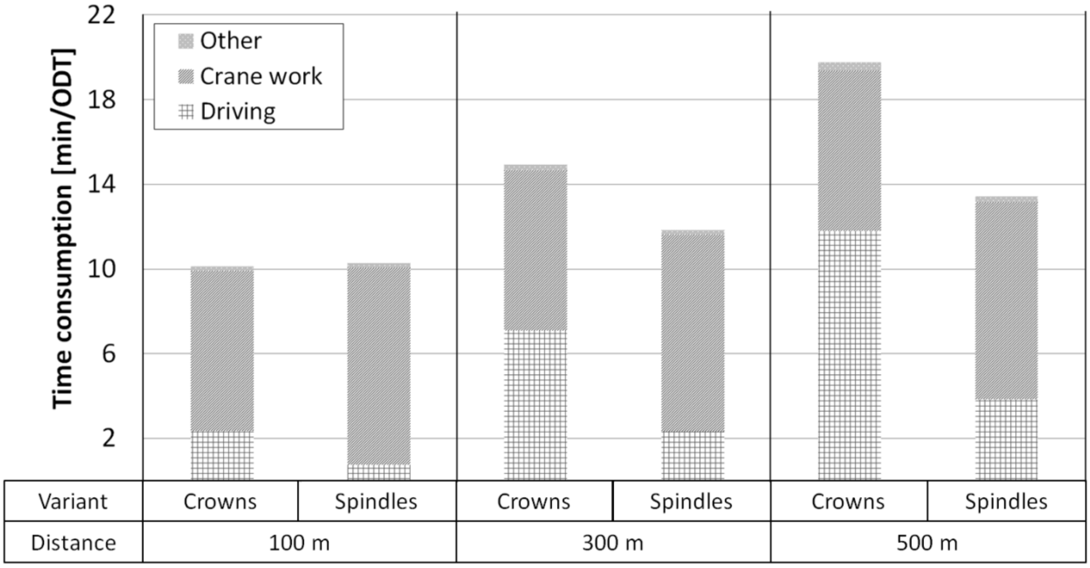

Figure 2: Time consumption in minutes per oven dry ton [min/ODT] for forwarding whole crowns and roughly delimbed spindles in varying extraction distances.

Table 1: Fine fraction and ash content of whole crowns and roughly delimbed spindles (mean values of three measurements each).

		Fine fraction (< 3.15 mm) [w-%]	Ash content [w-%]
Motor-manual	Whole crowns	25.6	2.2
	Delimbed spindles	11.6	0.9
Fully mechanized	Whole crowns	28.4	1.4
	Delimbed spindles	5.0	0.5

The positive effect on nutrient balances correlated to tree size; it was lower for predominant trees and increased with the diameter at the base of the spindles (i.e. top diameter of the last saw log or industrial wood section). Changes in biomass exports will be used to calculate nutrient balances for further relevant sites in Bavaria once the analysis of biomass samples is complete.

5. Preliminary conclusion

The described harvesting method can be an economically and ecologically feasible alternative for energy wood utilisation on sites with low levels of available nutrients. Compared to the common practice of utilising whole crowns, the nutrient exports can be reduced considerably. At the same time, necessary forest protection measures can be executed cost-effectively. The additional cost of harvesting can be compensated for by higher forwarding productivity.

6. Acknowledgements

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Role and assessment of unconventional biomass resources

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Abstract: The major part of the European green energy production accounts for biomass. In the decentralized energy production, the biomass used in combustion technologies is largely derived from woody biomass (dendromass). In order to ensure sustainability and maximum use of dendromass capacity available for energy purposes, other "non-conventional" sources (e.g. biomass from abandoned land, or located next to line-based facilities) should also be taken into account. In a pilot project performed by the Bioenergy Research Group of the Institute of Forest and Environmental Techniques of UWH a biomass potential survey was carried out on a non-cultivated area with heterogeneous vegetation dominated by invasive species. The research group of UWH created a commonly usable protocol that allows reliable estimation of biomass volume available for energy purposes generated in natural or semi-natural systems of greater heterogeneity of species and age structure.

Keywords: bearing capacity, cone penetration resistance, trafficability, VWC

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1. Introduction

The use of biomass for energy purposes has many potential benefits, including a neutral carbon cycle energy production, the security of domestic supply and a more limited reliance on fossil energy source imports. The growth of biomass-based energy production has the potential to stimulate development, especially in rural areas through local energy supply and creation of jobs. Recently biomass is the most important renewable source in the EU-28, accounting for just under two thirds (64.2 %) of primary renewables production in 2013. (Fig. 1) (Eurostat, 2015)

Forest biomass is one of the strongholds of the strive towards the policy targets established by the European Union within the so-called "2020 climate and energy package" (Ferranti, 2014). In 2012, the total supply of wood for energy in the EU was about 1 billion m³, (8500 PJ) 70% of which amount came from forests and 30% from outside forests (Mantau et al. 2010). With respect to woody biomass, different categories of resources can contribute to the supply of renewable energy, among which forestry residues, wood industry residues and short rotation energy crops are the most important energy sources (Karjalainen et al. 2004; EEA 2007). Complementary felling could also represent a substantial source of bioenergy. A significant amount of registered residual forest biomass could be collected and used for energy purposes (e.g. in Hungary it amounts to 10 % of the woody biomass from logging). Several technological development projects are ongoing in this subject currently. (Molnar et al. 2013). Lower quality by-products (bark, wood fines and dust) are also beginning to play a greater role for instance in the energy supply system of timber processing plants.

EU Member States expect to mobilize extra domestic biomass resources for heating and electricity generation and to increase the amount of biomass destined to these industries by 50% (from 76 Mtoe in 2006 to 113 Mtoe) by 2020. It is expected that forests will continue to be the predominant source of biomass supply, with an overall share of over 66% of total biomass as a renewable energy source by 2020 (rising from 62 Mtoe to 75 Mtoe) (EC 2013b).

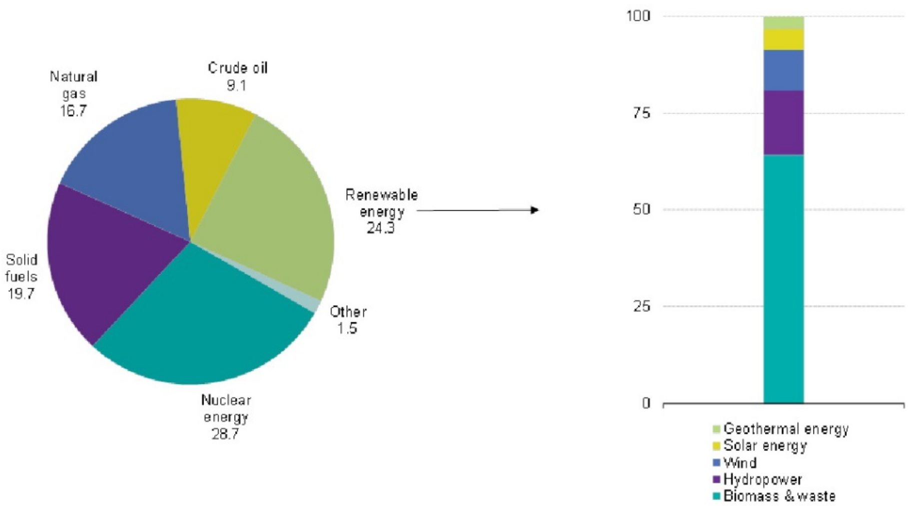

Figure 1: Share of biomass in EU-28 primary renewables production in 2013.

In order to sustain the future needs of woody biomass, mobilization of resources will be necessary. Recent projections under LULUCF (LULUCF: Land Use, Land-Use Change and Forestry) reveal that wood harvest rates are expected to increase by about 30% by 2020 as compared to 2010 (EC 2013), in order to satisfy the multiple and multifaceted demands towards this resource. (Ferranti, 2014) However, several industrial sectors (energy industry, wood and pulp industry, other material uses, etc.) will compete for this resource, and other sectors such as forest biodiversity conservation and forest recreation will enter the competition.

The above mentioned trends require a reassessment the available volume of biomass resources and investigation of possibilities for involving new, non-conventional biomass resources.

There is limited information regarding other dendromass bases, however these biomass quantities may be significant, and exploitation of additional resources can be harmonized with other sectoral – e.g. nature conservation, agriculture, infrastructure development – goals, furthermore could contribute significantly to the reduction of the stress on forests. These non-conventional sources of biomass include the volume of the biomass located on the uncultivated, natural or semi-natural areas, where woody plants of different invasive and/or non-invasive species and ages are developed.

2. Material and method

In Hungary, the Danube Ipoly National Park Directorate (DINPD) is the nature conservation manager of protected sites corresponding to 15,000 hectares of which 2,700 ha forest and the remaining part is mainly grassland. The protected area suffers conservation problems linked with invasive alien species. Starting from a nature conservation project based on the alien species removal, the park had the idea to change the problem into an opportunity using the organic material derives from nature conservation as a source of biomass for feeding local heating systems.

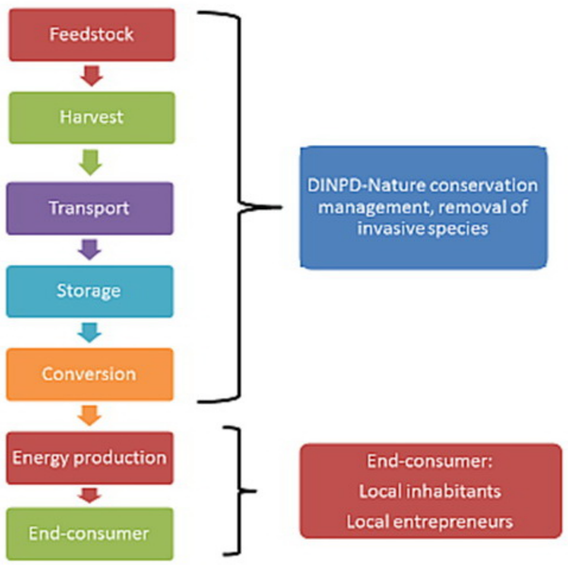

Figure 2: Local supply chain based on biomass from nature conservation developed and activated by Danube Ipoly National Park, Hungary.

Within the frame of BioEUParks project the park developed a supply chain (Fig. 2), in which case the Park was both the owner of the biomass and the responsible for harvesting, transport, storage, and conversion. The final users are local inhabitants, institutions of municipalities and DINPD itself. (Scrimshaw et al., 2016)

Balance of biomass production and consumer demands is essential in order to maintain a sustainable local supply chain. Therefore there was a need for a survey on biomass derives from nature conservation activities. The biomass potential survey of an area of ca. 30 ha located next to DINP visitor center at SAS Mountain was carried out by the University of West Hungary's research team in 2015. In the examined system, due to the heterogeneity resulting from the variability and characteristics of invasive and non-invasive woody crops, evaluation of the biomass production using methods for estimating tree yields in forestry and tree plantation practice was not feasible; therefore it was necessary to develop a specific survey method. The process can be summarized in steps shown in Fig. 3.

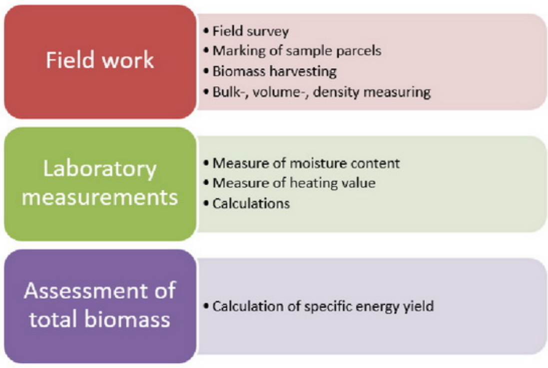

Figure 3: Steps of biomass potential and biomass-based energy potential assessment.

2.1. Field survey

Based on the visual check of the survey area in order to review dendromass composition and map the heterogeneities it was established that the vegetation is dominated by shrubs (blackthorn [*Prunus spinosa*] and hawthorn [*Crataegus monogyna*]), however the relative volume of main stock forming tree and shrub species are widely differing, mixed with ash-tree (*Fraxinus ornus*), sporadically, and the ratio of non-core component shrubs could reach up 30-40%.

Following the vegetation mapping sampling plots had been designated with pointers. Determination of the number and size of the sample parcels based on the size and heterogeneity of the area to be surveyed. In this case three sampling plots of 0.02 hectares each with representative vegetation had been designated and harvested (Fig. 4). The biomass was chopped by a low-power chipping machine.

Quantitative measurements and samplings were carried out on the spot. Required numbers of samples were taken for further tests, followed by delivering to the laboratories, where the sample preparation and measurement of energetic characteristics were implemented.

Determination of biomass yield of each sampling plot was based on the calculation of volume and bulk density of the heap of woodchips. The calculation of heap volume was performed according to standard methods from literature (Little, 1980). To measure the bulk density a sampling pot of standard volume was used, followed by weighing and calculation.

Figure 4: Motor-manual harvesting of invasive shrubs in one of the three sampling plots.

2.2. Laboratory measurements

The moisture content and calorific value measurements were performed in the laboratories of UWH. Moisture content varies by the type of biomass, the date of harvest and the storage method. For the measurements of moisture content of wood chips oven drying and analytical mass measurement were performed in 5 repetitions (5 samples per sampling plot).

Besides the determination of calorific value of mixed woodchips individual tests and calculation were carried out on each dominant woody crop samples, in 3 repetitions. Wood and bark was separated and tested in each measurement.

3. Results and calculations

Estimation of the total biomass and specific energy yield available in the experimental area was based on the results of measurements summarized in Table 1.

Table 1: Results of measurements and calculation of total biomass yield of the surveyed area.

	Plot no.1	**Plot no.2**	**Plot no.3**
Dendromass volume [m^3]	1,21	1,46	0,99
Average bulk density [kg/m^3]	245,00	231,70	192,05
Average moisture content [%]	17,40	17,70	27,34
Average calorific value (abs. dry matter) [MJ/kg]	15,71	15,51	15,53
Relative yield (abs. dry matter) [t/ha]	12,24	13,92	6,91

Based on the results of sample analysis – 7-14 atro-tons/ha dendromass yield and 15.58 MJ/kg average calorific value (relative to abs. dry matter) –, 109-218 GJ/ha energy yield was calculated.

By comparison of the test results with the furnace needs the minimum size of the area could be calculated to produce the required amount of non-conventional biomass feedstock for local combustion facilities.

4. Summary

Wood harvest rates are expected to increase further, in order to satisfy the multiple and multifaceted demands towards this resource. Forest biomass for energy is a means to local energy supply and diversification, to improve the development of rural areas and to increase employment rates. However, the production of forest energy wood may conflict with forest biodiversity conservation and nature protection goals and also social issues related to the forest environment.

The Danube-Ipoly Park study case based on the matching of nature conservation management with sustainable exploitation of woody biomass represents a key example on how to guarantee the forest multifunctioning and the setting up of a model of sustainable supply chain within protected European areas. In this particular case study, practical methods used in forest management to estimate biomass potential were not usable for the different features and high heterogeneity of the examined area. Therefore a survey protocol for assumption of biomass potential in natural/semi natural systems of high heterogeneity has been developed and tested by the UWH Institute of Forestry and Environmental Techniques.

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Logistic analysis of wood chips procurement chain from forest to power industry plants - method

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Abstract: We present an analysis of the wood harvesting residues procurement process. In this case chips are supplied to large power plants. Analysis is based on data collected in north-eastern Poland. Typical logistic division of the system objects categories are applied - movable or active objects (vehicles skidding, trucks, choppers, etc.) and stationary or passive ones (storage yards, warehouses). To determine the time of execution of the operations by the active objects (machines), because of the stochastic character of the process and its environment, we apply description of uncertain dynamic systems derived from dynamic programming. The necessary data were obtained during field research of wood harvesting and transport process

Keywords: wood harvesting, wood procurement, logistic, mathematical modeling

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1. Introduction

Biomass is one of the most important renewable energy sources. In Poland, due to its geographical location and climate, biomass is the most important renewable energy source. In the case of forest biomass, for energy purposes can be allocated medium sized firewood (retail customers only) and without such a limits, fuelwood (e.g. rejected pulp wood), thin trees and branches and tops from final fellings. The last one is the main source of energy wood in Poland. Harvesting residues procurement is carried out on a large scale and has the character of completely mechanized production process. In its implementation there are numerous interruptions, the occurrence of which can be minimized by conducting analyzes using the methods of operations research and logistics. We present an analysis of the wood harvesting residues procurement process. In this case chips are supplied to large power plants. Analysis is based on data collected in north-eastern Poland.

2. Material and Methods

Investigated process has a clear biphasic nature, in the first phase raw material is processed and transported to the place of transfers (next to forest road), from that point wood material (predominantly chips) is transported to customers – this is second phase. Energy wood harvesting can be described as a parallel process of production, the first and second phase are carried out simultaneously and are interconnected. Typical logistic division of the system objects categories are applied - movable or active objects (vehicles skidding, trucks, choppers, etc.) and stationary or passive ones (storage yards, warehouses). Depots are described by the following characteristics: location, load capacity, input capacity and output capacity. Depots serve as a buffers to reduce the probability of interruptions, that cause downtime and prolongs the process. To determine the time of execution of the operations by the active objects (machines), because of the stochastic character of the process and its environment, we apply description of uncertain dynamic systems derived from dynamic programming.

A typical description of the duration of the cycle (n) of operation (t_i) has the following form:

$$t_i(n) = t_{mi}(n) + w_i(n) + p_i(n)$$

and consequently duration of the process (T_i) after implementation of the n cycles is presented as the following sum:

$$T_i(n) = T_i(n-1) + t_i(n) + z_i(n)$$

A key advantage of the method is the formal record of duration of interruptions (z_i) and thus the possibility of minimizing that time. The duration of the next (n) cycle of operations (t_i) results from the function describing the average duration (t_{mi}), function defining random deviation (w_i) and randomly occurring or planned downtime (p_i). The interruptions (z_i) are described by following equations.

Interruptions at the beginning of cycle number n:

$$z'_i(n) = \begin{cases} T_{i-1}(n) - T_i(n-1), & if\ T_{i-1}(n) > T_{i-1}(n-1) \\ 0, & if\ T_{i-1}(n) \le T_{i-1}(n-1) \end{cases}$$

Interruptions at the end of the cycle number n:

$$z''_i(n) = \begin{cases} T_{i+1}(n-1) - \left[T_i(n-1) + t_i(n) + z'_i(n)\right], & \\ & if\ T_{i+1}(n-1) > T_i(n-1) + t_i(n) + z'_i(n) \\ 0, & if\ T_{i+1}(n-1) \le T_i(n-1) + t_i(n) + z'_i(n) \end{cases}$$

In order to gather the necessary data, time studies of operation cycles of machines used in the reporting process were performed (e.g. mobile chipper with or without chip bin, forwarder adopted to transportation of tree branches, truck with hook lift container, semi-trailer truck etc.). Variants of machines (vehicles) modifications, that enable to decrease the duration of the downtime, were also considered. The operational cycle can be described in typical way.

As example we present below the operational cycle of mobile chipper.

Operation cycle of chipper has been divided into the following components:

t_1 - driving without load, from the unloading site to the point of start of residues collection and chipping;

t_2 - chipping, containing a collection of the remains using a crane and the necessary movements of the machine;

t_3 - driving back with a cargo (storage tank filled with wood chips) to the place of unloading, after the completion of chipping;

t_4 - discharge, spillage of chips to truck semitrailer.

As a result of field measurements average values of individual times are specified and also probability distributions characterize their variability. For the example variability of mobile chipper chips dumping time is presented on figure 1.

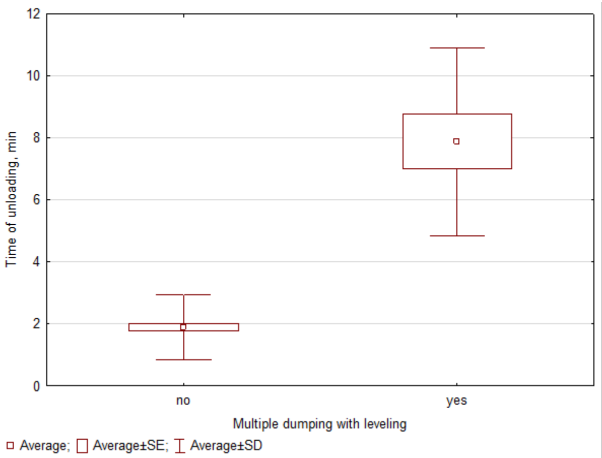

Figure 1: The comparison of chips dumping time. On the left - the entire container at one time, on the right - chips dumping spread over several stages with chips leveling using a crane

The results of simulation can be used to calculate the parameters characterizing the efficiency of the use of machinery.

3. Results and conclusions

It has been shown that analyzed process is very sensitive to the size and distribution of post-harvesting areas. This method can be very useful for quickly changing production processes carried out by machine groups consisting of at least several interacting units. The method of description of uncertain dynamic systems derived from dynamic programming can be applied in forestry on the condition of gathering large enough data sets. Only then it is possible to satisfactory fit probability distributions. Especially demanding is the description of the operation of transport vehicles for which the distribution parameters depend on the distances of transport. Preliminary calculations were fulfilled for the process in which logging residues were collected by the forwarder (suitable for transporting branches and tops), and then transported to the storage yard at forest road. Further branches were collected from the piles by self-propelled chipper, equipped with a bin for chips. After filling the bin, chipper was moving to the truck and chips were spilled out into semitrailer. In case of absence of reserve of logging residues average time of truck loading can rise from 121,4 to 219,7 minutes.

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Chapter 3. Environmental impact of forest operations

Visual Quality Assessment of Road Network within the Forested Areas

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Abstract: The effects of different roads standards on visual quality have been investigated. The pictures of some roads within the forested areas of Uşak Forest Enterprise Directorate were taken and road template components such as cut slope, fill slope, and road platform were evaluated for visual quality purposes. The effects of different road types (valley road, hillside road, and hill road) and road surface types (native road, forest road, gravel road, and asphalt road) on visual quality were also evaluated for road template components and different weather conditions (normal and wet weather). The results indicated that vegetation cover on cut and fill slopes was considerably effective on visual quality. It was found that hillside roads were better than other road types regarding with visual quality. Native roads and forest roads exposed better visual quality in normal weather conditions, while asphalt and gravel roads were better in wet weathers.

Keywords: Forest roads, road types, visual quality, aesthetic assessment

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1. Introduction

Forest road networks are main infrastructures that provide access to forest resources for afforestation, forest mensuration, forest protection, forest harvesting, and forest transportation activities (Akay and Sessions, 2005). Forest roads are generally designed and constructed by considering technical, economic, and environmental constraints (Akay, 2006). During road construction stage, forest soil and vegetation are subject to displacement along the roadway which may increase erosion risk and sediment yield to streams. Thus, road alignment as well as road components (i.e. surface, cutslope, fillslope) should be carefully planned to minimize potential environmental damages. The amount of road surface material and road surface type should be carefully determined and cutslope and fillslope should be vegetated right after road construction. Those activities not only reduce environmental effects but also increase visual quality of the roads.

In recent decades, there has been increasing interest in reducing the effects of road networks on visual quality of natural landscape (Eleftheriadis and Tsalikidis, 1990). Especially in forested areas, road networks which are exposed as open surface without green vegetation negatively affect visual quality. The effects of road networks on visual quality are evaluated based on various factors such as unnatural alteration of topographic structure, existence of vegetation, formation of linear corridors, and color and texture changes. Slopes covered with green vegetation along roadway are considered as one of the most important factors that affect visual quality (McDonald and Litton, 1987). In a study conducted by Akay et al. (2007), visual quality of forest roads in eastern Turkey was evaluated by considering road surface, cutslope, fillslope, and surrounding area along a roadway. The results indicated that vegetation cover over slopes seriously affected visual quality of forest roads.

In this study, it was aimed to evaluate visual quality of forest roads with various types (valley road, hillside road, hill road) and various road surface types (native road, forest road, gravel road, and asphalt road) within a sample forested area located in Uşak Forest Enterprise Directorate in western Turkey. The road template components (i.e. cut slope, fill slope, and road platform) and different weather conditions (normal and wet weather) were considered for visual quality purposes. In the study, firstly, pictures of forest road sections were taken from different sites and a survey was implemented for visual quality assessment. The visual effects of road networks when observed from both far distances and close distances were evaluated within forested areas. The data were statistically analyzed by using SPSS 16.0 (SPSS Inc., Chicago, USA) program.

2. Material and Methods

2.1. Study Area

The study area is located in Paşacık Forest Enterprise Chief (FEC) of Uşak Forest Enterprise Directorate in Denizli Forest Regional Directorate (Figure 1). The area of Paşacık FEC is 29000 hectares where dominant species are Brutian Pine, Black Pine, and Fir. In the study area, the forested area is reported as 12500 hectares. Average ground slope and elevation are 39% and 1171 m, respectively.

2.2. Survey

For survey application, total of 96 pictures of forest roads were taken from Paşacık FEC in 2015 Spring-Summer (May-July) and 2015 Fall (September-November). The pictures were taken during day time between 10:00 AM and 3:00 PM. Pictures were recorded into computer and some of them were eliminated during preprocessing stage. The pictures with clear view and natural formation were selected for survey stage. Then, selected 82 pictures were displayed to 30 people (academicians, forest engineer, graduate students) who are related to forestry, landscape, and forest roads subjects.

Before implementing the survey, the aim of the study was clearly explained and five warm up pictures were displayed to the participants. The warm up pictures indicated good and bad examples of road template components, road type, and road platform. For each picture, the participants were asked to give grades from 1 to 5 (1=very low, 2=low, 3=average, 4=high, 5=very high). Visual quality assessments were completed under three groups: 1) Close distance evaluation, 2) Far distance evaluation, 3) Road surface types.

Figure 1: Study area.

Figure 2: Sample pictures displayed for visual quality evaluation of roads at close distance.

Figure 3: Sample pictures displayed for visual quality evaluation of roads at far distance.

For close distance evaluation, 43 pictures were displayed to participants for visual quality assessment of road template components (Figure 2). On the other hand, 39 pictures were displayed for far distance evaluation of visual quality considering road template components and road types (Figure 3). The average visual quality values of the road components were recorded for each participant based on visual quality grades given by his/her for all pictures.

The participants were also asked to give visual quality grade for overall status of road sections displayed in the pictures typed (Table 1, 2, and 3) and included (Figure 4) at the end of the paragraph. For far distance evaluation, the number of pictures indicating valley road, hillside road, and hill road were 14, 12, and 13, respectively. Pearson correlation method was used to search relationship between road template components. Linear regression analysis was implemented to examine the effects of road components on overall visual quality of road sections.

Table 1: Survey form used for visual quality assessment of road sections at close distance.

No	Visual Quality Grades (1=very low, 2=low, 3=average, 4=high, 5=very high)																			
	Cutslope					Fillslope					Road Platform					Overall Status				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1																				
2																				
..																				
..																				

Table 2: Survey form used for visual quality assessment of road sections at far distance.

No	Road Types			Visual Quality Grades (1=very low, 2=low, 3=average, 4=high, 5=very high)																			
	Valley Road	Hillside Road	Hill Road	Cutslope					Fillslope					Road Platform					Overall Status				
				1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1																							
2																							
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Table 3: Survey form used for visual quality assessment of road surface types.

No	Road Surface Types				Visual Quality Grades (1=very low, 2=low, 3=average, 4=high, 5=very high)														
	Native Road	Forest Road	Gravel Road	Asphalt Road	Cutslope					Fillslope					Road Platform				
					1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1																			
2																			
..																			
..																			

Figure 4: Sample pictures displayed for visual quality evaluation of road surface types at normal (left) and wet weather (right) conditions.

3. Results and Discussion

3.1 Close Distance Evaluation

The average visual quality grade and overall visual quality grade given by each participant was indicated in Table 3. The basic statistics about visual quality grades were given in Table 4. The results indicated that average visual quality grades for road components (cutslope, fllslope, road platform) and overall status were 3.0, 3.3, 3.2, and 3.2, respectively.

Table 4: Average visual quality grades for close distance evaluation.

No	Average Visual Quality Grades			
	Cutslope	Fillslope	Road Platform	Overall Status
1	3.6	3.8	3.6	3.5
2	3.2	3.6	3.8	3.6
3	2.8	3.2	3.0	3.2
4	2.6	3.4	2.0	2.9
5	2.4	2.6	2.4	2.6
6	2.6	3.2	3.2	2.9
7	3.0	4.2	4.2	3.6
8	4.0	3.8	4.0	3.7
9	3.2	3.2	3.4	3.5
10	3.0	3.8	3.6	3.2
11	2.6	2.6	2.8	2.9
12	2.2	2.6	2.6	2.6
13	2.4	2.8	3.0	2.5
14	2.2	3.2	3.2	3.2
15	2.4	3.0	3.0	3.0
16	2.6	2.8	2.6	2.8
17	4.0	3.6	4.2	3.7
18	3.2	2.6	3.4	3.3
19	3.0	3.0	2.6	2.8
20	2.8	3.2	3.8	3.0
21	2.4	2.6	2.4	2.6
22	3.4	4.0	3.4	3.5
23	3.4	3.2	3.4	3.1
24	3.4	3.4	3.6	3.3
25	4.2	3.8	2.8	3.7
26	3.2	3.2	3.6	3.4
27	2.6	3.2	2.8	2.7
28	3.8	3.8	3.8	3.7
29	3.4	3.6	3.8	3.5
30	3.2	3.8	3.2	3.5

The Pearson correlation indicated that there was a statistically significant relation between road template components ($p<0.01$). The linear regression was model developed to indicate effects of road components on overall visual quality grade. The regression model was statistically significant ($p<0.05$) for all tree road components with R^2 value of 0.825 (Table 6). The regression model in which visual quality of overall status was dependent variable (y) and visual quality of road components was independent variables (x_1=cutslope, x_2=fillslope, x_3=road platform):

$$y = 0.743 + 0.324x_1 + 0.260x_2 + 0.187x_3 \qquad (1)$$

Table 5: Basic statistics about visual quality grades.

Variables	Average	Minimum	Maximum	SD
Cutslope	3.0	2.2	4.2	0.55
Fillslope	3.3	2.6	4.2	0.47
Road Platform	3.2	2.0	4.2	0.56
Overall Status	3.2	2.5	3.7	0.39

The results indicated that the visual quality was highly affected by cutslope, followed by fillslope. In a similar study, McDonald and Litton (1987) also reported that existence of vegetation cover on road slopes greatly effects visual quality.

3.2. Far Distance Evaluation

The average visual quality grade and overall visual quality grade given by each participant was indicated in Table 7. The basic statistics about visual quality grades were given in Table 8. The results indicated that average visual quality grades for road components (cutslope, fllslope, road platform) and overall status were 3.2, 3.1, 3.0, and 3.1, respectively.

The Pearson correlation indicated that there was a statistically significant relation between road template components ($p<0.01$). The linear regression was model developed to indicate effects of road components on overall visual quality grade. The regression model was statistically significant ($p<0.01$) for all tree road components with R^2 value of 0.97 (Table 9). The regression model in which visual quality of overall status was dependent variable (y) and visual quality of road components was independent variables (x_1=cutslope, x_2=fillslope, x_3=road platform):

$$y = 0.115 + 0.205x_1 + 0.511x_2 + 0.243x_3 \qquad (2)$$

The results indicated that the visual quality was highly affected by fillslope, followed by road platform. In a similar study, Benson and Ulrich (1981) indicated that bare surfaces without vegetation cover negatively effects visual quality.

Table 6: Regression table for visual quality grades at close distance evaluation.

Model		Non-standard Coefficients		Standard Coefficients	t	P
		B	Standard Error	Beta		
1	(Continuous)	0.743	0.220	-	3.372	0.002
	x_1	0.324	0.077	0.464	4.191	0.000
	x_2	0.260	0.093	0.313	2.781	0.010
	x_3	0.187	0.072	0.273	2.596	0.015

In the next stage, the effects of road types on visual quality were evaluated for far distances. The visual quality grades given by each participant for three road types (valley road, hillside road, hill road) were listed in Table 10. The results indicated that average visual quality grades for road types and overall status were 2.9, 3.7, 2.9, and 3.2, respectively.

It was found that hillside roads had better visual quality grades than other road types because hillside roads are less visible from far distances. The results indicated that road template components were easily visible from far distances which reduces visual quality. Especially road slopes without vegetation cover are seen as bare ground surfaces which negatively effects visual quality.

Table 7: Average visual quality grades for far distance evaluation.

No	Average Visual Quality Grades			
	Cutslope	Fillslope	Road Platform	Overall Status
1	2.3	4.0	4.0	3.4
2	2.7	4.7	2.7	3.4
3	2.3	3.3	3.0	2.9
4	3.7	2.0	3.7	3.1
5	2.3	4.0	2.0	2.8
6	4.0	2.7	3.0	3.2
7	4.0	3.3	3.3	3.5
8	2.3	2.3	2.0	2.2
9	2.3	3.7	2.0	2.7
10	2.3	3.3	2.0	1.4
11	2.7	3.7	2.3	2.9
12	4.0	5.0	3.3	4.1
13	1.7	3.7	2.0	2.5
14	1.7	4.7	3.3	3.2
15	3.7	5.0	4.0	4.2
16	3.0	2.0	2.7	2.6
17	3.0	3.3	2.0	2.8
18	2.3	3.7	3.7	3.2
19	2.7	4.7	3.0	3.5
20	3.3	2.3	2.0	2.5
21	3.7	3.7	2.7	3.4
22	3.0	5.0	2.3	3.4
23	3.0	4.3	3.3	3.5
24	4.0	2.7	3.7	3.5
25	2.3	3.7	2.0	2.7
26	3.3	4.0	2.7	3.3
27	2.3	4.3	2.7	3.1
28	4.0	3.7	4.0	3.9
29	2.7	4.7	3.3	3.6
30	2.3	4.3	3.7	3.4

Table 8: Basic statistics about visual quality grades.

Variables	Average	Minimum	Maximum	SD
Cutslope	3.2	2.0	4.3	0.62
Fillslope	3.1	1.3	4.7	0.63
Road Platform	3.0	1.0	4.0	0.68
Overall Status	3.1	1.5	4.3	0.54

Table 9: Regression table for visual quality grades at close distance evaluation.

Model		Non-standard Coefficients		Standard Coefficients	t	P
		B	Standard Error	Beta		
1	(Continuous)	0.115	0.102	-	1.127	0.270
	x_1	0.205	0.039	0.237	5.291	0.000
	x_2	0.511	0.036	0.592	14.064	0.000
	x_3	0.243	0.038	0.306	6.344	0.000

Table 10: Average visual quality grades of different road types for far distance evaluation.

No	Average Visual Quality Grades			
	Valley Road	**Hillside Road**	**Hill Road**	**Overall Status**
1	2.3	4.0	4.0	3.4
2	2.7	4.7	2.7	3.4
3	2.3	3.3	3.0	2.9
4	3.7	2.0	3.7	3.1
5	2.3	4.0	2.0	2.8
6	4.0	2.7	3.0	3.2
7	4.0	3.3	3.3	3.5
8	2.3	2.3	2.0	2.2
9	2.3	3.7	2.0	2.7
10	2.3	3.3	2.0	1.4
11	2.7	3.7	2.3	2.9
12	4.0	5.0	3.3	4.1
13	1.7	3.7	2.0	2.5
14	1.7	4.7	3.3	3.2
15	3.7	5.0	4.0	4.2
16	3.0	2.0	2.7	2.6
17	3.0	3.3	2.0	2.8
18	2.3	3.7	3.7	3.2
19	2.7	4.7	3.0	3.5
20	3.3	2.3	2.0	2.5
21	3.7	3.7	2.7	3.4
22	3.0	5.0	2.3	3.4
23	3.0	4.3	3.3	3.5
24	4.0	2.7	3.7	3.5
25	2.3	3.7	2.0	2.7
26	3.3	4.0	2.7	3.3
27	2.3	4.3	2.7	3.1
28	4.0	3.7	4.0	3.9
29	2.7	4.7	3.3	3.6
30	2.3	4.3	3.7	3.4

3.3. Road Surface

The average visual quality grades given by participants to each road section under normal weather conditions were listed in Table 11. The results indicated that average visual quality grades for road surface types (native road, forest road, gravel road, asphalt road) were 3.7, 2.8, 2.5, and 3.5, respectively. It was found that native roads provided the best visual quality due to natural view and vegetation cover on the road components.

In the second case, the visual quality of road surface materials was evaluated based on their resistance in wet weather conditions. Table 12 indicates the average visual quality grades given by participants to each road surface type. The results indicated that average visual quality grades for road surface types (native road, forest road, gravel road, asphalt road) under wet weather were 1.6, 1.8, 3.4, and 3.7, respectively.

It was found that asphalt roads were in better shape comparing with other surface types, followed by gravel road and forest road. In normal (dry) weather conditions, native roads had received the highest grades since the structures of road components, especially road surface, were in good shape and covered by vegetation. However, road components were dramatically affected by surface runoff in wet weather conditions which reduced the visual quality of native roads. Likewise, forest roads had received lower visual quality grades in wet weathers. On the other hand, asphalt roads had received the highest visual quality grades since their pavement and slope stability are more resistant in wet weathers comparing with other surface types.

Table 11: Average visual quality grades of road surface types under normal weather conditions.

No	Average Visual Quality Grades			
	Native Road	**Forest Road**	**Gravel Road**	**Asphalt Road**
1	5.0	2.3	3.0	3.3
2	4.7	3.3	3.0	3.7
3	3.7	3.7	4.0	4.0
4	5.0	4.0	1.0	2.3
5	4.0	2.7	3.0	3.3
6	3.0	2.0	2.0	3.7
7	1.7	5.0	2.7	4.0
8	4.3	1.3	1.7	2.3
9	3.0	2.7	1.7	3.7
10	4.0	4.0	2.7	4.3
11	2.0	3.7	3.3	4.0
12	3.7	4.3	3.3	3.7
13	3.7	1.3	1.7	2.7
14	2.7	1.3	1.0	3.7
15	3.3	3.7	3.0	4.0
16	4.0	1.7	2.3	3.0
17	3.7	2.3	3.7	4.7
18	4.7	1.3	1.0	2.3
19	3.7	4.7	3.0	4.0
20	4.3	3.3	3.0	3.7
21	2.7	1.0	1.0	2.0
22	3.3	2.3	1.0	3.3
23	5.0	1.0	1.0	2.7
24	3.3	4.0	3.0	4.3
25	2.7	4.0	3.7	4.3
26	4.0	2.3	2.3	3.7
27	3.0	3.7	2.7	3.0
28	3.0	2.0	4.3	4.7
29	4.7	2.7	2.7	2.7
30	5.0	2.3	3.0	3.0

Table 12: Average visual quality grades of road surface types under wet weather conditions.

No	Average Visual Quality Grades			
	Native Road	**Forest Road**	**Gravel Road**	**Asphalt Road**
1	1.0	1.0	4.3	4.0
2	1.3	1.3	4.0	4.0
3	2.0	2.7	4.0	4.0
4	2.0	2.0	5.0	5.0
5	2.0	1.0	3.3	3.0
6	1.0	1.0	2.0	3.0
7	2.0	2.0	2.3	3.7
8	1.3	1.0	2.7	3.3
9	1.0	1.7	2.7	3.7
10	1.3	1.0	2.0	2.7
11	2.3	2.3	2.0	3.0
12	2.0	2.0	2.7	4.0
13	1.0	1.0	4.3	3.0
14	1.0	1.0	3.3	3.3
15	1.7	1.7	3.3	2.7
16	2.0	2.0	4.3	4.0
17	1.7	2.3	5.0	5.0
18	1.0	1.0	4.0	3.0
19	2.3	3.7	3.7	4.3
20	1.7	1.7	3.7	3.7
21	2.0	2.0	3.3	3.3
22	1.0	1.0	3.0	3.7
23	1.0	1.7	4.0	4.0
24	2.0	2.7	3.0	4.0
25	1.7	3.0	3.3	4.0
26	1.0	1.0	2.3	3.3
27	2.0	2.3	2.3	4.0
28	2.7	4.3	3.7	5.0
29	1.7	2.0	3.7	4.0
30	1.3	1.3	4.0	3.3

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Theory and practice of ploughing

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Abstract: Forest soil preparation in the applied work is based on four principles of soil preparation - trenching, drilling, plowing, and milling. Each of these types of tillage has its own mechanisms, the theoretical basis . Theories of ignorance or disregard leads to inadequate mechanism for use in practice. One of these mechanisms is a forest plow with the modifications which combines a transparent classification.

Keywords: ploughing theory, forest plough classification

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1. Introduction

Ploughs have been used in forest soil preparation for a long time. The theory of plough usage does not change regardless if it is used in farming or forestry even though the working conditions in both situations differ. Increase in contraction power has been observed due to the rapid technological development. This has lead to the use of new materials and technology in the plough production for farming and forestry purposes.

Newest ploughs that are used in forest soil preparation do not resemble the classical idea of ploughs. Therefore a need for a broader forest plough classification has emerged.

A significant job has been already done in a form of forest plough classification which is based on V. Gorjackin (Василий Прохорович Горячкин 1868—1935) ploughing theory. Mentioned paper researched the development of ploughing theory based on technology development.

2. Materials and methods

Plowing theory

The theoretical part of the plowing process developed by Russian academician V. Gorjackin. It states that all forms of plowing is based on three basic activities of wedges (Gasiņš L.1975)

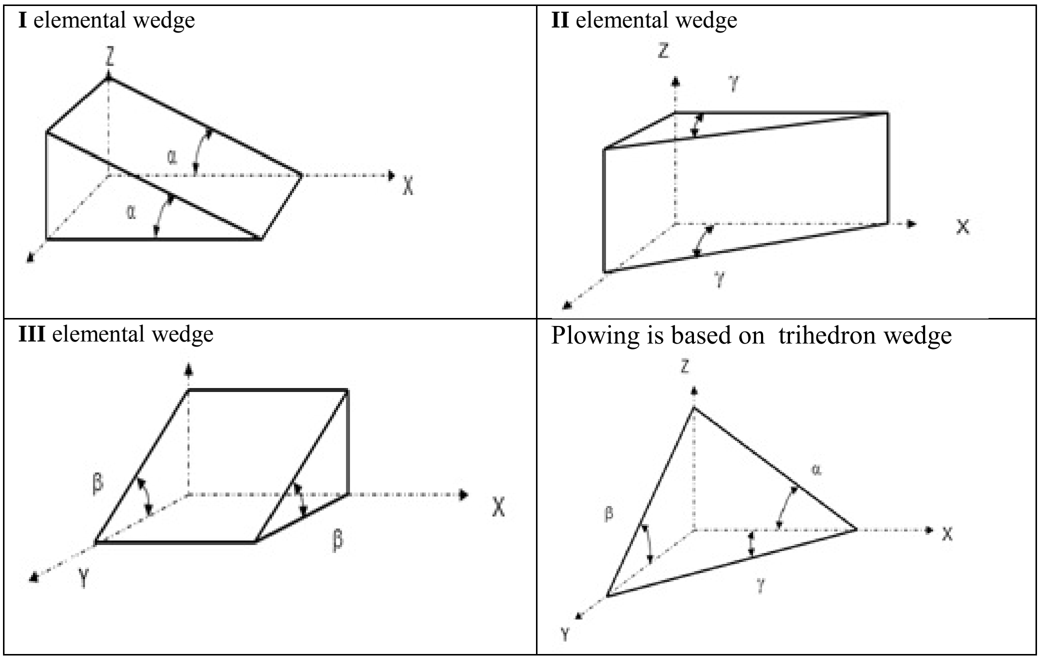
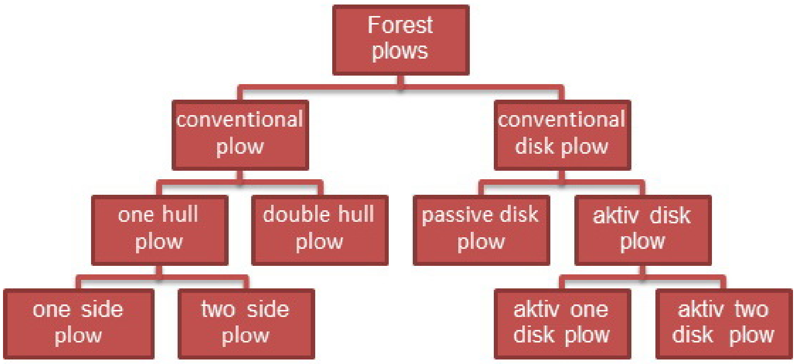


Figure 1: Theori of the plowing process.

Picture 1: Trihedron wedge on the plow.

How to recognize the plows? It can be done easily if previously developed forest plough classification is used (T.Blija FORMEC 2015, 2013, 2011). An overview of classification is available below:

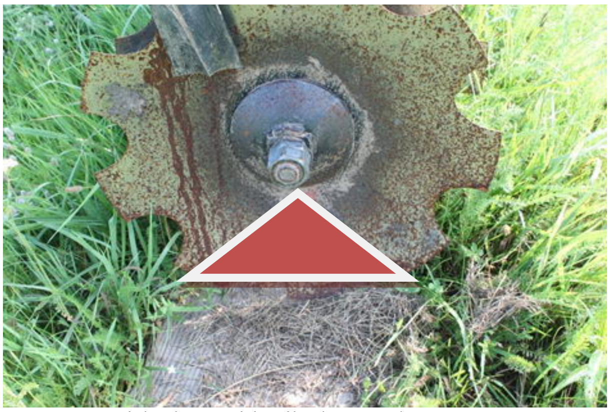


Picture 2: Forest plough classification by T.Blija.

3. Discussion

Some forest soil preparations mechanism producers are mistakenly naming ploughs as mills or scarifier. This phenomena is occurring in Europe e.g. Czech Republic (TPF-1,TPF-2 (Diskinėfreza TPF-2)).

Picture 3: Diskinėfreza (?) TPF-2 (up), disk ploug (down).



Picture 4: Disk ploug with trihedron wedge.

Ploughing – soil transformation using three wedge theory (Gasiņš L. 1975).

Issue with incorrect titles is occurring also in Nordic countries e.g. Latvia, Sweden and Finland. Disc trenchersT21.b., Bracke T26.a - Disc trencher, Bracke T35.a - 3- Row Disc Trencher

So far, many authors (Mangalis I. 1989, Mangalis I, Liepa J. 1980, Mangalis I 2004, www. brackeforest.com) have not been able to understand the membership of a disk plow activity theory.

Soil Processing Facility manufacturers should distinguish between two things:

Movement theory

Movement application possibilities.

For instance:

Disk Trencer T21.a can not only make skarifikation Finnish and Swedish forest soils , but also to prepare the forest soil of different depth of furrows. It follows that the practice is a great opportunity to diversify the tillage methods. Diversifying the ways of plowing , it is possible to achieve a more efficient and environmentally friendly reforestation .

Picture 5: Disk trencer T21.a (up), Scheibenegge T21.a. (down). (www. brackeforest.com).

4. Conclusion

1. By not using a plow drawn rankings are difficult to navigate the forest plow diversity and their application
2. Not knowing or ignoring plowing theory comes to the completely wrong plow operating explanations
3. In a number of cases the plow operation is explained by a completely different mechanism of action theory.
4. In such a situation we find ourselves in universities teaching the students in-depth course on forest soil preparation

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A study of lateral drains (waterways and gullies) in section 1 of mekaroud forest roads

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Abstract: The role of forests in sustainable development will occur when comprehensive attention is paid to our forest ecosystems; this includes forest roads with significant density. Several factors are involved in the degradation of forest roads, most notably, the runoff generated by rainfall, which directly threatens the forest road. This study aims to investigate the lateral drains within 50 km of forest roads in the sequence 1 Mekaroud of watershed forest with an area of 2732 hectares was 36 Kazemroud, using topographic maps with a scale of 1: 25,000, software, GPS devices and ARC GIS 9.2, EXCEL and HYFA by controlling the status of existing drains pipe and culverts) and then to determine the maximum flood discharge occurring consecutively using a reasoning approach with different return periods of 2, 5, 10, 25, 50 and 100 years considering the intensity of rainfall, the runoff coefficient, concentration time, area, channel length and scope, conditions, topographic, hydrological and vegetation of the area was conducted in each sub area. The results of this study indicate that out of 90 sub-basins in five different directions forest road, 120 points of fracture in the slope of the road (thalweg) exist. And in only 70 of them waterways and gullies with an average distance of 400 to 650 meters from one another are constructed which are doing the drainage of the water. In addition, a total of 70 in the path of water flow through the flood with a return period of about 90 percent capacity of discharge for only 2-year return period, 70 percent for 5-year period, 50 percent for100-year period, 35 percent for discharge of 25 and 50-year return and less than 30 percent for discharge of 100-year return period were observed.

Keywords: Water, forest roads, drainage reasoning approach, runoff, return period, discharging

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1. Introduction

The role of forests as a principle in sustainable development is quite obvious. This unique role has presented new definitions and concepts at the international level. Therefore, knowing the accurate identification of human impacts on forests is of the most urgent issues. One of the most important such impacts is the construction forest road network and forest logging constitute more than 70% of the costs. It is essential to consider how we intervene in this critical system, while inflicting the least environmental damage and the most efficient transport network with minimum cost necessary. Usually the construction of forest roads, despite its advantages, has a decisive role in the aspects of soil erosion, landslides, cut of water artery upstream to downstream and generally disrupting the ecosystem balance which is interference on it should be carefully. One of the most important factors that directly threat forest roads is water. Establishing roads in the domain causes the runoff in road surface or levee was result severe soil erosion. Therefore, the water flows should properly be directed at the side channels of the road and drain by technical water-related structures such as bridges, underpass pipes and overflow or fountain from the upstream to the downstream side. In this study attempts to investigate the full qualitative and quantitative water-related structures was constructed for forest roads in order to draining runoff from rainfall of side channel or waterways, pass pipe by scientific methods in return period 2-5- 10-15- 25-5-0-100 year. Arnold (1957), conducted a study of drainage structures built in areas of forest roads in the mountainous roads of North West America by using a reasoning approach with 25-year return period lasting 15 minutes to concluded whatever rainfall intense is higher the, the distance between must be the shorter .

Piehl et al (1988) in central Oregon coastal ecosystems conducted a research on capacity of guided maximum amount of runoff channel 128 with 25-year return period and The results showed that in 40% of cases they were not able to pass through the 25-year return period flood. Nazari (2000), for the design of educational systems in forest roads in the area of Kheiroudkenar Gorazbon Noshahr used a reasoning approach to estimate the maximum runoff within a 50-year return period in road A,B and C. The results of his study showed that in the roads A, B, C return 50 years old, in the road B although More than 80 percent of the drain to drain runoff occurred with the return period more than 50 years. But 70 percent of the waterways and drains are constructed in this way are able to discharge the maximum runoff More than 100 years return period. This means that the a large width of waterway and excessive costs in their construction was used. But only 25 percent of drains in road C were able to guide and discharge runoff which is generated with a return period of 50 years, But in 75 percent of cases can conduct and discharge of runoff generated in the aftermath of rainfall with a return period of not more than 10 years. This represents a large portion of the small crater in the road construction and to increase the risk of failure waterways waterways in the direction of the airport. But in road A although pipes with a diameter of 40 cm were selected for construction of waterways, in some cases, due to deformation of the slope of the road, get levels runoff was smaller than the amount of computing, as a result, the volume and speed of runoff accumulates high levels of the corresponding parts is low in side ducts. Therefore, in these cases in order to avoid increasing the cost of construction waterways with a diameter of 40 cm to 30 cm diameter pipe was proposed.

Ballard (2000), Keim and Skaugset (2003) found that disruption of the forest floor can expose mineral soil to raindrop impact, which can reduce infiltration capacity. Also, the combination of canopy removal and forest floor disturbance may result in excess overland flow during a rainfall of high intensity and affect a range of hydrological processes, including infiltration and erosion. Fast initial growth and quickly formed cover are essential to minimize the soil movement from roadside slopes. This is especially true of newly constructed roadside slopes. Soil on newly constructed roadside slopes is often loose and also is void of the vegetation cover that protects the surface soil from rain drop splash and surface flow (Grigal 2000; Grace 2000).

As Wallbrink and Croke (2002) mentioned, the creation of water diversion is a very effective strategy to control the runoff and soil loss. On steep slopes, runoff affected by the slope gradient leads to increasing soil erosion (Fox, Bryan 1999). Water diversions are used in forestry operations to mitigate the impact of logging because water diversion is a major region of sediment deposition (Croke et al. 2001; Wallbrink, Croke 2002). Because of the cost involved in constructing and maintaining water diversions, it is important to determine their location. Nikoei, Mehrdad (2000), using a reasoning approach to determine the maximum runoff water with a return period of 20 years, attempted to design a drainage plan for the forest roads of 'Koliyyeh sara' county in Guilan. The results of his study show that in the aforementioned area, the necessary improvement requires 3 pipes of varied diameters (30-110 cm) in 200 meters of distance from one another (Mahdavi, 1992).

2. Materials and methods

2.1. The characteristics of the study area

The region of the study is situated in 20 km between 'Abbas abad' town and the county of 'Kalardasht' which is in the 1st series of Mekaroud forest network in the watershed area 3 of 'Kazem roud' and it is under the protection of the Department of Natural Resources and Watershed of Noshahr, Mazandaran province. It is also within the confine of the Department of Natural Resources and Watershed of 'Kalardasht' with the latitude of 14" 33' 36° and 20", 38', 36° of north and longitude of 5", 7', 51° and 30", 11', 51° of east, within a height of between 500 and 1700 meters above the sea level and covers an area of 2732 hectare (Ballard, 2000). The area has an annual rainfall of 980 mm and with an average temperature of 12o C it is considered to have a humid and cold climate. In territory divisions of the country, it is located in Mazandaran province, city of Chalous, county of Klaradasht and the town of 'Hassan kif'.

2.2 Procedure

Fot this study in order to investigation run off and drain in the first step start to, gathering the information and data. Since the unit of planning and studying in studies of hydrological is watershed, primarily was produced, topographic maps with a scale of 1: 10,000 and insert the border set on it and turn it into a larger scale.Then forest roads network and distribution of hydrographic network was determined on the map.and located the exact position of waterways and culvert constructed along this road, on the map.and was prepared hydrologic units map (Basin) and match them with the on the fieled. After digitalization of information was produced all of the base maps by Arc GIS software and then to control the final, do field operations such as geographical location and waterways by GPS device, Picked up the road longitudinal profile slied, The side channel, slop of road and channel and recorded in tables which provides.Then in each track in order to determine the drainage areas, was identified a sub-domain border and each of the units of water from the highest point to the lowest point boundary of water outlet .Totally of 90 sub-domains were determined and extracted information in each of these units includes the area of the field, stream length, number of waterways, minimum and maximum elevation, etc. by ARC GIS software and attempted to estimate the maximum runoff occurs in the return periods of 2, 5, 10, 20, 25, 50 and 100 years old) on each route and hydrological units

2.2.1. Suitable method to estimate the maximum runoff

To estimate peak flood and runoff, various methods can be used that depend on the intended purpose, available statistics, specifications watershed, breadth of watershed and importance of the project and the available time to analyze the data. Usually watershed area is a very important parameter to select the appropriate method for calculating the water flow of run off.

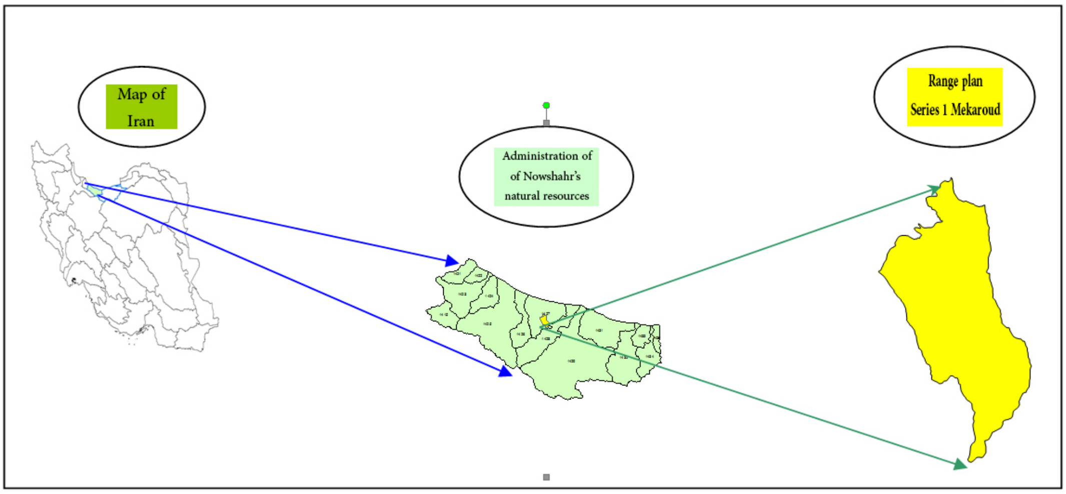

Figure 1: Area of study.

So the reasoning method, which is one of the simplest ways to estimate surface runoff in small areas (up to 1000 hectares and without hydrometric data, is used in this research, which it is widely used in the world today. The method relies on the principle that in rainfalls with the same return period of increases is raining, average rainfall intensity decreases, average intensity of rainfall will decrease. When the time raining become more than the duration of area of focus, the average of rainfall intensity will be lower than the average rainfall intensity period that their during is equal to duration of area of focus. In this case, despite the fact that all the fields are participating in surface flow, maximum surface current will go lower. On the other hand, if the duration of rainfall is less than duration of focus, although the rainfall intensity will increase, but only parts of the land will be involved in surface flow. And so we get to the reasoning method:

The maximum surface flow rate can be expected only when the duration of rainfall is equal to the duration of focus.

Mathematical reasoning method in accordance with equation (1) is:

$$Q = \frac{1}{360}\ C.I.A \quad (1)$$

Which in that:
A: Is the extent of area in hectare.
Q:Is the maximum surface runoff (flood peak) in terms of cubic meters per second with the same return period as back downpour.
C: Surface runoff coefficient that the values of this coefficient, depend on various factors like slope, underground drainage system , cover of vegetation, the amount of dead leaves , organic matter content ,soil moisture and also depends on rainfall intensity. Multiple table is provided for estimating surface runoff that The most complete one of them is the table that Chow presented, which in that depending on the level of study, including urban areas, agricultural land, grassland, and jungle and the slope of three classes area (0 to 2 percent, 2 to 7 percent and more than 7 percent) is considered. At this table intensity of rainfall is considered as variable return period (100, 50, 25, 10, 5, 2 and 500 Years) .However, due to survey in the woods, followed Parcel area and mapping slope Classifieds, Classifieds slope in the study area were more than 7 percent.
I: The average intensity of rainfall is equal to the duration of the concentration of the area is expressed in millimeters per hour that is obtained from various methods such as curve intensity, duration, frequency and empirical formulas. In this study, to obtain the severity-duration of rain (I) Instead of curve severity, duration - frequency of rainfall, a formula known as the second empirical method of Dr. Ghahramanhas been used. Because firstly obtain intensity and time – frequency curves is subject to have graphs of rain gauge stations which majority of these stations are located in Caspian plain areas and their application are not suitable for the study area. Secondly, in this way, short-term rainfall from 15 minutes to 2 hours with different return periods is estimated. Thirdly, according to surveys conducted of all proposed equations such as the method of Vaziri, Qanbarpour, Sobhani, etc., and expert comparing, consistent of the second method of Dr. Ghahraman with is more suitable for the region. It has the following mathematical equation.

$$P_T^t = (0.4055 + 0.2636Ln(T - 0.44) \cdot \cdot (-0.242 + 1.2452 \cdot t^{0.2674})) \cdot \rho_{10}^{60} \quad (2)$$

Which in that:
T: Return period in year
t: Duration of short time rainfall in hour
P_T^t : Rainfall intensity at a given concentration
ρ_{10}^{60} : A one-hour rainfall with a return period of 10 years that is obtained from equation (3).

$$P10^{60} = e^{0.9153} \cdot x_1^{1.1314} \cdot x_2^{-0.3072} \quad (3)$$

Which in that:
x_1: The average 24-hour maximum precipitation in millimeters and
x_2: The average annual rainfall in millimeters.

Now, to estimate the maximum runoff in the area mentioned by the reasoning method is used equation (1) which in that according to the calculations if for example the extent of area is (A=5.6) hectare and runoff coefficient in accordance to the Chow table is (C=0.35) and the amount of intensity - duration of rainfall as calculated by the second method of Dr. Ghahraman is equal to (I=64.1) Millimeters per hour for the return period of 2 years. If we the obtained the maximum amount of runoff (peak flood) happened in the area A1-1 values will be as follow in equation:

$$Q = \frac{1}{360} \cdot 0.35 \cdot 64.1 \cdot 5.55 = 0.34\ {m^3}/{s} \quad (4)$$

Also the flood peak discharge for return periods of 5, 10, 25, 50, and 100, respectively will be 0.3, 0.6, 0.8, 0.1, 1.1, and 1.4. Now, by comparing the obtained flow rate and by maximum flow rate capacity in water path (pipe), It can be concluded that the built water path by diameter 0.8 centimeter can pass the maximum flood with all the mentioned return periods (according to figure 2).

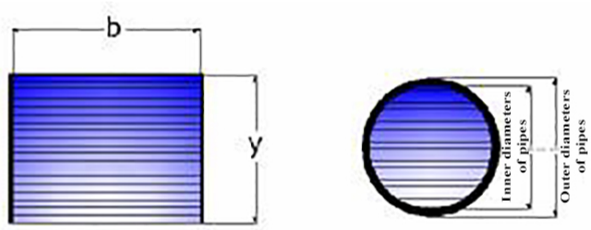

Figure 2: The cross sectional area of the flow in the pipe (waterway) and bridge (culvert)

2.2.2. Calculating the time of concentration

Concentration time is the time that water takes to reach from the farthest areas to the exit point. This time is calculated from several ways and usually the amount of concentrating time is depend on the main channel length, the slope of the flow of hydraulic conditions, such as roughness coefficient, hydraulic radius that In this study Kirpich method has been used and its mathematical equation is like this (5):

$$T_c = 0.0195 \cdot L0.77 \cdot S^{-0.395} \quad (5)$$

which in this:
T_c: Time of concentration in minutes, L: Channel length in meter, and S: Is the slope of the water in meter on meter

To get the slope of the equation (Equation 6) is used:

$$S = \frac{\Delta h}{L} \tag{6}$$

Which in this Δh : height difference and L: Horizontal distance.

2.2.3. Calculating the mean flow velocity in the water path (pipes) and culverts (bridges)

For calculating the mean flow velocity in water path, Manning formula can be used that its mathematical equation is the following (equation 7):

$$V = \frac{R^{\frac{2}{3}} \cdot S^{\frac{1}{2}}}{n} \tag{7}$$

Which in that:
V: Water velocity in the pipe or culvert (meters per second)
S: Water path and culverts are in meters per meter
n: Roughness coefficient of the pipe wall and bridge and etc. (Manning roughness coefficient)
R: Hydraulic flow radius in meter that is calculated in culverts by equation (8)

$$R = \frac{b \cdot y}{B + 2y} \tag{8}$$

which in this b: Length in meters and y: Width or height in meters and in pipes by equation (9)

$$R = \frac{A}{p} \tag{9}$$

which in this:
A: The flow cross section in terms of square meters that is calculated by equation (10)

$$A = \pi R^2 \tag{10}$$

P: The drenched surrounding by water flow in meters (see Figure 1) that the is calculated with equation

$$P = 2\pi r \tag{11}$$

witch in that π =3.14157 and R is pipe diameter in meters and in culverts (Figure 1) is calculated from equation

$$C = b + 2y \tag{12}$$

Finally, by having the cross section and the flow rate using the equation (13) Flow rate (Cubic meters per second) can be obtained in a certain diameter pipe (Figure 1).

$$Q = A \cdot V \tag{13}$$

For example,for calculations in the watershed A1-1 from forest road number A1 (Figure 5) where the existing pipe diameter is 0.80 meters, slope of pipe S=0.03 and pipe roughness coefficient n=0.02, the water velocity in the pipe and the maximum flood discharge with different return periods is as follows:

Pipe diameter in meters $D = 0.8$

Pipe radius in meters $R = \frac{D}{2} = \frac{0.8}{2} = 0.4$

The cross section of the pipe in square meters
$A = \pi R^2 = 3.14 \cdot 0.4^2 = 0.5$

$P = 2\pi R^2 = 2 \cdot 3.14 \cdot 0.4 = 0.5$

$R = \frac{A}{P} = 0.2\ m$

Water velocity in the pipe in meters per second

$V = \frac{R^{\frac{2}{3}} \cdot S^{\frac{1}{2}}}{n}$=2.96

Finally, by having the cross section and the flow rate using equation (13) flow rate in a pipe with a diameter of 80 cm will be equal to:
Flow rate in the pipe in cubic meters per second
$Q = A \cdot V = 0.5 \cdot 2.96 = 1.48$

3. Results

The results of the study on the status of and discharge capability of surface runoff with different return periods in waterways, culverts and constructed side channels in the project area showed that:

3.1. Route A

This way, a length of about 11 km as the asphalt main direction (public road) is name with the code name A and relative slope is3 to 7% with a width of 10 to 12 meters, including dirt shoulder and has a history of more than 50 years, which has been used as a public utility road.

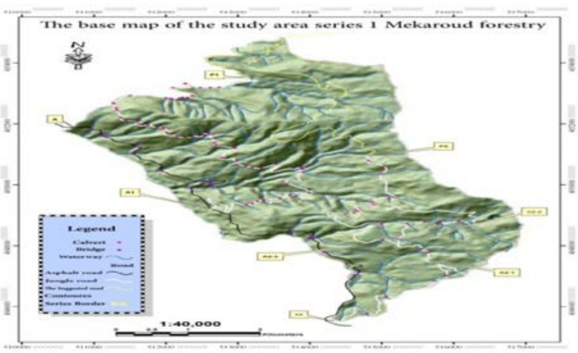

Figure 3: The base map of the study area series 1 Mekaroud forestry.

Along this pathway trapezoidal channels with different substrate feeder stone, clay and sandy clay has been established in some areas that because of the importance of keeping the channel is empty and runoff flows there easily.

Figure 4: Map of sub watershed of route A series Mekaroud forestry plan.

In this road, 18 bridges are constructed with an average distance of about 650 meters and is divided each of these buildings as a sub-watershed that covers a total area of over 1920 hectares of slopes upstream which contains routes of A1, A2, A2-2, A2-3, and a part P2 route. R. Calculations of this road about the maximum discharge of flood (peak) occurred with different return periods 2, 5, 25, 50, and 100 years. In the other hand calculations of cross sections of drainage for each sub watershed reveals that in 100% of built bridges, it will be able to discharge maximum runoff occurred with the return period 2, 5, 10 years and 95% of them will be able to pass the peak flow with return periods 100 years and more (figure 4 and table 1)

3.2. Route A1

The route that in (Figure 5) is shown by code name A1, from with length of 13.3 kilometer road which has been split from the man route with the code name of (A), is being consider as a grade 2 forest road to andl its construction has been started in 1987. The average relative slope of the roads is 5% and its width is 6 to 8 meters, including road shoulder and its covers the upper slopes area of over 962 hectares, which includes route A2-3 and has been divided to 39 sub-basins. Each of these sub-basins runoff is discharged by a water path. Along the way, only 28water path with an average distance of 48 meter has been built and still in 11sub areas, including (A1-5, A1-7, A1-8, A1-9, A1-10, A1-13, A1-14, A1-37, A1-38, and A1-39) no structure has been built. Calculations show that maximum runoff discharges (peak) occurred at different return periods of 50, 25, 10, 5, 2 and 100years also calculation of the cross-sectional area of drainage for each sub area shows that only 75% of the built water paths can discharge the runoff with a return period of 2 years, 68% of water paths with return period of 5 years, 61% of water paths with return period of 0 years, 39% of water paths with the return period of 25 and 50 and only 28% of built water paths will be able to pass through the maximum return period of 100 years. (Figure 5 table 1)

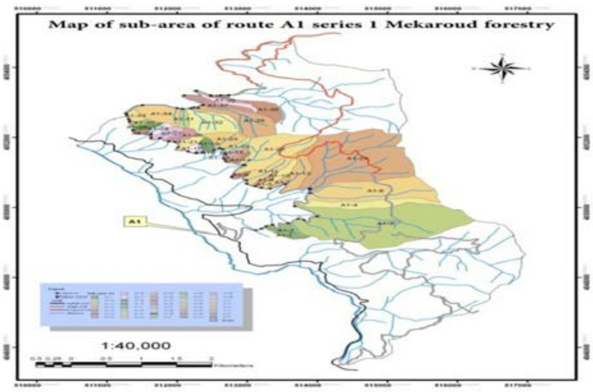

Figure 5: Map of sub watershed of route A1 series Mekaroud forestry.

3.3. Route A2

This path is 3.6 kilometers divided from path A and is shown with the code name of A2 and is continued until the confluence of paths A2-2 and A2-3 (Landfill site). The road was built by width of 6 to 8 meter and the relative slope of 5 to 10 percent. The constructed channel in the roadside is in the form of U and V and because of the slope of the route and proper maintenance, it is completely empty of sediments and runoff flows through it easily. In this route, in order to drain runoff from upstream of the road to lower parts the road, 6 cement pipes water path with a diameter of 80 cm with an average distance of 600 meters have been placed. Because of proper pipe diameter, the relative slop and proper maintenance of channels, the pipes are not filled with sediment and are completely empty. It should be noted that most of the runoff, due to relatively high Slope of roads and canals (especially in the first kilometers) through a side channel flows to the asphalt route A. This route covers an area of over 106 hectare of the upper range and is divided to 8 sub areas. Each of these sub areas is discharged by a water path. Calculations reveal that maximum runoff discharges (peak) that occurred at different return periods of 2, 5, 10, 25, 50, and 100 years and also calculation of the built cross sections for drainage for each sub areas shows that around 100 percent water paths can discharge the maximum run off with return period of 2 years, 71 percent of water paths with return period of 5 years, 57 percent of water path with the return path of 10, 25, and 50 years and only 71 percent of built water paths can pass through the maximum flow with the return period the of 100 years. (Figure 6, table 1)

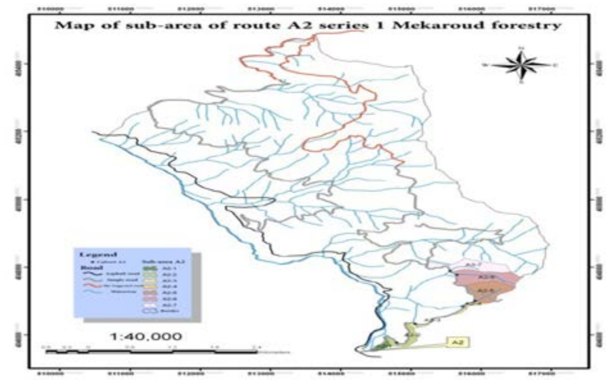

Figure 6: Map of sub watershed of route A2 series Mekaroud forestry.

3.4. Route A2-2

This route is 3.8 kilometer long, and is located on the highest point of the area, In other words ridge area and is named A2-2. It includes an area of over 183 hectares which is divided to 9 sub watershed and each of their runoffs are discharged by a water path.

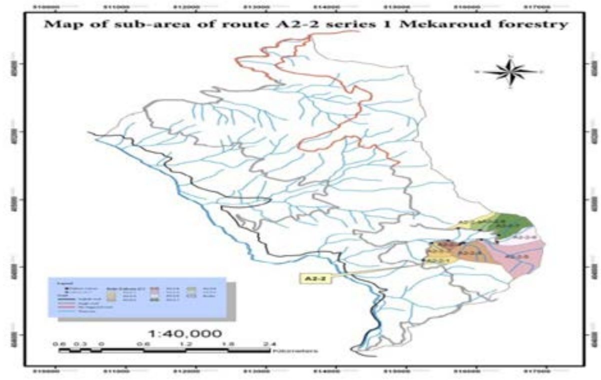

Figure 7: Map of sub watershed of route A2-2 series Mekaroud forestry.

It should be noted that currently only 6water path has been constructed along the way and still in three sub watershed (A2-2-7, A2-2-8, and A2-2-9) no instruction has been built. Calculations revealed maximum flood (peak) occurred at different return periods of 2,5, 10, 25, 50, and 100 years. Also calculations of the cross-sectional area of drainage for each sub watershed revealed that around 100 percent of built water paths can discharge the maximum Runoff with return period of 2 years, 66 percent of water paths with return period of 5 years, 50 percent of water paths with the return period of 10 years and only 16 percent of water paths can pass through the maximum flow that occurred with the return periods of 5, 25 and 100 years. (figure 7, table 1)

3.5. Rout A2-3

This route is 7.1 kilometer long and is located after branching out from A2 between A2-2 and A1. It has the code name of A2-3 and has a relative slope of 5 to 15 percent and relative width of the route including dirt shoulder is about 6 meters. Construction of the road began in 1372 in the form of manual layout and continues to present. Channel side of the road, in some areas, because of proper slope and channel steel, are free of sediment and runoff is flowing smoothly through it but in most places because of low slope and type of channel and also lack of adequate dredging, runoff isn't flowing smoothly through it and it's flowing on surface of the route which is causing damage. This road is divided into 17 sub watershed which also is include the sub watershed of rode A2-2. that covers over 436 hectares of upper slopes and runoffs of each of these sub areas is discharging by a water path.

Currently only 14 water paths with an average distance of 540 meters has been constructed. In three sub areas (A2-3-12, A2-3-14 and A2-3-15) no structure has been built. Calculations revealed that the maximum of runoff discharges (peak) occurred at different return periods of 2, 5, 10, 25, 50, and 100 years and also calculation of the cross-sectional area of drainage for each sub watershed revealed that about 93 percent of culvert are able to discharge maximum runoff with return period of 2 years, 71 percent of water paths with return period of 5 years, 41 percent of water path with the return period of 10 years and 20 percent of water paths with return period of 25 and 50 years and only 21 percent of built water paths can pass through maximum flow that occurred with the return period of 100 years. (Figure 8, table 1)

Overall calculation for the maximum run off at different return periods and calculation of the cross-sectional area for the flow, and comparing them with existing waterways and culvert in each of the sub areas reveal that some existing waterways(pipe) and culvert are small and will not be able to pass through the maximum runoff occurred with the return period of 10, 25, 50, and 100 years. In Table 1, results of each calculation water paths and culverts has been estimated with weighted average method.

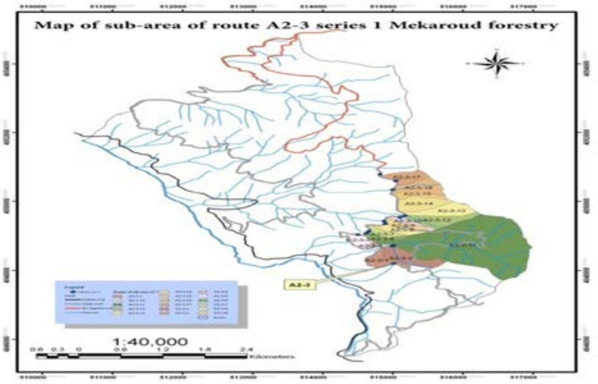

Figure 8: Map of sub watershed of route A2-3 series Mekaroud forestry.

4. Discussion

The results of the waterways, culverts and side channels built on various routes with a total length of about 50 km is forest road, stating that:

A. Runoff from the slopes above the road into two areas in each case, (ducts and waterways side ,pipe, culvert, ,…) shall cross the road.
B. More than 80 percent of the roads are built or without side channel or channels are filled with fine sediments or leaves.
C. Road maintenance, especially channels and waterways monitoring in this case is very poor.
D. the fracture spot roads (valley) due to a change of slope, most of the road are locking of any technical building-to conduct runoff from from the slopes above the road to the slopes down.
E. Construction of the road waterway is not appropriate for flood peak and run more than one project type.
F. Insertion tube (waterways) with a suitable gradient isn,t according to the instructions of the Executive Office of Forest and Rangeland and Watershed Management Technical Council in 1382 and it has caused discharge drain pipe is very low. (mount of drain pipes with a diameter of 80 cm was approximately 0.43 cubic meters per second, while if the dip tube come up only 5% to 6 mount of drain pipes increases 6 cubic meters per second feed rate).
G. At more than 90% of the exit of the waterways or culvert over the past few years has established., due to the lack of riprap (Picking a stepping stone) would occur scour of down road that was result in severe erosion road.

This finding is in line with the findings of Nikouei (2000), Nazari (2000), and Campbell and Sidle (1984) respectively, with return periods of 20, 50 and 25-year return period.

Table 1: Results of the ability to pass the maximum flood drain in water paths and drains constructed to separate each route in the research area.

The route	Number of constructed water path or culvert	Percentage drain ability of the maximum flood pipe and culvert by year return period…					
		2	5	10	25	50	100
A2-2	6	100%	66%	50%	16%	16%	16%
A2-3	14	93%	71%	41%	23%	23%	21%
A2	6	100%	71%	57%	57%	57%	71%
A1	27	75%	68%	61%	39%	39%	28%
A	17	100%	100%	100%	100%	100%	95%

5. Suggestions and Implications

Time concentration of the watershed is very effective role on runoff and flood discharge in other words, whatever time concentration of watershed is water velocity slower and destructive power is less, and also at the time of the flood, in addition in many cases is important factor in clogging waterways or canals opening is along the road, In order to breaking of slop, control of sediment and thus enhancing time concentration it is suggested that the on upstream waterways roads do watershed management practices (type of Gabion stone and mortar)

According to research conducted in fractures road (valley) and flood runoff road is an important factor in the destruction, It is proposed to correct the longitudinal profile of the road, or the waterway of the appropriate diameter.

Table 2: Features of sub-domains and results of determining the dimensions of the structures in the thalweg in each forest roads forest road series 1 Mekaroud.

Type of existing structure		**Discharge maximum flood with a return period of the year....**						**Rainfall intensity return period of the year....**						**Time of concentration**	**Length of the slopes**	**Area**	**Number of sub-domain**	**Name of the road**
Diameter in cm	**pipe**	**(Cubic meters per second)**						**(Mm per hour)**										
		100	**50**	**25**	**10**	**5**	**2**	**100**	**50**	**25**	**10**	**5**	**2**	**minute**	**meter**	**hectare**		
80	*	1.41	1.1	1	0.8	0.6	0.3	199	176	153	123	99	64	4.07	650	5.6	A1-1	
80	*	2.2	1.8	1.6	1.2	0.9	0.5	213	189	164	132	106	69	3.58	550	8.2	A1-2	
80	*	65.9	53	47.3	36.3	27.8	16.2	238	211	183	147	118	77	1.96	485	216.9	A1-3	
80	*	7.2	5.8	5.2	4	3	1.8	156	138	120	96	77	50	4.47	980	36.2	A1-4	
80	*	0.5	0.4	0.4	0.3	0.2	0.1	287	254	221	177	143	93	2.16	320	1.4	A1-5	
80	*	19.8	15.9	14.2	10.9	8.3	4.9	160	142	124	99	80	52	4.37	860	96.4	A1-6	
80	*	1.2	1	0.9	0.7	0.5	0.3	211	187	163	130	105	68	3.79	520	4.5	A1-7	
80	*	1.3	1	0.9	0.7	0.5	0.3	219	194	169	135	109	71	3.46	550	4.7	A1-8	
80	*	1	0.8	0.7	0.6	0.4	0.2	239	212	184	148	119	77	2.93	330	3.3	A1-9	
80	*	2	1.6	1.5	1.1	0.9	0.5	156	138	120	96	78	50	5.84	952	10.1	A1-10	
80	*	3.3	2.7	2.4	1.8	1.4	0.8	135	120	104	83	67	44	6.71	1074	19.3	A1-11	
80	*	4	3.1	2.8	2.1	1.6	1	129	115	100	80	64	42	7.4	1000	23.5	A1-12	
80	*	1	0.8	0.7	0.5	0.4	0.2	247	219	191	153	123	80	2.56	412	3.1	A1-13	
80	*	1.2	0.9	0.8	0.6	0.5	0.3	226	200	175	140	113	73	2.95	400	4	A1-14	
80	*	1.6	1.3	1.2	0.9	0.7	0.4	241	214	186	149	120	78	2.53	430	5.2	A1-15	
80	*	0.6	0.5	0.5	0.4	0.3	0.2	322	286	249	199	160	104	1.54	257	1.6	A1-16	
80	*	1.3	1.1	1	0.7	0.6	0.3	325	288	251	201	162	105	1.56	260	3.3	A1-17	
80	*	0.6	0.5	0.4	0.3	0.3	0.1	165	146	127	102	82	53	4.82	320	2.8	A1-18	
80	*	1.4	1.1	1	0.8	0.6	0.3	270	240	209	167	135	87	2.17	387	4.1	A1-19	
80	*	1.9	1.6	1.4	1.1	0.8	0.5	199	176	153	123	99	64	3.54	576	7.7	A1-20	A1
80	*	2.6	2.1	1.9	1.4	1.1	0.6	232	206	179	144	116	75	2.84	464	8.8	A1-21	
80	*	9	7.3	6.5	5	3.8	2.2	103	92	80	64	51	33	9.93	1442	68.5	A1-22	
80	*	4.8	3.9	3.5	2.7	2	1.2	203	180	156	125	101	65	3.47	580	18.7	A1-23	
80	*	24.5	19.7	17.6	13.5	10.3	6	97	86	75	60	48	31	11.52	1990	198.2	A1-24	
80	*	0.7	0.6	0.5	0.4	0.3	0.2	273	242	211	169	136	88	2.48	260	2	A1-25	
80	*	2.6	2.1	1.8	1.4	1.1	0.6	220	195	170	136	109	71	3.2	528	9.1	A1-26	
80	*	2.9	2.3	2.1	1.6	1.2	0.7	244	216	188	151	121	79	2.82	460	9.2	A1-27	
80	*	2.4	1.9	1.7	1.3	1	0.6	264	234	204	163	131	85	2.08	420	7	A1-28	
80	*	1.4	1.1	1	0.8	0.6	0.3	227	201	175	140	113	73	3.27	438	4.7	A1-29	
80	*	1.9	1.5	1.3	1	0.8	0.5	272	241	210	168	135	88	2.35	370	5.4	A1-30	
80	*	1.9	1.6	1.4	1.1	0.8	0.5	231	204	178	143	115	74	3.18	550	6.7	A1-31	
80	*	5.7	4.6	4.1	3.1	2.4	1.4	113	100	87	70	56	36	10.69	1640	39.7	A1-32	
80	*	2.6	2.1	1.9	1.4	1.1	0.6	330	292	254	204	164	106	1.47	320	6.2	A1-33	
80	*	10.9	8.8	7.9	6	4.6	2.7	317	281	245	196	158	102	1.76	350	27	A1-34	
80	*	7.4	6	5.3	4.1	3.1	1.8	125	111	96	77	62	40	8.09	1360	46.6	A1-35	
80	*	3.2	2.6	2.3	1.8	1.3	0.8	140	124	108	86	69	45	6.78	1258	17.9	A1-36	
80	*	3.1	2.5	2.2	1.7	1.3	0.8	213	188	164	131	106	69	3.78	640	11.4	A1-37	
80	*	0.7	0.6	0.5	0.4	0.3	0.2	192	170	148	119	96	62	4.89	620	2.9	A1-38	
80	*	1.8	1.5	1.3	1	0.8	0.5	147	130	114	91	73	48	7.21	1118	9.8	A1-39	

Table 3: The results of determining the dimensions of the structures in the thalweg in each forest roads forest road series 1 Mekaroud (A).

Type of existing structure			Discharge maximum flood with a return period of the year.... (Cubic meters per second)						Rainfall intensity return period of the year.... (Mm per hour)						Time of concentration	Length of the slopes	Area	Number of sub-domain	Name of the road
Diameter in cm	Cross section in square meter	bridge	100	50	25	10	5	2	100	50	25	10	5	2	minute	meter	hectare		
80	2	*	12.8	10.3	9.2	7	5.4	3.1	144	127	111	89	72	46	5.53	750	69.4	A-1	
80	15	*	17.8	14.3	12.7	9.8	7.5	4.4	70	62	54	43	35	22	14.45	2320	199.5	A-2	
80	6	*	9.3	7.5	6.7	5.1	3.9	2.3	133	118	103	82	66	43	6.89	1183	54.8	A-3	
80	20	*	28.8	23.2	20.7	15.8	12.1	7.1	74	66	57	46	37	24	19.86	3634	302	A-4	
80	2	*	2	1.6	1.5	1.1	0.9	0.5	232	206	179	144	116	75	2.62	465	6.8	A-5	
80	2	*	7.7	6.2	5.5	4.2	3.2	1.9	119	105	92	74	59	38	6.93	1170	50.3	A-6	
80	4	*	29.3	23.5	21	16.1	12.3	7.2	72	64	55	44	36	23	19.19	3900	317.7	A-7	
80	3	*	20.8	16.8	15	11.5	8.8	5.1	151	133	116	93	75	49	8.36	1400	108.1	A-8	
80	20	*	38.1	30.6	27.3	21	16.1	9.3	83	73	64	51	41	27	15.9	3200	358.7	A-9	
80	3	*	4.6	3.7	3.3	2.5	1.9	1.1	190	168	147	118	95	61	4.57	950	18.9	A-10	A
80	80	*	6.2	5	4.5	3.4	2.6	1.5	125	111	97	77	62	40	9.22	1800	38.9	A-11	
80	8	*	2.3	1.9	1.7	1.3	1	0.6	277	246	214	171	138	90	2.95	400	6.6	A-12	
80	12	*	15.5	12.5	11.1	8.5	6.5	3.8	247	219	191	153	123	80	3.37	695	48.9	A-13	
80	20	*	15.5	20.3	18.1	13.9	10.6	6.2	102	90	78	63	51	33	14.13	2800	186.9	A-14	
80	12	*	15.5	5.7	5.1	3.9	3	1.7	277	245	214	171	138	89	2.65	550	20	A-15	
80	8	*	15.5	9.4	8.4	6.5	4.9	2.9	170	151	131	105	85	55	6.37	1320	51.9	A-16	
80	6	*	15.5	3.4	3.1	2.3	1.8	1	189	168	146	117	94	61	5.49	1100	17.7	A-17	
80	8	*	15.5	9.8	8.7	6.7	5.1	3	223	198	172	138	111	72	4.2	830	45.9	A-18	

Table 4: The results of determining the dimensions of the structures in the thalweg in each forest roads forest road series 1 Mekaroud (A2).

Type of existing structure		Discharge maximum flood with a return period of the year.... (Cubic meters per second)						Rainfall intensity return period of the year.... (Mm per hour)						Time of concentration	Length of the slopes	Area	Number of sub-domain	Name of the road
Diameter in cm	pipe	100	50	25	10	5	2	100	50	25	10	5	2	minute	meter	hectare		
80	*	1.8	1.4	1.3	1	0.7	0.4	351	311	271	217	175	113	113	130	3.9	A2-1	
80	*	3.6	2.9	2.6	2	1.5	0.9	281	249	217	174	140	91	91	244	10.1	A2-2	
80	*	1.9	1.5	1.4	1	0.8	0.5	329	292	254	204	164	106	106	105	4.5	A2-3	
80	*	1.1	0.9	0.8	0.6	0.5	0.3	343	304	265	212	171	111	111	60	2.5	A2-4	A2
80	*	4.4	3.5	3.1	2.4	1.8	1.1	123	109	95	76	61	40	40	683	27.8	A2-5	
80	*	4.3	3.4	3.1	2.3	1.8	1	103	92	80	64	51	33	33	970	32.2	A2-6	
80	*	3.4	2.7	2.4	1.9	1.4	0.8	104	92	80	64	52	34	34	920	25.4	A2-7	

Table 5: The results of determining the dimensions of the structures in the thalweg in each forest roads forest road series 1 Mekaroud (A2-2).

Type of existing structure		Discharge maximum flood with a return period of the year.... (Cubic meters per second)						Rainfall intensity return period of the year.... (Mm per hour)						Time of concentration	Length of the slopes	Area	Number of sub-domain	Name of the road
Diameter in cm	pipe	100	50	25	10	5	2	100	50	25	10	5	2	minute	meter	hectare		
80	*	2.5	2	1.8	1.4	1	0.6	184	163	142	113	91	59	2.42	352	10.5	A2-2-1	
80	*	3	2.4	2.2	1.7	1.3	0.7	223	197	172	138	111	72	1.73	252	10.6	A2-2-2	
80	*	4.5	3.6	3.3	2.5	1.9	1.1	130	115	100	80	65	42	4.42	640	27.2	A2-2-3	
80	*	1.7	1.3	1.2	0.9	0.7	0.4	223	197	172	138	111	72	1.77	244	5.8	A2-2-4	
80	*	6.4	5.2	4.6	3.5	2.7	1.6	82	73	63	51	41	27	9.35	1300	61.1	A2-2-5	A2-2
80	*	3.2	2.6	2.3	1.8	1.3	0.8	122	108	94	76	61	39	4.66	731	20.4	A2-2-6	
80	*	5.1	4.1	3.6	2.8	2.1	1.2	135	120	104	84	67	44	3.73	570	29.2	A2-2-7	
80	*	1.6	1.3	1.1	0.9	0.7	0.4	136	121	105	84	68	44	3.61	570	9.1	A2-2-8	
80	*	1.3	1.1	0.9	0.7	0.6	0.3	110	97	85	68	55	36	5.07	720	9.3	A2-2-9	

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The study of Damages on Soil and Seedlings in Traditional an Mechanical Methods Transportation (Case Study: Series 7 Neyrang Forest, Watershed No 45 Golband, Nowshahr)

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Abstract: Transportation in any form of mechanized or traditional imposes damage on soil and regeneration in the nature. But it is reasonable effort to maintain the forest sustainability by minimizing the damage. In this study, a research was carried on soil in order to examine the effects of moisture, relative density, compactness, porosity, compaction distribution and pressure on the surface based on random samples of two skid trails and control with 60 soil samples. Also, in order to assess the damages to regeneration, the one hundred percent inventory, before and after skidding processes was used. The results showed that the damages to regeneration in mechanized trail (99.91%) are more than that in traditional trail (44. 4%). This study on damage to the soil shows that when soil moisture is increased, the amount of compaction in both trails consequently increases. It also shows that moisture content more than 50% in the mechanized trail and 35% in the traditional trail reduces the soil compaction. The amount of soil relative density in mechanized and traditional trails compared to control ones has increased. The amount of compactness and porosity of the soil in mechanized trails compared to traditional ones has increased. Percent of compaction distribution in mechanized trail was observed to be 2.3 times higher than that in traditional trail, but the pressure on the surface under the hooves of mules (1.98 kilograms per square centimeters) is more than that under the chain wheels of skidder (0.18 kilograms per square centimeters).

Keywords: soil porosity, traditional, soil damages, mechanized

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1. Introduction

Since the exploitation of the forest as a biological necessity for forest is useful and essential, thus the achievement to quantitative and qualitative improvement of forest stands and providing favorable conditions for seedling establishment and revitalization depends on proper and practical implementation of exploitation operation. One of the most important one of these damages is compactness and soil compaction and the other is regeneration destruction that this compactness in the forest leads to a delay in regeneration, reduced growth of trees or saplings and soil erosion. Extraction of timber using animal power are part of small-scale transportation systems which has long been used in countries like the United States of America, Brazil, India, Chile, Canada, Italy and other European countries.

Usually after forest harvesting operations, destructive effects are observed on the soil which among them, skidders traces are more remarkable and include compaction, and wheels and logs traces. Compaction will reduce the soil infiltration and increase runoff; on the other hand, it inhibits root growth and weakens the vegetation cover. Also, wheels and logs traces in a long path with a high slope result in rainwater running off on them and soil erosion (Jamshidi, 2008).

Soil compaction reduces the growth of existing trees or saplings which will be deployed later in this arena. Regeneration is a process by which forest trees can reproduce and maintain its dynamics and reliability and thus the forest can continue its sustainability by which. This process has a fundamental role in the evolution of forest; if it undergoes changes and shortcomings, the future of forests is certainly endangered. Several factors can be effective in this field, and be associated with some limitations. The limitations may be biological, natural and human related which in any forest, depending on its situation and conditions, the amount of impact on each of them is different. In the studied forests which have been thinned and diminished due to the multiple and continuous destructions caused by natural and unnatural factors, regeneration problems is more serious and obvious. Disorders which occur following winching operations, construction of trails and skidding on them on the soil and hydrological processes, impose large damages to the surface roots of trees and field regeneration (Meek & Plamondon, 1996).

In forest harvesting operations and after using skidding machines, usually destructive effects on the soil (compaction, wheels trace and logs trace), regeneration (eradication, bending, buring, fractures and wounds) and the remaining stands (wounded trunk, broken branches or crown) are observed (jamshidi, 2008; Demir et al., 2007; Molong, 1995).

An study entitled as the effect of two ground-based skidding system in negative slopes and different slope condition was conducted in the northern forests and bulk density changes took place in 10 cm layer of soil as a result of skidding with skidder and log transportation by mules which the average bulk density in skid trails is significantly higher than the bulk density in undisturbed nearby areas, but bulk density increment is not significant for the mule trails (Jamshidi, 2008).

Another study entitled as evaluating the effects of operation on regeneration and forest soil compaction was performed in ground-based skidding system in the Guilan province Asalem forest which showed that after operation in the area, there was 14.11 percent of healthy regeneration, 5.03 percent of wounded regeneration and 9.08 percent of destroyed ones, and the results show that the most damages were related to the destroyed regeneration ,Also in the soil compaction, the lowest and highest bulk density of soil were obtained as 1.271 grams per cubic centimeter in control area and most 1.723 grams per cubic centimeters in skid trails, respectively (Tavankar, 2008). Another research that was done in the Amazon forests obtained the amount of soil compaction increment in clear-cutting and whole tree operation in Amazon forests to be 5 to 15 percent in the first 20 cm of the soil surface (Magnusson et al., 1999).

A study entitled as damage caused by exploition on the remaining stands in Bolivia forest indicated that due to the exploitation operations, severe damages are imposed to vegetation, and soil texture which reduce the potential for regeneration in the area. In this study, most of the damages are related to eradication, root damage, trunk damage, and wounded bark and cambium layer (Scott et al., 2002). A study entitled as impact of mechanized transport on density status of forest sandy soils in the Netherlands forests was performed differently at three different depths and the results of soil compaction caused by skidder in traffic trails at the depths of 10-0, 20-10 and 30-20 cm showed that soil compaction on skid trails the three paths has been greater than that in control trails (Ampoorter et al., 2007). A study entitled as impact of forest environment on the amount and intensity of soil compaction and disturbance of soil profile in skid trails during ground transportation in Canada's forests was conducted and the results showed that in exploitation with skidders, in general 0.17 grams per cubic centimeters of forest soil bulk density has increased and, on average, 62% of compaction occurs in the first 10 cm of soil in skidders first pass (Williamson et al., 2000).

The aim of this study is to estimate the amount of transportation damages in ground-based skidding methods on regeneration and forest soil.

2. Materials and methods

2.1. The characteristics of the study area

The research was done in 729 and 731 parcels of Noshahr Neyrang series with the altitudinal range of 150 to 350 meters above sea level. The forests of this series are located between latitudes of 36° 33' 40" to 36° 37' 30" and longitudes of 51° 28' 25" to 51° 26' 30". Parcels area are 60.6 (Parcel 729) and 64.9 (Parcel 731) hectares respectively, the forest form is irregular uneven-aged seed origin, soil structure is granular at surface and multi-faceted in depth, and forest type is hornbeam-alder hornbeam along with other species.

2.2. Procedure

In order to identify the area of operation, first forest survey was done and then two skid trails in each of the forest areas were selected with the length of 200 meters that in one of them, timber extraction operation is conducted by traditional method (using mules) and the other timber extraction operation are done using mechanized methods (using Skidder). The selection of each trail must be in such a way that has similar conditions in terms of output load volume, domain slope, cross slope, stands type, climatic conditions and soil texture. Alongside these trails, the untouched trails (control) are separately determined which a total of four trails (skidder trail, control skidder trail, unpaved trail, and control unpaved trail) has been chosen. The width of skid trails vary according to the size cars and animals which this value has designed to be 5 and 3 meters in skidder trail and unpaved trail, respectively. In order to compare the regeneration on trails with forest regeneration some plots named as control plots are needed. These plots were harvested around the skid trails. To check the damage on regeneration, before doing operations along the skid trails, counting the existing seedlings in a range of trails was done. Then, with the completion of log transportation on desired trails, their regeneration was evaluated and quantifying the damages on regeneration was conducted. In addition, considered regeneration was divided into two groups of healthy and damaged and damaged group was evaluated in terms of damage and type of injury to the injured groups (all leaves or a part of the leaves shedding on the ground), semi-injured (bending of seedlings), broken top, mashed (lying on the ground), eradicated in mechanized trails and … in traditional trails that for comparison, one hundred percent inventory was used.

In order to perform soil physical examinations (to determine soil bulk density, soil relative density, percent of soil compaction, etc) in each of the timber extraction mechanized and traditional trials, 20 sample plots were determined by randomly selecting the first points for sample. Then at intervals of 20 meters from each depth of 10-0 and 20-10 cm in both trails (mechanized and traditional) and also in each of the traditional control and mechanized trails with 10 sample plots at intervals of 20 meters and the depth of 10-0 and 20-10 cm, sampling was performed. Thus, the total samples examined to determine the bulk density of soil were 60 which these samples were harvested using two-inch standard cylinder with a diameter of 5 cm and a height of 10 cm by clearing the harvest site from vegetation and humus. Then, these samples were transferred to laboratory and dried at 105°C for … hours inside the oven and then were weighed again to obtain the bulk density and moisture content and some other soil physical characteristics (Aflaki, 2008). Percent of compaction distribution is calculated according to the area of traffic location compared to the area of which these two methods are covered for the same output volume of 100 cubic meters. Pressure per unit area (P_{kg/cm^2}) was calculated with respect to the weight of livestock (W_m), Skidder (W_z) and transported logs (W_w). Also for comparison of treatment means (relative density, compactness and soil porosity) in skid trails with control trails which are more than three groups, one-way analysis of variance (Duncan) is used (Barzegar, 2004).

For data analysis, first the normality of the data was evaluated using Kolmogorov-Smirnoff test. To evaluate the effect mules and cars traffic on soil bulk density from one-way and two-way analysis of variance, if the effect of each factor in one-way and two-way analysis of variance is significant, Duncan multiple comparison test was used for grouping.

3. Results

3.1. Imposed damages in log transportation trails

After finishing the transportation operation, regeneration state and damages was evaluated that results are shown in Tables 1 and 2.

According to Table 1, we will find that the percent of damage to the regeneration in mechanized trails (99.91%) is more than the traditional ones (41.14%). According to Figure 1 it can be seen that mechanized trails imposed the most damage to the regeneration in the form of eradicating (99.72%). This study shows that the damage of animals was low and the greatest amount of damage to the regeneration was observed in mashed form (16.54%). Reason for this extent of damage is because there is very small regeneration on the trail. Also amount of damages related to semi-injured (8.83%) and injured (5.44%) regeneration can be due to endless traffic of animal in the trail.

3.2. Compaction and soil disturbance in the traditional and mechanized timber extraction methods

The results of data analysis and comparison of skid and control trails in relation to relative density and soil compaction indexes in the depths of 10-0 and 20-10 cm and soil porosity at a depth of 20-0 cm on skidder trail and unpaved trail and control trail between tow skidder trail and unpaved trail is shown in Tables 3 and 4 in level of 95%. Analysis of variance showed that the location of control or crushed sample has a significant effect on soil bulk density, relative density, compactness, and soil porosity in two methods.

Table 1: The frequency of regeneration before and after transport in skid and control trails.

trail		Before skidding	Healthy regeneration after skidding		Injured regeneration	
			Number	Percent	Number	Percent
trail Control	Mechanized	1062	1062	./.100	0	./.0
	Traditional	836	836	./.100	0	./.0
trail Skid	mechanized	5925	5	./.0.09	5920	./.99.91
	Traditional	2479	1495	./.58.86	1020	./.41.14

Table 2: Frequency of attendance and damage percent to the regeneration in two traditional and mechanized trails.

		Healthy	Injured	Semi-injured	Broken top	mashed	eradicated	…
trail Skidder	Percent	5	2	0	4	6	5908	-
	Number	./.0.09	./.0.03	./.0	./.0.06	./.0.1	./.99.72	-
d trail Unpave	Number Percent	1459	135	219	199	410	-	57
		./.58.86	././5.44	./.8.83	./.8.03	./.16.54	-	./.2.3

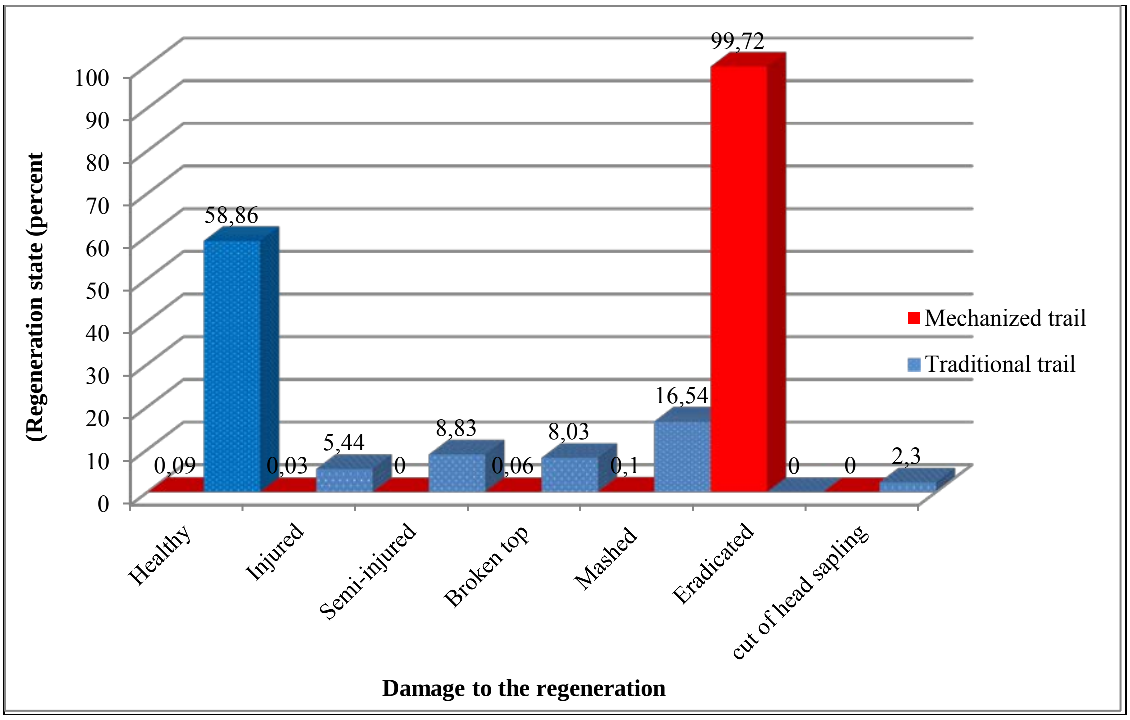

Figure 1: Frequency of attendance and damage percent to the regeneration in two traditional and mechanized trails.

3.3. Soil relative density

The averages of relative density percent in mechanized and traditional and control trials compared to each other at any depth have significant difference but between two of depth in the each direction (mechanized and traditional), no significant differences was observed (Table 2). The relative density of traditional trails in two depths is more than that in mechanized trails. Similarly, the relative density of control traditional trail is greater than that in control mechanized trail. As a result, traditional transportation method leaves the greatest impact on soil compaction compared to mechanized method (Figure 2).

3.4. Compactness and soil porosity

The average of soil compactness percent only in depth of 10-20 cm in traditional and mechanized trails is significantly different and other trails have no significant difference compared to each other (Figure 3). Soil compactness in mechanized trail in two depths is more than that in traditional trail. Compactness in mechanized trail was the same in both depths but in traditional trail it has most effect on soil surface depth of 0-10 cm.

Table 3: Comparison of treatment means (± standard deviation) in mechanized, traditional and control trails in the different depths.

Variables / Trail	Relative density of depth (cm)		Compactness of depth (cm)		Porosity of depth (cm)
Control skidder trail	0-10	10-20	0-10	10-20	0-20
Skidder trail	^{a}22.27±0.76	-	-	-	^{b}73.84±1.78
Control unpaved trail	^{b}24.72±1.31	^{b}24.69±1.26	^{ab}9.73±4.41	^{b}9.63±4.43	^{b}73.55±3.9
Unpaved trail	^{c}29..92±0.91 ^{c}30.08±1.64	- ^{c}30.78±2.07	- ^{a}6.04±3.63	- ^{a}4.74±4.83	- ^{a}66.27±2.53

(Treatments that are marked with the same letters have no significant differences in the level 0.05 and are equal)

Table 4: Analysis of variance between variables of relative density, compactness and soil porosity in the mechanized and traditional methods and in different depths.

Variables		Sum of squares	df	Average of squares	f statistics	Sig
Relative density percent	Between groups	719.725	5	143.945	73.425**	0.000
	In groups	105.864	54	1.960		
	Total	825.589	59	-		
Compactness percent	Between groups	192.423	5	64.141	3.391**	0.028
	In groups	681.036	36	48.918		
	Total	873.459	39			
Porosity percent	Between groups	497.118	5	165.706	19.139**	0.000
	In groups	311.691	54	8.658		
	Total	808.809	59			

(*: Significant difference at the level of 0.05 and **: significant difference at the level of 0.01)

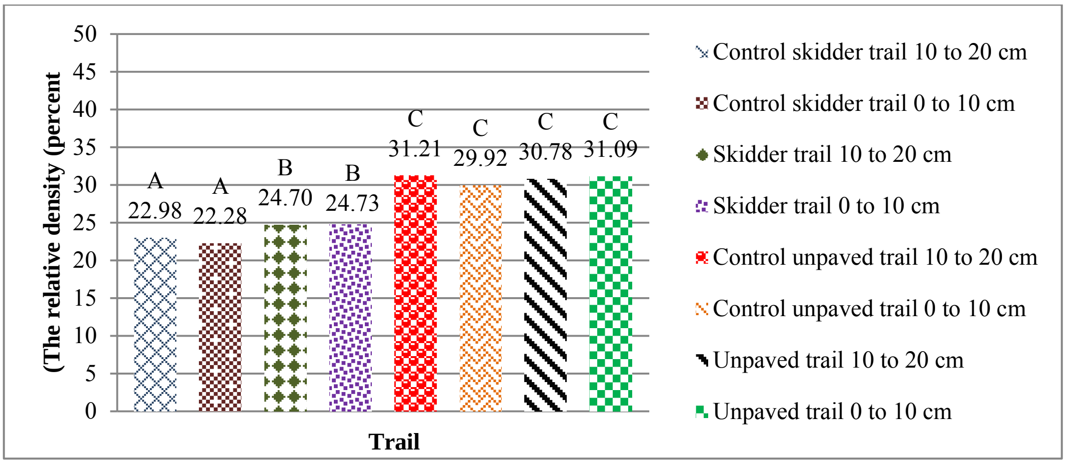

Figure 2: The relative density percent in the different depths of skid and control trails (mechanized and traditional).

3.5. Soil moisture

The content percent in each of the harvested plots and the optimal moisture content in traditional and mechanized trials showed that the dry bulk density of soil in places where soil moisture was closer to the optimum moisture content, has increased (Figure 5).

According to Figure 5, we will find that when soil moisture is increased, the amount of compaction in both trails consequently increases. Also it shows that the moisture percent more than 50% in mechanized and 35% in traditional trails reduces soil compaction.

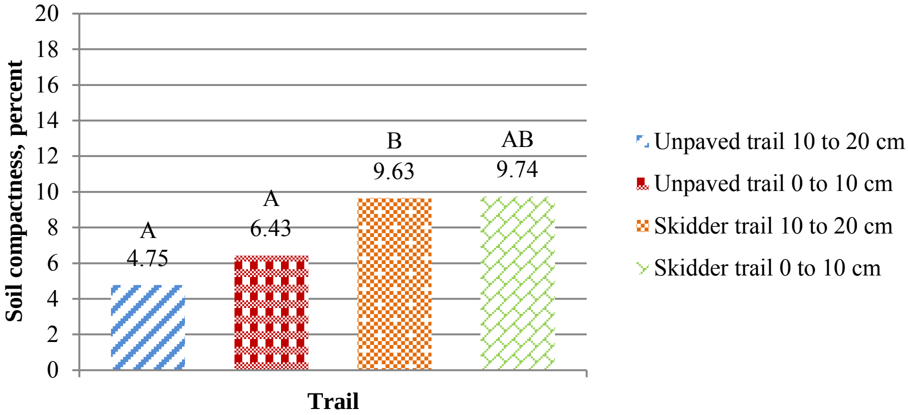

Figure 3: Soil compactness percent between the different depths of skid trail.

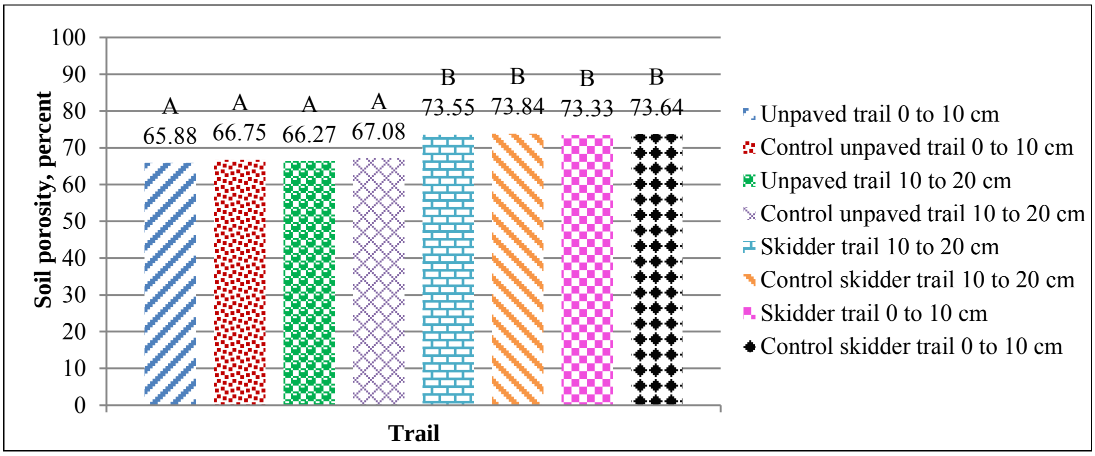

Figure 4: Soil porosity percent at different depths in the skid and control trails.

(In Figures 4, 5 and 6, treatments that have been identified with the same letters have no significant difference in the level of 0.05 with each other and are equal)

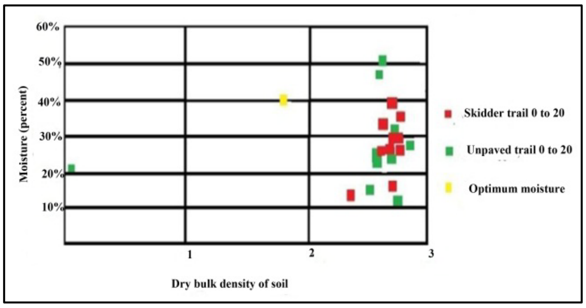

Figure 5: The relationship between moisture percent and bulk density in mechanized and traditional trails.

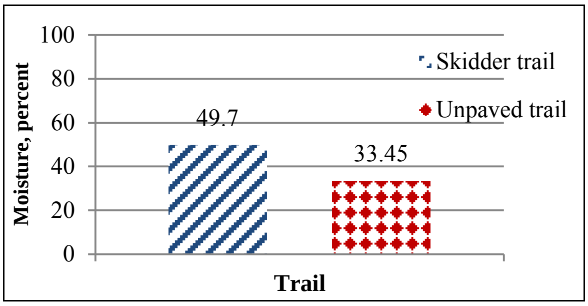

Figure 6: The comparison of mean moisture percent between the two trails.

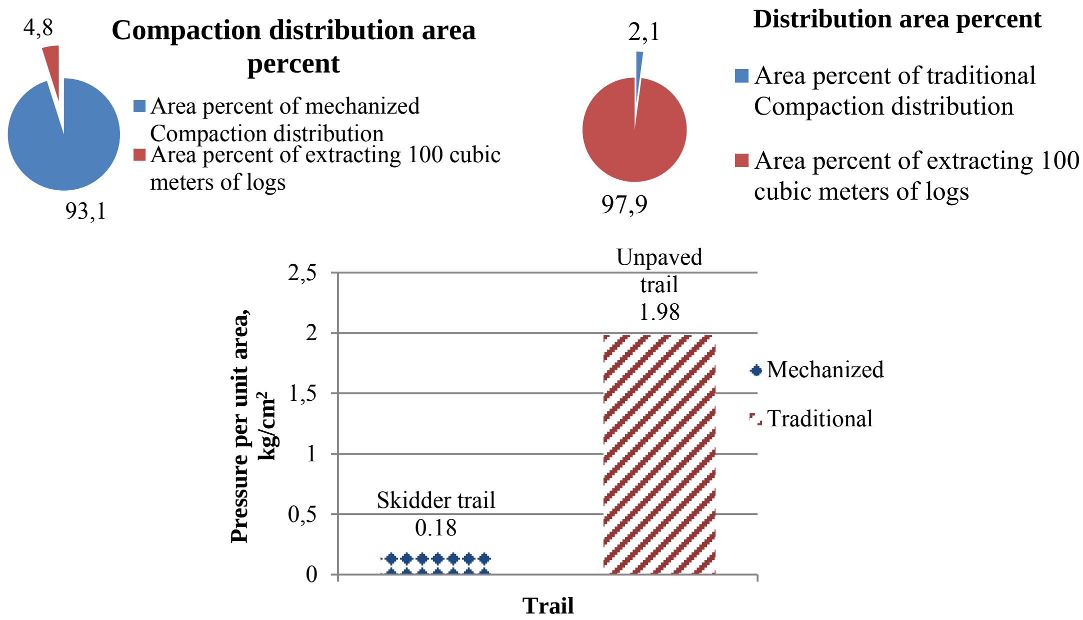

Figure 7: Figure of pressure on percent area and compaction distribution area in mechanized and traditional trail.

3.6. Percent of compaction distribution area

An area where 100 cubic meters of logs were cut and ready to transport which is an area of approximately 25,000 square meters and also an area of 527 and 1,200 square meters were respectively, traveled with mules and skidders. Finally, the compaction distribution area in these two methods with respect to expressed areas was 2.1 percent for traditional method and 4.8 percent for mechanized method. The pressure per unit area was obtained 1.98 kilograms per square centimeter (198 kPa) in the traditional method and 0.18 kilograms per square centimeters (17.66 kPa) in mechanized method (Figure 7).

4. Discussion

Healthy regeneration percent in mechanized skid trail (0.09%) was observed to be less than that in traditional trail (58.86%). The result of this research is completely consistent with the result of wang (1997). He came to the conclusion that the damage caused by animals' exploitation is less than that of machines. Damage on regeneration in trails given the volume and size of logs at transportation in mechanized method is more than that in traditional methods. JorGholami and Majnonyan (2010), concluded that due to log transportation in traditional method with mules, the damage percent compared to total number of seedlings and trees is 23.5 Percent and the ratio decreases with increasing altitude, so that the ratio of injured ones to the total is equal to 18.8 percent. In soil moisture it was observed that with increasing moisture to the extent that is called Proctor optimum moisture tests, the amount of compaction in both trails is increased and with increased humidity from this limit (49.7 percent in mechanized trail and 45.33 percent in traditional trail) the amount of compaction is reduced. The amount of relative density in two mechanized and traditional trails compared to their control trails have gained that this amount can be seen more in the traditional trails. The results of some other studies showed that most of soil compaction occurs in the surface layers, but when operating heavy vehicles with high load capacity were produced, the compaction of soil lower layers was also became important (Ampoorter et al., 2010).

The relationship between traffic intensity and soil bulk density is logarithmically significant (Bolding et al., 2009). Some investigations also indicate that animal transportation will reduce damage to trees, disturbance and compaction in surface depth of soil to a depth of 5 cm (Davis, 1992; Fecklin et al., 1997).

Han et al (2009) compared the whole tree and short logs systems and concluded that both systems significantly increase the penetration resistance in high levels of soil moisture. Pressure under the hooves of mules was obtained to be 1.98 kilograms per square centimeter (1.98 kPa) and much higher than that of the chain wheels of skidder with 0.18 kilograms per square centimeters (17.66 kPa). In another study Joshua (2008) stated that an animal could compress the soil as much as a skidder especially at the depot, which the reason is that with countless traffic of animals, the weight in the area of hooves, is applied on the ground.

In soil porosity there is a significant difference between traditional and mechanized trails which this can be the result of skidder weight and more power compared to that of mules. Also in control mechanized and control traditional trails this difference is significant but in the each of the trails compared to each other, there was no significant difference. Aflaki (2008) also concluded that the porosity was highest in control area and lowest in animal traffic area. According to considered area for the extracting 100 cubic meters of logs, the compaction distribution percent was obtained in the traditional and mechanized methods and it was observed that the compaction distribution percentage in mechanized method was 2.3 times higher than the traditional method and this means that more areas are affected by Skidder compared to mule for extracting 100 cubic meters of logs. Fecklin et al (1997) in a study concluded animal skidder trail was 1% of total exploitation area and skidder trail was approximately 4.6 percent of the total area.

The final results showed that to minimize damages to soil and regeneration in forest primarily it is necessary to conduct the logs extraction only through the already predicted trails and determine the traffic number in these trails. It is natural that in order to avoid increasing traffic along the shorter trails, the cross coverage to be less. It is necessary to point that although at first glance the skidder trail construction looks like more disturbances in forests but in the end by observing the ranges and brink of destruction, natural regeneration will be done faster.

Acknowledgements

Hereby I appreciate all those who helped me in this research.

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Protection of Oak Roundwood in FSC Certified High Forests

Milivoj Franjević[1], Boris Hrašovec[1], Tomislav Poršinsky[2], Andreja Đuka[2]*

Abstract: Due to FSC certification of forests many methods of roundwood protection that were used throughout the years are now prohibited and therefore it becomes unavoidable to introduce innovative biotechnical methods for oak roundwood protection. Synthetic semiochemicals, flight barrier traps as well as insecticide treated polymer nets were tested as means of integrated oak roundwood protection in lowland high oak forests in Croatia. Ambrosia bark beetles phenology and varying stand conditions of different harvesting seasons must be well understood in order to have effective methods of roundwood protection. Field measurements showed that early seasonal deployment of semiochemically baited flight barrier traps can reduce the number of bark beetles that infest oak timber. It was also recorded that without additional protection with polymer nets it is not possible to protect oak timber in regard with strict standards EN 1316-1: 2012: 2012 (E): Hardwood round timber – Qualitative classification Part 1: Oak and beech.

Keywords: integrated roundwood protection, ambrosia bark beetles, EN 1316-1: 2012: 2012 (E)

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1. Introduction

Problems connected with oak roundwood protection from ambrosia bark beetles are present for a long time in Croatian high forests. Efforts to minimize damage from ambrosia bark beetles are visible in different strategies of integrated forest protection of oak roundwood. Methods of integrated protection active or passive can be divided in connection with integrated oak roundwood protection and can be defined in four generations of protection against ambrosia bark beetles. First generation was present until mid 40ties of 20th century and based on cultural and mechanical methods of protection and chemical protection with carbolineum. Second generation was from mid 40ties until late 50ties mostly based on use of insecticides primary DDT, BHC and Lindan but soon have lot of opponents because of extremely negative effects on ecosystem and wildlife. Third generation begins with early 60ties and lasts until 80ties. In this period protection from ambrosia bark beetles was based on use of olfactory manipulation by means of defining attractive and repellent properties of chemical compounds and developing of pheromones used in traps for purposes of mass trapping, also it brings new understanding in behavior and phenomena of aggregation behavior of ambrosia bark beetles. Third generation of protection is important because of development of barrier panel traps which are used in mass trapping and also for purpose of monitoring ambrosia bark beetle population. Fourth generation begins with 90ties and promotes all previous methods of integrated protection from ambrosia bark beetles integrated in new technologies that are not harmful to forest ecosystem.

Cultural methods

- forest operations in period of winter with no activity of ambrosia bark beetles
- transport of oak roundwood from forest in short time after forest operations
- removal of physiologically weak trees from oak stands in which ambrosia bark beetles develop and overwinter
- forest hygiene in broadest meaning

Mechanical methods

- drying (exposing to sun) of oak roundwood and transport out of forest
- submerging of oak roundwood in water and sprinkling of water on oak roundwood for prevention of ambrosia bark beetle development

Chemical methods

- spraying of oak roundwood with insecticides (it is important to spray insecticides before ambrosia bark beetles attack oak roundwood)

Methods of oak timber protection which in past where implemented are now banned following the FSC criteria. In the least decades, growing concern about environment protection and efficient forest protection focused on a new approach in forest protection – integrated pest management (IPM). Holistic in approach, it takes into account all the aspects of forest ecosystem and forest management operations chaining them together into the environmentally friendly and economically efficient protection of managed forests. Introduction of new biotechnical methods of oak timber protection seem as an obvious tool in the new ecological, economical and legal circumstances. The purpose of this research was to explore the possibilities of targeted ethological manipulation of adult ambrosia beetles during their swarming flight in search for oak timber suitable for infestation. Some of the commercially available products, as well as few of those in the preproduction phase, were applied in trials testing their potential in the integrated oak timber protection. Intercept flight barrier traps with various semiochemicals and FSC approved polymer nets with incorporated insecticides were tested in field conditions during the period 2003, 2009–2011. Oak logs were used for evaluation and verification of efficiency of each tested chemicals/trial designs.

With the repeated population monitoring and consecutive catches of ambrosia beetles in oak stands where trials were set up it turned out that *Trypodendron domesticum* (Linnaeus, 1758) has two generations per year in Croatian environment. It was also observed that population of Asian species *Xylosandrus germanus* (Blandford, 1894) established in Croatian oak stands within the last decade. Valuable biological knowledge was collected on several species of ambrosia bark beetles that inhabit our forests and damage oak roundwood including *Xyleborus dispar* (Fabricius, 1792), *Xyleborus monographus* (Fabricius, 1792), *Xyleborus saxesenii* (Ratzeburg, 1837). It was observed that *T. domesticum* is actively flying from beginning of the January when weather conditions are favourable (dominantly, incursions of warmer weather so typical for the last decade which is consistent with the report of Intergovernmental Panel on Climate Change (IPCC 2007) that states that ground air temperature in 21st century rises from 1.8°C to 4°C depending on greenhouse gases emissions stated by Meehl et al. 2007 and Ramanathan and Feng (2009). *Trypodendron signatum* (Fabricius, 1792) activity follows in February. *Platypus cylindrus* (Fabricius, 1792) has a period of activity from early June untill early October. Introduced Asian bark beetle species *X. germanus* appeared for the first time in trials in 2009, and since then it became the second most frequent species in pheromone trap catches in 2011. It is concluded that attention to this invasive species spread and population buildup is important. The same applies to its role in the now expanded Croatian ambrosia beetle group.

2. Material and Methods

In lowland even-aged oak stands methods of integrated oak roundwood protection were tested during period from 2003 to 2011. In that period pheromone baited panel traps were used for purpose of olfactory manipulation, trapping and monitoring of ambrosia beetle phenology. Locations for trials were Jastrebarsko in Zagreb county and Otok near Vinkovci. Locations were selected as representatives of pedunculate oak areal with Jastrebarsko as most western part of its areal and ecologically inferior to oak stands in eastern part of Croatia. Nevertheless ambrosia bark beetles that infest oak timber are equally represented through pedunculate oak areal. IPM® Tech InterceptTM panel traps were used because of their advantages over Lindgren® and Theysohn® panel traps in Cerambycid and Scolytid trapping. IPM® Tech InterceptTM panel traps catch beetles from all four quadrants and are less susceptible to weather conditions and predatory entomofauna which can influence results of trapping (Czokajlo et al. 2002). Also, because of different strategies that were used in oak timber protection from ambrosia beetles traps were not always active at same time of year. Although they were always active in period when ambrosia bark beetle swarming can be expected. IPM® Tech InterceptTM panel traps were completed with different attractive components in years of experiment. Simultaneously with panel trap exposure (pedunculate) oak timber was placed in various designs and separated in control and protected group. After the conclusion of experiment all timber was debarked and bark beetle pin holes counted on site (Fig. 2).

Data from control and treated/protected group of oak timber were statistically analyzed. Also data from traps and weather station was used for purpose of establishing correlation between phenology and species occurrence. Throughout duration of these experiments panel trap catches were collected weekly and analyzed in laboratory.

In year 2003 panel traps were completed with lineatin that is known attractive component for ambrosia beetles (MacConell et al. 1977). Six traps in five repetitions were set 10 meters from logs in circular position and spaced 60° from each other. In Jastrebarsko control group there were 80 oak logs and protected group counted 85 logs, Otok control group consisted of 61 oak logs and protected group of 55 logs. Period of experiment was from 4^{th} March 2003 till 2^{nd} April 2003.

Figure 1: Design of field trials in 2010 with use of barrier panel traps around exposed oak logs in even aged oak stands.

In Jastrebarsko control group in year 2009 for trapping in panel traps ETOH, GLV (Green leaf volatile) and Domowit-Trypowit D® were used. Twelve traps in five repetitions were set 20 meters from logs in circular position and spaced 30° from each other. ETOH and Domowit-Trypowit D® were used in panel traps as attractive components. As a repellent on exposed oak roundwood, ampoules of Tompin® were used. This is a pheromone component used for baiting of species from genus *Tomicus* (*Tomicus piniperda*, *Tomicus minor and Tomicus destruens*) and it contains aggregation pheromones but also α-pinen which is primary attractive component found in bark and resin of conifers. Six Tompin® ampoules were attached on every oak log bundle. Period of experiment was from 17^{th} March 2009 till 28^{th} April 2009. Control and protected/treated group consisted of 50 oak logs each.

In Jastrebarsko in year 2010 twenty-four traps were set 20 meters from logs in circular position and spaced 15° from each other ETOH and Domowit-Trypowit D® were used in panel traps as attractive components. As a repellent on exposed oak roundwood ampoules of Hostowit® and Kombiwit® were used on oak log bundles. Hostowit® has universal attractive component for bark beetles on conifers.

Kombiwit® is aggregation pheromone for *Ips typographus* and *Pityogenes chalcographus*. Control and protected group consisted of 50 oak logs each. Period of experiment was from 21st April 2010 till 26th May 2010. All oak logs used in trials were 1 m long (Fig 1.).

On 8th of June 2011 oak tree was cut down and logs were protected with Woodnet® system product of BASF® The Chemical Company (Fig. 2.).

Figure 2: Pin holes on debarked one-meter logs and protected oak roundwood.

According to still used »old« Croatian Standards of Forest Exploitation Products (Anon. 1995) which are derived from ex-Yugoslav standards JUS (Anon. 1989), oak roundwood is classified to two types of veneer (I. and II. class of veneer logs) and three sawlog classes (I., II. and III. class of sawlogs). Roundwood was protected within half hour after cutting. Removal and evaluation of Woodnet® system protection was done on 1st of September 2011. During period of Woodnet® system evaluation IPM Tech® panel traps were collecting data in same forest management unit.

In year 2011 monitoring of swarming period for ambrosia bark beetles was conducted in lowland oak stands with five randomly positioned traps that were set with ETOH and Domowit-Trypowit D® and used in panel traps as attractive components. Period of experiment was from 11th January 2011. until 6th June 2011. ETOH is known attractant for ambrosia beetles (Moeck 1970) and Domowit-Trypowit D® is commercially available product for trapping of beetles from *Trypodendron* genus. In year 2011 monitoring of ambrosia beetle phenology was conducted from early January till early June in that time Spectrum Technologies Inc. Watchdog® Weather Station 2000 Series was used for temperature measurements.

3. Results

During period of trapping with lineatin in year 2003, 30 panel traps were set. In that year trials were conducted on two locations Jastrebarsko and Otok.

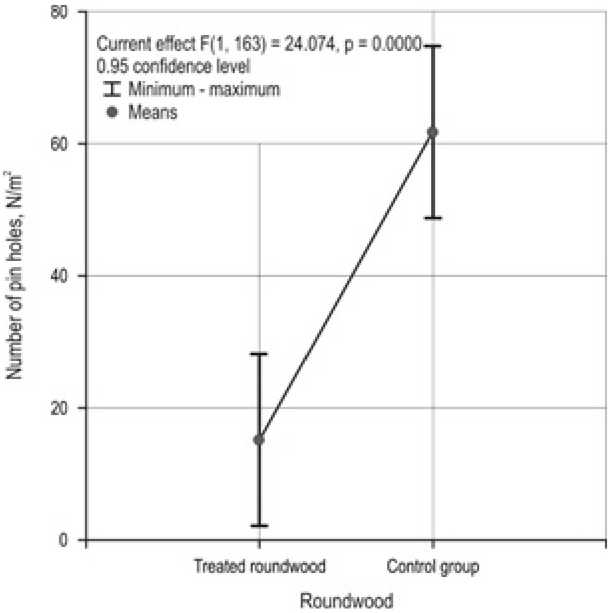

Figure 3: Statistical analysis of pin holes in oak roundwood per square meter for treated (T) and control group of logs in Jastrebarsko 2003 protection with lineatin baited traps.

Results after debarking showed insufficient level of protection regarding both sites of experiment, but on location Jastrebarsko a distinct difference between protected (15 pin holes per square meter) and control (62 pin holes per square meter) group of oak timber (Fig. 3 and Table 1) has occurred. Location Otok showed no distinct difference (Fig. 3 and Table 1) between two groups of oak timber an also insufficient level of protection regarding FprEN 1316-1: 2012 E standards for oak roundwood with protected (15 pin holes per square meter) and control (24 pin holes per square meter).

Table 1: Descriptive statistics for compareson of Jastrebarsko and Otok 2003 field measurements.

Effect	Factor level	N	Mean	Standard deviation	Standard error	-95.00%	+95.00%
Total		281	31.75118	59.75916	3.567933	24.73370	38.76865
Logs	Treated	140	17.74801	38.47428	3.251670	11.13888	24.17714
Logs	Control	141	45.65503	72.67621	6.120441	33.55458	57.75547

Period of trapping in Jastrebarsko 2009 with panel traps baited with ETOH, GLV and Domowit-Trypowit D®. There were 60 pheromone baited panel traps overall positioned in 12 traps around oak roundwood bunch in five repetitions but level of oak roundwood protection was also insufficient. There was distinct difference between control and protected group of oak roundwood but protection was low with protected group of oak roundwood (22 pin holes per square meter) and control group (59 pin holes per square meter). Period of trapping in Jastrebarsko 2010 with panel traps baited with ETOH, GLV and Domowit-Trypowit D®. There were 24 pheromone baited panel traps overall positioned around single oak roundwood bunch with control group. Level of oak roundwood protection was also low with control group less infested with ambrosia bark beetles. Protected logs had (11 pin holes per square meter) and control group (9 pin holes per square meter.

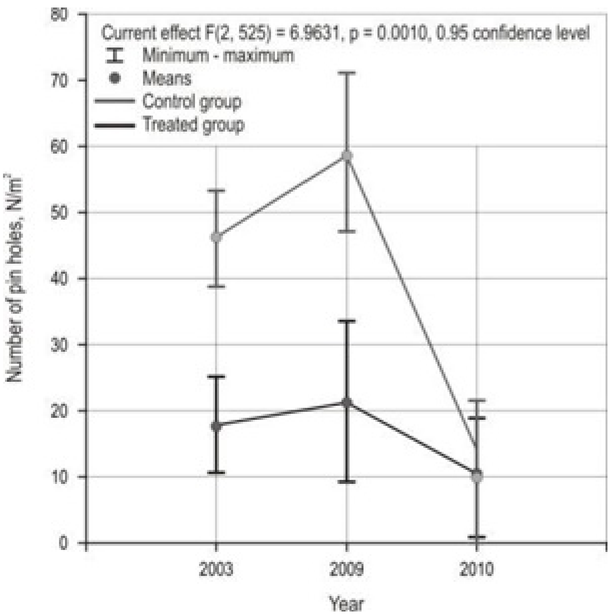

Figure 4: Statistical analysis of pin holes in oak roundwood per square meter for treated and control group of logs in Jastrebarsko 2003, 2009 and 2010.

Analysis of oak logs protected with Woodnet® system on 1st of September 2010 was done after 3 months of exposure. Detailed observation and debarking of oak timber showed only 24 pin holes overall. All observed pinholes were on places were bark was previously damaged. In six pinholes females of *X. monographus* were found. No other xylophagous insects or their remains were found on the Woodnet® system or near it. Only evidence of system toxicity were remains of beetles from genus *Geotrupes* near Woodnet® system.

In year 2011 phenology of ambrosia bark beetles was monitored and correlated with average weekly temperatures (Fig. 5). If daily temperatures exceeds 9°C it is sufficient for activation of early ambrosia bark beetles from *Trypodendron* genus (Petercord 2006).

During the experiments of integrated oak roundwood protection, insufficient levels of protection were achieved with pheromone baited traps. Reasons for that can be explained in fact that ambrosia bark beetle are polifagous species and every generation has to found their suitable host for development, so in managed forests there are relatively few of them. Suitable trees are randomly positioned in forests and their number varies from year to year. Position of suitable trees is unpredictable for ambrosia bark beetles and they have developed complex mechanisms for finding of suitable hosts which is generally based on semiochemicals and aggregation pheromones (Wood 1982). Ambrosia bark beetles are aggregation insects and their populations are pulse eruptive (Thalenhorst 1958, Berryman 1987). Periods of gradation usually lasts from 5 to 7 years and during that period bark beetle can damage large amount of trees (Bombosh 1954, Schroeder and Lindelöw 2002, Jakuš et al. 2003). According to this, protection of oak roundwood during experiments was more efficient in regard of protected/treated vs. control groups (pin holes) in early period of ambrosia bark beetle swarming. Panel traps were more attractive during early period of dispersion flight and sweeping forest for suitable hosts. Panel traps were more influenced with period of exposure than with attractive component used during our experiments. Once aggregation process started in exposed oak logs pheromone baited traps lost its efficiency in protection of oak timber.

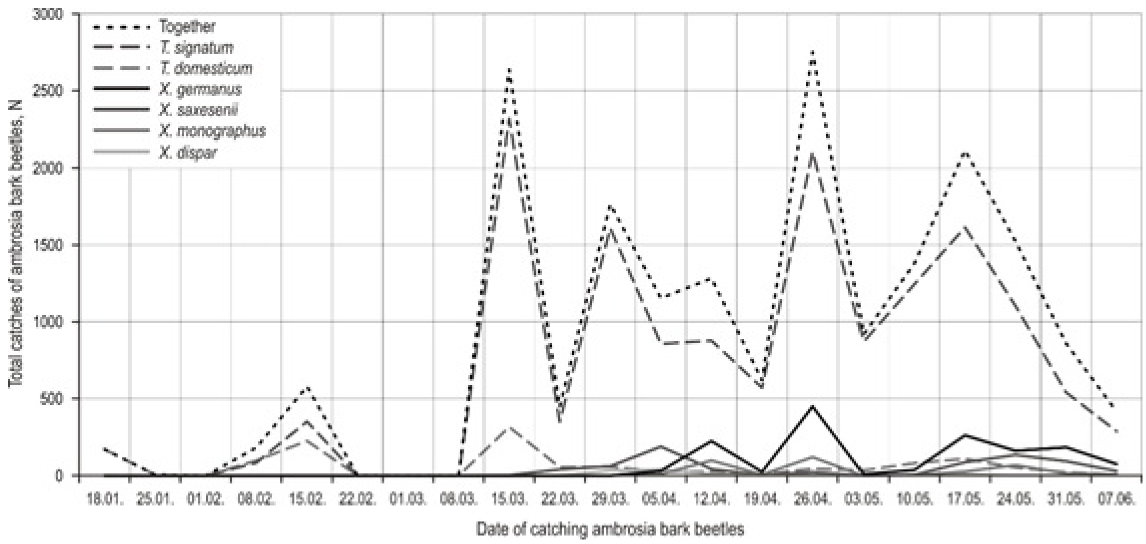

Figure 5: Ambrosia bark beetles catches in year 2011.

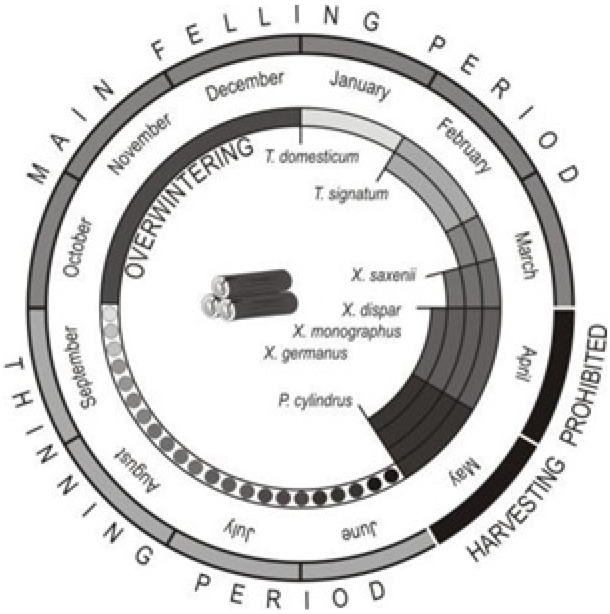

Figure 6: Risk of pin hole damage on oak roundwood in regard of ambrosia bark beetle species swarming period and forest operations.

Overall levels of protection achieved with pheromone baited traps were insufficient in regard to strict FprEN 1316-1:2012:2012: E Hardwood round timber – Qualitative classification – Part 1: Oak and beech, which does not permit any insect attacks in A and B quality class, whilst for C class insect attacks are permitted only in sapwood. In terms of still used »old« Croatian Standards insect attacks are also not permitted in veneer classes. Repellents used in experiments were inefficient although some species of ambrosia bark beetles are polyphagous (*X. dispar, X. germanus*). Protection of oak roundwood with Woodnet® system achieved excellent results, showed great modularity and usability in FSC certified forests. Data collected during 2011 is valuable for understanding phenology and is crucial in implementation of integrated oak roundwood protection. Winter part of experiments shows risks in forest operations for exposed oak roundwood in regard with swarming periods of ambrosia bark beetles especially form *Trypodendron* genus (Fig. 6). From monitored species of ambrosia bark beetles in European literature univoltine species are: *T. domesticum, T. signatum, X. dispar, X. germanus* (Maksymov 1987, Bruge 1995), *P. cylindrus*, as bivoltine species *X. saxesenii, X. monographus* and for some authors *X. germanus* (Faccoli and Rukalski 2004) are mentioned. Monitoring of ambrosia bark beetles in 2011 bivoltinisam for *T. domesticum* in weather conditions that are favorable for early first swarming in January and second in May (Franjević 2013). Existents of second generation for *T. domesticum* are described by some foreign authors (Eichhorn and Graf 1974, Petercord 2006.).

In regard with results of this experiments recommendations for forest operations with oak roundwood would be to protect exposed oak roundwood from middle of winter (January). Weather in winter with daily maximal temperatures exceeding 9°C are favorable for begening of *T. domesticum* swarming. Use of protective systems like BASF Woodnet® for oak roundwood that was not possible to transport from landing areas and barrier panel traps equipped with attractive components as early warning for start of ambrosia bark beetle swarming. Strict European standards (FprEN 1316-1:2012:2012: E) do not allow any timber infestation for the most valuable assortments (A and B quality class) and highest risk for exposed oak timber is in period from mid January till middle of March in regard to dominant species *T. domesticum* and *T. signatum*. Research results give some guidance in the ongoing development of novel approach in integrated oak timber protection. They reveal the realistic potential of the use of semiochemicals in the process, either for their use as a monitoring tool (very usable) or means of reduction of timber damages (generally low) and mass trapping of timber beetles (also very low).

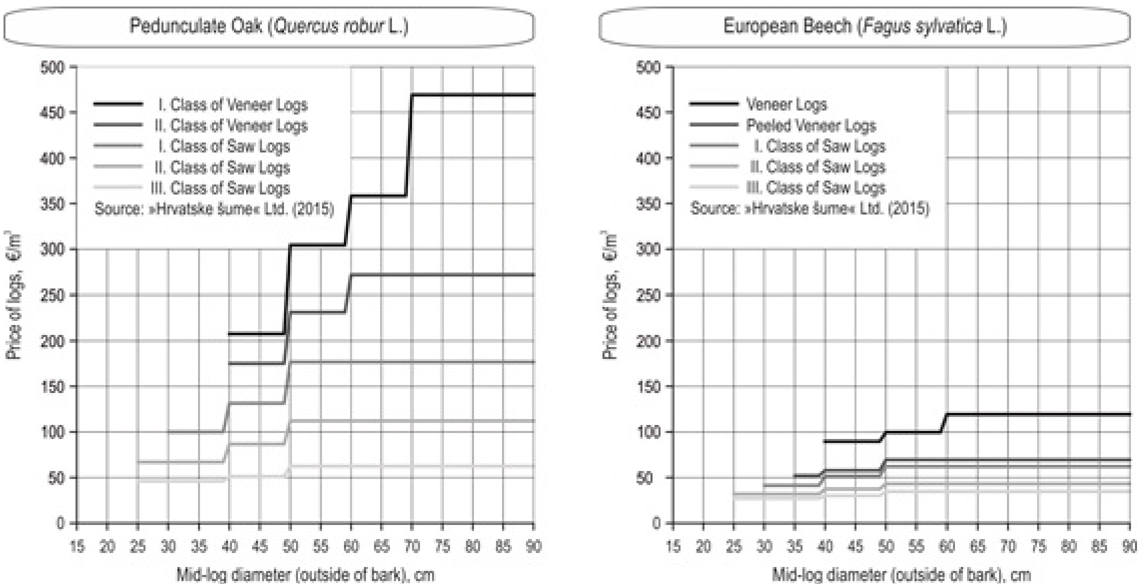

Figure 7: Discrepancy in prices between most valuable specie – pedunculate oak and most common specie – European beech logs on Croatian timber market.

Figure 8: Oak timber on roadside landing – possible challenge in using net systems.

A newly developing method of targeted mechanical protection via the use of chemically treated (FSC and WHO approved) polymer reusable net is scored as highly promising. Regarding flight periods of species that infest oak timber and suggests methods of protection. Even though research was done on pedunculate oak timber and roundwood, proposed integrated protection systems can be used on any roundwood because ambrosia bark beetles are polyphagous species that can successfully develop on broad specter of broadleaves and conifers alike. Integrated timber protection, even with higher costs in the beginning (BASF Woodnet® price is 125 €/100 m^2 and previously used, but now banned, Deltacid in dose of 15 L/100 m^2 was 26 €), brings both ecological (through FSC certification) and economical benefits at the end. On Croatian timber market, according to Business annual reports of national company »Hrvatske šume« Ltd. (state owned company that manages 80% of all forests) for years 2009 and 2010, pedunculate oak and sessile oak I and II. Classes of veneer (which must also be without insect damage) together account to 42.48% of all veneer assortments together. According to timber products' price list (Fig. 7) from the company »Hrvatske šume« Ltd. (Anon. 2012), I. class veneer logs of pedunculate and sessile oak are 3.15 times more costly than beech (*Fagus sylvatica*), which is according to Beuk et al. 2007 the most common tree species in the Republic of Croatia (which amounts to 37.4% i.e. 113.2 million m^3 of all timber), 1.52 time more costly than narrow-leaved ash (with overall share 3.9% i.e. 11.8 million m^3) and other ash species (*Fraxinus anfustifolia* L. and other) and 4.33 time more costly than hornbeam (*Carpinus betulus* L.) with overall share 7.7% i.e. 23.2 million m^3.

One can conclude that integrated timber protection, in explained manner will bring many advantages in forest management of broadleaved species, but also it should be mentioned that use of systems like BASF Woodnet® will bring the need of changing/adjusting roadside landing organization (Fig. 8). Manipulation with covering/uncovering logs presents a challenge (especially in terms of poorly organized landings or for example elongated skidder roadside landings), but nevertheless BASF Woodnet® systems should be used for the most valuable assortments which are on the landing site at the end of the harvesting season waiting for the biding process.

The results of the research give some guidance in the ongoing development of novel approach in integrated oak timber protection. They reveal the realistic potential of the use of semiochemicals in the process, either for their use as a monitoring tool (very usable) or means of reduction of timber damages (generally low) and mass trapping of timber beetles (also very low). A newly developing method of targeted mechanical protection via the use of chemically treated (FSC and WHO approved) polymer reusable net is scored as promising. Regarding flight periods of species that infest oak timber and suggests methods of protection.

The use of proposed integrated timber protection measures will also ensure the sustainability of carrying (in terms of company »Hrvatske šume« Ltd.) or receiving (in terms of private forest owners) the FSC certificate for the forest management. As it has already been stated FSC certificate represents a great honour, as it is an international acknowledgement that forests are being managed according to very strict standards, and it is a recognition to the whole forestry profession. Use of FSC approved measures for timber protection is in accordance with minimising negative environmental and social impacts of pesticide use as well as promotion of economically viable management, which is the objective of FSC programme as well as promoting environmentally responsible, socially beneficial and economically sustainable forest management.

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Propagation of noise generated by light-lift helicopters in natural environments: a case study in the Italian Alps

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Abstract: The use of light-lift helicopters in the Italians Alps has received some attention in the recent years as an alternative to cable extraction in the case of long extraction distances coupled with terrain obstacles. By contrast helicopter logging rises discussion about environmental noise propagation especially when logging is performed in proximity of Sites of Community Importance (SCIs) or Special Areas of Conservation (SACs). As a consequence, the purpose of this study is to evaluate the potential area of influence of light-lift helicopter logging by performing a noise propagation analysis.

The noise measurements consisted in monitoring the noise level according to the position of the helicopter and as a consequence also to the different work elements of the helicopter logging. In order to collect information about the position of the helicopter respect to the sound level meter, a time study supported by GNSS receiver mounted inside the helicopter was thus performed.

Noise propagation analysis uses GIS a tool specifically developed by Colorado State University able to calculate noise propagation patterns for one-third octave frequency bands (0.125-2 kHz) around a point sound source.

Keywords: helicopter logging; coppice; steep terrain; noise

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1. Introduction

Noise level emanating from forest activities is generally conspicuous in forested, semi-natural and natural areas where ambient background sound level is generally low (Leipus et al., 2010). As a consequence, forest operations and the used forest equipment are considered key sources of anthropogenic noise potentially producing wildlife disturbance (Potočnik & Poje, 2010).

Concerning noise propagation in natural and semi-natural areas due to forest operations, there are still few information from the international literature which focuses mainly on the propagation of the impulsive noise generated by chainsaws (Cavalli et al., 2004; Potočnik & Poje, 2010) and its effect on wildlife (Tempel & Gutiérrez 2003) or on the propagation of noise generated during helicopter logging operations (Delaney et al., 1999; Messingerová & Tajboš, 2006).

The use of light-lift helicopters in the Italians Alps has received some attention in the recent years as an alternative to cable extraction in the case of long extraction distances coupled with terrain obstacles (Grigolato et al., 2016). By contrast helicopter logging rises discussion about environmental noise propagation especially when logging is performed in proximity of Sites of Community Importance (SCIs) or Special Areas of Conservation (SACs) (Lindenmayer & Noss, 2006; Sitzia et al., 2016). Even if in the last decades some researches have focused just on noise propagation in logging operation generated by heavy- and medium-lift helicopters (Delaney et al., 1999; Messingerová & Tajboš, 2006), there are still a lack of information about the intensity of potential noise generated by light-lift helicopters and their propagation across natural environments.

The purpose of this study is to evaluate the potential area of influence of light-lift helicopter logging by performing a noise propagation analysis. The case study will consider a logging operation in a coppice stand for firewood production located within a SCI-SAC area in the Eastern part of the Italian Alps.

2. Material and Methods

2.1. Case study

A mixed broadleaves coppice stand located in proximity of the Piave valley in Italy (UTM N 5097630 m; E 271179 m) was selected as a representative working site. The altitude ranges from 625 m a.l.s. to 750 m a.l.s., and precipitation is about 1250 $mm \cdot y^{-1}$. The stand is south-west exposed in a limestone bedrock. Terrain slope is approximately 70% and none primary or secondary forest roads are crossing the stand. Again, terrain trafficability is considered very poor because of the high presence of wide area of rocks rubble. The main tree species are beech (*Fagus sylvatica* L.), with a sporadic participation of hop hornbeam (*Ostrya carpinifolia* Scop.), manna ash (*Fraxinus ornus* L.) and field maple (*Acer campestre* L.). Before the cut, the average number of coppice stools was estimated in 1090 per hectare with an average diameter of the shoots of 14.7 cm at breath height. An average of 159 standards was determined per hectare with an average diameter of 27.5 cm.

For this type of forest, the traditional coppice stand clear cut was allowed with the recommendation to leave at least 150 standards per hectares. In total the harvesting area covered 2.5 ha. Harvesting was performed in February and March 2015 by motor-manual felling and by processing trees at stump site in 1 m length assortments (firewood logs) up to 4 cm as minimum diameter. Branches and part of the trunks smaller than 4 cm were left on forest-ground by banding them in rows along the maximum slope of the terrain. Firewood logs were also gathered in rows in order to facilitate the following preparation of firewood bundles. As a consequence, in order to prepare suitable load for light-lift helicopter (roughly 11.5-12.0 kN), in April and May 2015 a crew of 4 operators back to the stand to put together the firewood logs into bundles of approximately of 1.2 m^3. The volume of the bundles was valued by the forest enterprise by expecting a wood moisture content about 35-40% and a wood density of 920-1000 $kg \cdot m^{-3}$ at time of the extraction operation (beginning of July 2015).

The extraction operation was performed by a light-lift helicopter Eurocopter AS 350 B3 Ecureuil with a maximum declared cargo-swing load of 12.5 kN at 1000 m a.s.l. Anyway the helicopter company suggests to the forest enterprise to not exceed the 11.5 kN in the preparation of the bundles in order to keep low the risk to arrange bundle exceeding erroneously the maximum payload capacity of the helicopter.

2.2. Noise measurements and work elements study

The noise measurements consisted in monitoring the noise level according to the position of the helicopter and as well the different work elements of the helicopter. The measurements were aided by an HD2010 (Delta Ohm®) spectrum analyser integrating a sound level meter with multi-parametric data logging capability and a HD WME microphone able to measure the noise ranging in frequency spectrum from 16 to 18 kHz in the octave bands and one-third octave bands. The sound level calibrator HD9101 – Class 1 (Delta Ohm®), producing a signal of 114 dB at the frequency of 1000 Hz, was used for the calibration of the sound level meter before each measurement.

The noise was recorded in equivalent continuous sound level (Leq) for the one octave bands and one-third octave bands frequency spectrum at 1 s interval, in F (Fast) time and Z (Zero) frequency balancing. Another sound metric recorded was the sound exposure level (SEL) which represent the total sound energy and which is commonly used for describing aircraft noise events.

In order to collect information about the position of the helicopter respect to the sound level meter, a time study supported by GNSS receiver mounted inside the helicopter was performed according to the protocol proposed by Grigolato et al. (2016). The georeferenced points, acquired by the GNSS receiver located inside the helicopter cabin, were thus synchronized with the time study (conducted at turn level) as well with the noise measurements.

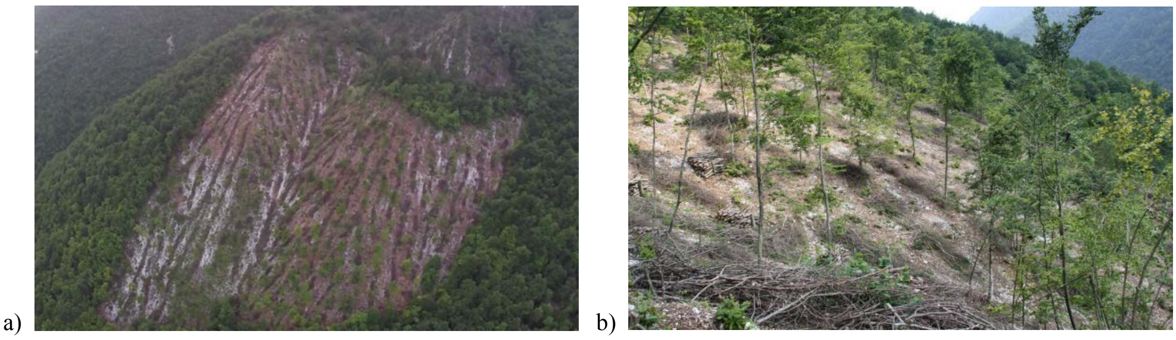

Figure 1: Overview of the clear cut area (a) and a particular of the same area after the felling and bucking operations (b).

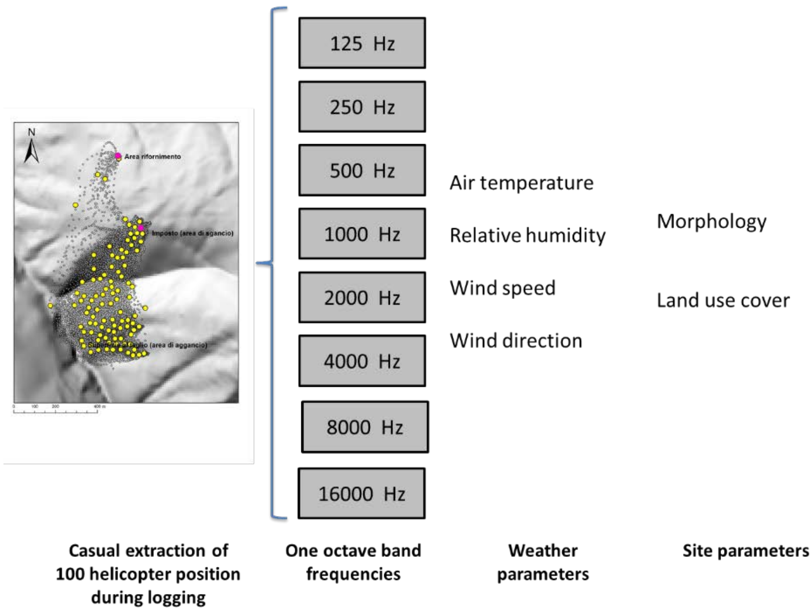

Figure 2: overview on the model layout and used parameters.

The recorded georeferenced data were then grouped and identified in relation to the consecutive cycle number and work elements. The time and the positional data recorded were in fact used to calculate distances travelled and average speeds as well the different work elements by assuming that low speeds (<15 km·h^{-1}) identified hooking and unhooking time elements, while high speeds identified loaded and unloaded travelling time elements (Horcher & Visser, 2011).

2.3. Noise propagation model

Noise propagation analysis was based on the use of the SPreAD-GIS toolbox, a tool specifically developed by The Colorado State University (Reed et al., 2012) for the ArcGIS (ESRI®). The SPreAD-GIS model I able to compute noise propagation patterns for one-third octave frequency bands (0.125-2 kHz) for one or multipoint sources.

The model returns the predicted pattern of noise propagation in the form of continuous surface around the source/s and the excess noise propagation representing the difference between the introduced noise and the background or natural environment noise levels.

The SPreAD-GIS model includes six factors to calculate the noise frequency band spatial propagation: a) spherical spreading loss; b) atmospheric absorption loss as a function of air temperature, relative humidity and elevation; c) foliage and ground cover (ground and vegetation) loss; d) downwind and upwind loss, e) decline in sound levels due to the morphology of the terrain; f) excess noise propagation where noise propagated from the source exceeds ambient sound conditions.

The SPreAD-GIS was applied for the following one octave band frequency of 125, 250, 500, 1000 and 2000 Hz (Figure 2). For each frequency the model run for 100 noise source points extracted randomly from all the positons recorded by the GNSS system during the whole working days. In GIS environment, then, the maximum area of influence was identified by sum the area of each noise source points identifying the maximum extension of the disturbed area.

2.4. Field measurement

To record equivalent continuous sound, pressure A-weighted (LAeq) and single event level A-weighted (SEL) as well as the octave bands and one-third octave bands, the sound level meter was located in 3 locations: at landing or unhooking area, at hooking area ad under forest canopy along the trajectory of the helicopter. Interval measurements consisted in five complete helicopter turns, approximately corresponding to 600-660 s. For each location, at least three replications were done.

Synchronization between the noise measurement and the position data obtained from the GNSS system installed into the helicopter cabin was based on two check of the timestamp of the data from all the used instruments. The first check was done before the beginning of the survey and the second check at the end of the survey. The difference between the instruments was recorded and then used to improve the synchronization of the data.

Each sound level meter location was also georeferenced by GPS Pathfinder ProXH™ (Trimble®) receiver offer with a post-processed accuracy of 30 cm.

The complete dataset including timestamp, helicopter coordinates, helicopter work elements, noise level measurement, the frequency spectrum in the one-third octave bands and the distance between helicopter and the sound level meter position was compiled in excel.

3. Preliminary results

3.1. Overview on the helicopter logging operation

The time studies shown a total of 9.87 hours of working time. The time distribution reported a reliable percentage of productive time (about 87%), while operational as well as mechanical delays being minimal. The remaining time (about 11%) agreed to the preparatory and service time at service landing. The operational delays were mostly related to transportation of materials, while mechanical was due to electronic problem of the hooking system. The productive time (PSH_0) of turn averaged approximately about 85.5 s. Fly loaded (productive time to fly from the end of hooking to landings) and fly unloaded (productive time to fly from the end of hooking to landings) sum more than the 60% of the total productive time, while hooking work element contribute also significantly to the total working time (Table 1).

Fueling amounting to 160-180 l per filling occurred every 45-50 minutes during productive time over a cumulative horizontal flight distance of about 38000-40000 m and a positive vertical elevation change of 5300-5700 m.

3.2. Equivalent continuous sound pressures level and single-event level

The equivalent continuous sound pressures level A-weighted - dB(A) and the single-event level recorded at each location are reported in Table 2. LAeq ranged from 73.3 dB(A) to 87.0 dB(A), while SEL from from 99.1 dB(A) to 114.6 dB(A).

In average, the lowest values were recorded when the helicopter was flown over the sound meter level located under the forest canopy, while the highest was recorded when helicopter was un-hooking the loads at the landing area.

Table 1: Summary on the work elements time.

	Cycle	**Unloaded fly**	**Hooking**	**Fly loaded**	**Unhooking**
	s	s	s	s	s
Total time	31464	10171	8018	11114	2161
Mean	85.5	28.4	22.4	31.0	6.0
St.Dev.	19.056	3.530	7.308	4.830	5.381
Min.	63.0	17.0	12.0	22.0	1.0
Max	136.0	54.0	62.0	55.0	44.0
Quantile 0.05	109.0	33.0	36.0	39.0	17.2
Quantile 0.95	66.0	23.0	14.0	24.0	1.0

3.3. Spectra analysis

As the commonly used A-weighted frequency attenuates the noise energy according to the human hearing range and sensitivity (Delaney et al., 1999), the unweighted spectra data in the one-third octave bands are here shown as A-weighted, but also weighted in according to strigiform hearing capacity and sensitivity (Figure 3). Spectra analysis of the noise at the different location clearly showed the importance of the spectra between 1000 and 8000 Hz. This range is dissimilar from the spectra generated by heavy-lift helicopter as shown in Delaney et al. (1999) who reported a significant range between 630 and 6000 Hz.

3.4. Noise propagation

The resulting excess noise (not-weighterd) in term of one octave bands in the range from 125 Hz to 16000 Hz is shown in Figure 4.

The results highlight the sum of the area where equivalent continuous sound pressure exceed the background environment noise. In particular, the area where the noise exceeds the background level is determined in interval of 10 dB.

According to Shannon et al. (2015), who indicates that wildlife disturb generally starts when noise exceeds more than 30 dB the background natural noise (evaluated in average in 34.8 dB), the SPreAD model highlighted that for the frequency in the range of 1000 Hz to 2000 Hz (the most relevant frequency range for the strigiform species) the exceeded noise (> 30dB) area corresponded approximately to 31 ha.

Again, the most important propagation was due to the 125 Hz frequency, which showed a potential extension of the disturbed area of more than 60 ha. Anyway this low frequency will have not particular effect on Strigiform as these show a very low sensitivity at low frequency (Delaney et al., 1999).

Table 2: Noise level summary on unhooking, hooking and flying over canopy.

	LAeq dB(A)					SEL dB(A)				
Locations	N.	Mean	SD	Min	Max	N.	Mean	SD	Min	Max
Unhooking area	15	85.5	0.700	84.4	87.0	15	112.8	1.093	110.3	114.6
Hook points	15	81.1	0.724	80.0	82.7	15	108.7	0.381	107.9	109.2
Fly-over	15	73.8	0.380	73.3	74.8	15	100.1	0.384	99.1	100.6
All	45	80.1	4.920	73.3	87.0	45	107.2	5.419	99.1	114.6

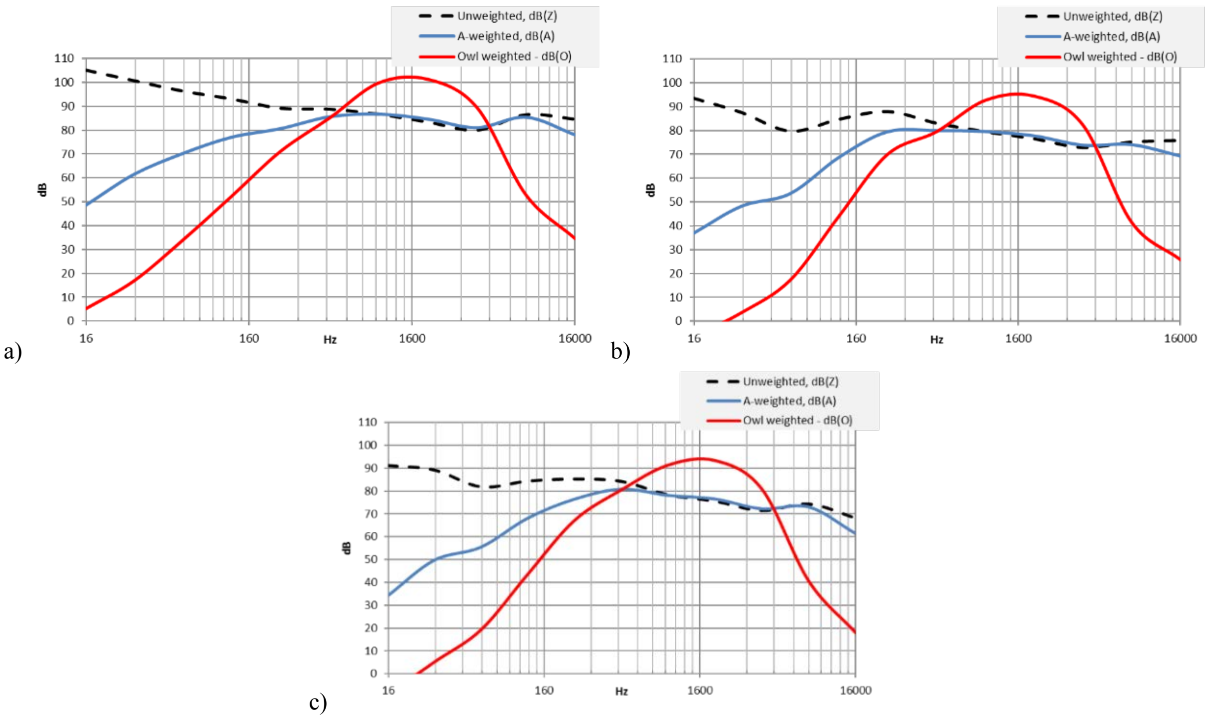

Figure 3: Noise frequency spectrum weighted for equivalent continuous sound pressure owl (O) and human (A) and for equivalent continuous sound pressure unweighted when helicopter was in proximity (within a radius of 15 m from the sound level meter) of the hooking (a) and unhooking (b) areas and over canopy (c).

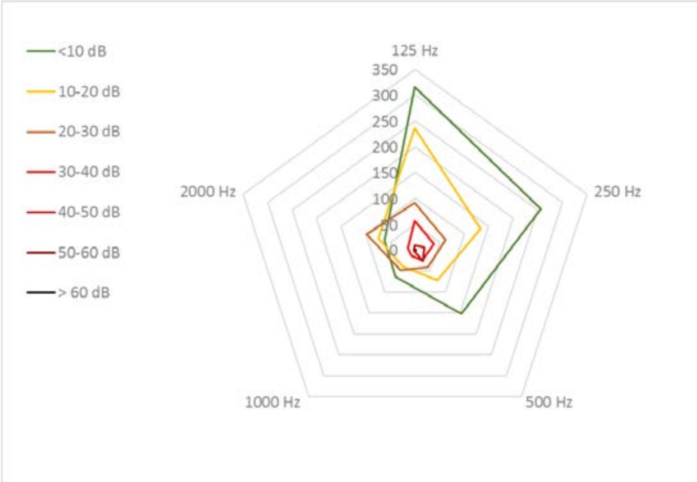

Figure 4: Excess noise propagation representing the difference between the introduced noise by the light-lift helicopter during logging operation and the background environment noise levels in term of area (ha) for the octave band in the range of 125 Hz and 2000 Hz..

4. Conclusions

This study is unique in proving an analysis about the noise propagation of light-lift helicopter during real logging operations. In particular, the noise level generated by the light-lift helicopter highlighted the potential area where noise can effect local strigiform community. This area is counted when noise exceeds for more than 30 dB the background noise: in the present case study it is evaluated in a dozens of hectares.

What is more from this study is also the shown potentiality of predicting noise exposure and noise exceeding natural background noise generated by forest operations by taking into account specific ambient condition and terrain morphology and by using empirical noise sources and ambient sound measurements (Proto et al. 2016).

Anyway, the case study highlighted the limit in terms of processing time. In fact, complex scenarios including the continuous change of the noise source location (as in this case with the helicopter positions during logging operation) substantiality increase the processing time for the noise propagation analysis.

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Integrated prevention concept for safety and health in forest operations

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Abstract: Prevention of safety and health risks in forest operations persists as a major challenge. Huge efforts have been taken over the last decades to reduce accident risks, mainly in motor-manual work, and to prevent work related diseases both for manual workers and machine operators. Still, the safety and health situation in forest operations is problematic. This is particularly the case in small and micro service enterprises which today form the majority of the forest operation workforce.
Although knowledge about beneficial work organisation, safety education and training, and safety and health management in forest enterprises is widely available, preventive measures are rarely implemented in forestry. Further, numerous examples of effective preventive measures which are appied in other industrial sectors, are rarely used in forestry.
A research team of forest operation experts, work scientists, psychologists, and contractors has formed for a three year project, funded by the German Ministry of Science, to develop an integrated prevention concept that meets the specific needs and management structures of small enterprises, that fosters health competences of individuals, that finds acceptance in enterprises, and is economically affordable. This concept, consisting of approved and newly developed prevention measures, will be adapted to the specific conditions in small forest enterprises, and will be tested and evaluated with forestry contractors and their workforce.
This paper presents the first project phase: An in depth analysis is carried out to assess and map which prevention measures are actually applied in German forestry. Assessment of effectiveness will identify drivers and barriers for success and distinguish good practices. This will ensure that already successfully applied measures will be further used, improved, and integrated into a wider concept. Further, it shall foster the integration of actors in actual prevention work, namely accident insurers, into the subsequent project work and the durable implementation of the project results. Assessments in forestry are complimented by the investigation of good practices of prevention measures in other sectors with regard to their applicability into a holistic prevention concept for forest operations. This will result in packages of prevention measures which will be assembled for testing and evaluating in forest enterprises.

Keywords: Safety and Health, Prevention, SMEs, Integrated research and development

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1. Ongoing challenge to prevent accidents and work related illnesses

Accident prevention and the reduction of health hazards always have been in the forefront of forest operations research and forest engineering. It is widely acknowledged that forestry work is one of the most dangerous professions with regard to accident risks, and it is also commonly known that forest machine operators are faced with serious stress and strain related health hazards. The risks to safety and health of forest workers have been analyzed and documented since decades. Subsequently, conclusions and recommendations for improving the situation were drawn up by many researchers. Already in 1964 Bernt Strehlke called for mutual initiatives of forest owners, workers, and accident insurers and for uniform accident prevention regulations. Strehlke further requested a continuous analysis of health risks related to the introduction of new technologies and processes.

Accident and health risk analyses, prevention initiatives and technical development led to the assumption: “Safety and Health in Forestry are Feasible!” This was acclaimed in the title of a seminar held in the year 1996 (FAO/ECE/ILO, 1997). At this seminar an international community of experts presented a wide range of solutions for various safety and health problems. Presentations and discussions highlighted the enormous accident risks of motor-manual work and the risks for machine operators to suffer from musculoskeltal disorders. The proposed solutions were among others

- to enhance training and education to develop the skills to work safely;
- to develop integrated safety programmes on enterprise and forestry sector level as a whole;
- to enforce safe behavior at workplaces, whereas it was understood that the behavioral aspects were not yet sufficiently understood;
- to pay high attention to the health implications of mechanized harvesting.

Since 1996 forestry has changed in many ways but the outlined problem are still relevant today.

The **organization** of forestry work has undergone a radical change with a continuing shift from a workforce that traditionally was directly employed by forest owners to private companies. Today, the majority of forestry work is carried out by service enterprises. In Germany close to the total of mechanized harvesting is in the hands of service enterprises which are mainly small or even micro companies with an average of three to four people working in forest operations.

A significant change is also related to **technical** development. Primarily, the ergonomic design of forest machine has improved significantly over the last twenty years. E.g. European ergonomic and safety guidelines for forest machines were developed as a key result of the EU funded project “Ergowood” (Gellerstedt, 2006). Forest machine manufacturers draw a high attention on safety and comfort in their workplace design (e.g. Komatsu, 2016). And last but not least ergonomics and safety are core aspects of testing and certifying forest machines by the Kuratorium für Waldarbeit und Forsttechnik in Germany.

Despite the enormous technical improvement and an overall risen awareness for the importance of safety and health in forestry work (see e.g. the UNECE/FAO Action Plan for the Forest Sector, Forestry and Timber Section, 2014), the situation has not improved significantly. Statistics show that accident rates are still on an unacceptable high level (e.g. in Austria Tsioras et al., 2014, and in Germany Morat, 2016). This accounts particularly for some state forest enterprises in Germany where, after a phase of reduction during the past ten years, the accident frequency increases again (Morat, 2016). However, a detailed analysis of the reasons is still subject to further research, but pure figures show that accident prevention in forestry has not yet achieved a desired effect and that it needs continuous efforts. While accidents have become better recorded for large enterprises, respectively state forest enterprises, there still is a considerable lack of empirical data for the safety situation in small and micro service enterprises.

Compared to accident risks health implications of operating forest machines are much more difficult to assess, since work related illnesses are effects of long term risk exposure that are still not documented sufficiently to draw conclusions. The assessment of risks therefore still relies on earlier scientific knowledge (for scientific review see Lewark, 2005) and on theoretical considerations taking into account on the positive side the ergonomic improvement and on the other hand risk factors related to increasing production pressure. This leads to a considered hypothesis that the health risks which were described in the past are not yet eliminated by advanced technology.

2. Complex problems call for integrated prevention concepts

Safety and health hazards are complex problems. They are firstly related to the personal behavior of the workers, their skills and motivation (or the lack thereof) to work safe. Secondly, they result from risks which lie in the nature of the work itself. This is particularly the case for motor-manual harvesting and skidder operations. And last but not least problems are connected to the planning and organization of tasks and operations and the management of safety and health in enterprises. In addition to these obvious factors there are many other aspects which have an impact on safety and health. Just to name one, individual predisposition and competences to cope with stress and risks, also related to age of workers, becomes more and more a matter of concern since the workforce in average is ageing.

Based on the awareness that safety and health in forestry work has not reached a satisfactory state, confirming that "Safety and Health in Forestry is Feasible", effective prevention needs to address the complexity of work processes and work organization. There are various health risks which separately do not reach critical levels, e.g. whole body vibration on modern forest machines which has not been rated as a health hazard (Rottensteiner, 2014), but in combination with long exposure time and mental strain work related diseases may arise.

Psychological, technical and organizational measures need to be integrated in prevention concepts rather than focusing on individual safety and health measures. To this end, a joint research project with an transdisciplinary approach was launched in June 2016. Funded by the German Ministry of Science a research team of forest work scientists, psychologists, technical and organizational ergonomists, and practitioners is ready to take the challenge to develop integrated prevention concepts for safety and health in forest operations.

3. State of the art of prevention

A general assessment of the existing and applied prevention measures shows that an enormous wealth of knowledge about work environment and working conditions exists. A review of the existing and practically applied measures has recently started, following the goal to build a catalogue of "good practices." Already a first overview of recently reviewed material shows, that for many problems solutions already have been proposed:

- The ILO "Code of Practice – Safety and Health in Forestry Work" (1998) provides an integrated framework for managing safety and health.
- Safety and health management systems are promoted in the "Guide to Good Practice in Contract Labour in Forestry" (FAO, 2011).
- A wide range of safety and health regulations exists.
- Health and safety management systems have been introduced in companies, mainly in some state forest enterprises. A successful example is reported from the forest enterprise of the federal state Hessen in Germany, where a continuous coaching and consulting project, which is directly addressed to forest workers at their workplace, has led to a substantial improvement of safety (Gerding, 2015).
- Recommendations for preventive work organization were the results of the two EU funded projects "Ergowood" (Gellerstedt et al., 2005) and "COMFOR" (Kastenholz et al., 2009).
- In addition to a keen knowledge of "good practices", ergonomic research continues to provide more insight into stress and strain in forestry workplaces (e.g. Häggström, 2015).

Despite the availability of a wide range of available prevention measures, safety instructions and regulations, it is a guiding question for the actual research activities:

Why are safety and health problems in forestry still alarming?

The reasons why the implementation of effective prevention measures works in one enterprise and fails in others need to be investigated closer. Knowledge about drivers and barriers for effective prevention will provide one of the keys to effective safety and health protection. Of course, there are general rules and regulations which are undisputable. (This accounts particularly for motor-manual harvesting, where neglecting of safety regulations still is a major accident cause.)

One driver definitely is management commitment to increase safety on the level of a whole enterprise. Enhancing skills and raising motivation of workers, and the enforcement of regulations have shown positive results in Hessen-Forst (Gerding, 2015) where an integrated company policy underlined with continuous interventions at the workplaces was implemented.

While drivers in many cases may be obvious, it will be much more difficult to detect barriers for effective prevention concepts. They can be related to the personality or competences the enterprise owners. Measures may not fit an individual enterprise and its task areas. Barriers may lie in the structure of an enterprises, e.g. when irregular or seasonal workers are employed which have insufficient skills. The forthcoming research activities will particular focus on identifying such barriers, and will assess how to overcome them.

One remarkable example for a barrier to long term effectiveness of prevention was the concept to reduce work related strain on forest machines by advanced work organization concepts. Since it was analyzed in Sweden that many machine operators suffer from musculoskeletal disorders (Pontén, 1988, see also Lewark, 2005), the Swedish labour authorities required to implement measures to reduce the risk exposure time of machine operators. As a result, work organization concepts were designed with job rotation between machines and job enrichment by adding organizational tasks to the workers´ tasks (Lidén and Erikson, 1991). This concept was widely promoted and it can be considered as state of the art for improving forest machine operators´ health (Gellerstedt et al., 2005, Kastenholz et al., 2009). However, after an enthusiastic uptake in Swedish forestry in the early 1990s, this concept was turned down. The general reason provided in subsequent reviews was: It was not economical (Häggström, 2015; Ager, 2014). Hultåker (2006) explained, that this promising and from the scientific point of view "best" work organization concept did not fit the organizational structure of small enterprises in Sweden and thus lacked acceptance in a long run.

This example shows that prevention measures first of all need to be accepted by the entrepreneurs and the workers to gain sustainable effects. To this end the recently launched project will develop and test integrated prevention concepts together with enterprises. It is expected that this will be the best way to reach acceptance and to overcome barriers. E.g. a low expectation of benefits from cost for prevention is expected to become a major obstacle. This barrier will be lowered, when entrepreneurs are integrated in the evaluation of prevention measures and when they are encouraged to draw up their own recommendations for designing integrated concepts that will fit the structure of their respective business.

4. Challenge to reach small and micro enterprises

The challenge for improving safety and health is particularly big for small and micro enterprises which offer services in forest operations. They very often have limited professional management capacities and frequently employ workers who are not formally trained and educated. Further, these micro enterprises are generally under continuous economic pressure due to low profit margins of their business. They are hard to reach and control by labour inspectorates and accident insurers and they have little access to consulting and support for prevention measures (Kastenholz and Lewark, 2005).

Therefore, particular attention of the upcoming research and development activities will be given to small and micro enterprises in forest operations. They are actually the most critical and most vulnerable target group with regard to safety and health. Statistical evidence for the particular high safety and health problems in small and micro enterprises is not yet sufficiently available, since there is still no mutual statistic for all forest operations in Germany (see Strehlke´s recommendations from 1964!). This applies to accidents but even more for work related illnesses like musculoskeletal disorders caused by physical strain both from manual and machine work. Apart from the very detailed epidemiological studies carried out in Sweden in the late 1980s (Ponten, 1988), there is rather limited knowledge about machine operators´ health. However, it is well known that, despite the enormous ergonomic improvement of forest machine workplaces, operators in small enterprises are still exposed to the most critical risk which is long working hours with repetitive tasks and high mental strain (Lewark, 2005).

The forest operations service sector is very heterogeneous and fragmented with regard to task areas, size of enterprises, skills and competences of workers and entrepreneurs, and technical equipment. Therefore, it can be foreseen that prevention concepts must integrate a variety of measures and need to be flexible and adjustable to individual enterprises. A major challenge is to develop the best approach to meet contractors´ mentalities and expectations to motivate them to implement prevention measures. Therefore, it needs the integrated approach from psychological, technical and of course forestry point of views to develop concepts which integrate existing measures, which have proven to be effective in forestry, and prevention measures that will be adopted from other industrial sectors.

5. From research to a prevention alliance for forestry

The overall objectives of the recently started integrated research approach are to

- improve safety and health in forestry work;
- raise the attractiveness of forestry work as a professional career;
- ensure the future availability of a competent and motivated forestry workforce.

Towards these goals the project partners have started with the broad assessment of the state of the arts in safety and health in forestry. Already at an early stage of the project work it becomes clear that we have a well equipped tool box with prevention measures which have proven their effectiveness in many companies and operations in forestry and in other industrial sectors. The major challenge is to transfer the existing knowledge and the available tools to the people who are concerned, who are the entrepreneurs and the workers.

It is of utmost importance that prevention measures will find acceptance particularly in small and micro enterprises. The argument "it sounds good, but that does not work here in my enterprise" is familiar to all researchers who strive for implementing scientific knowledge in practice. It needs to be better understood, why a prevention measure which has been scientifically generated and which has proven that it works in one place should not be effective in another enterprise. To this end contractors and workers are integrated in the research and development process from the very beginning. Testing and evaluating measures and concepts together with enterprises will uncover mental, psychological, social, organizational and technical barriers, and it further will lead to "prevention competences" in enterprises. This research approach will also integrate other important actors of prevention in forestry, namely the accident insurers, which in Germany also have the authority as labour inspectorates. They are particularly concerned how to motivate enterprises to improve safety and health, because their prevention approach more and more needs to rely on individual responsibility in enterprises, since their capacities to enforce and control safety regulations are rather limited.

The expected outcome of a three year research and development project are packages of prevention measures which will fit to the conditions of individual enterprises, which meet the needs and solve the actual safety and health problems, and which are acknowledged by entrepreneurs and workers for being beneficial and cost effective. Accident insurers will assess during the whole project process that the project approach will be complementary to their prevention tasks and that the results will become sustainably applicable. Thus, the project work will result in an alliance of various actors from science, consulting, authorities, and practice to improve safety and health in forestry.

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Forest operations versus recreational forest utilisation

Jarosław Kikulski

Abstract: One of the aspects of multifunctionality of forests is the influence of forest management (forest operations) on the possibility of recreational activities. Analyses concerning this relation were carried out regarding typical lowland forests in the Polish lakelands (Drwęca and Warlubie Forest Districts). Within the study time consumption of forest operations was calculated and individual questionnaire surveys were conducted with a representative group of 947 adult Poles. According to research results, forest work was found to be the factor slightly limiting the recreational use of forests, regardless of the specifics and intensity of forest operations.

Keywords: forest work, timber harvesting, leisure and recreation, multifunctional forests

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1. Introduction

In an era of the development of civilization social function of forest are more and more important. Simultaneously public demand for timber grows as well. One of the most important principles of Polish forestry is the balance in the scope of forest utilisation. The knowledge concerning the impact of forest management (forest work) on the possibility of recreational activities is crucial – as it forms the basis for optimal management of the forest.

The aim of the research was to determine the influence of forest management (forest operations) on the recreational use of forests. This article is the shorter version of the full paper published in *Sylwan* (Kikulski, 2011).

2. Material and Methods

Analyses were carried out in Warlubie and Drwęca forest districts (Figure 1) which are examples of lowland forests in the Polish lakelands – forests important also for recreational activities (Figure 2).

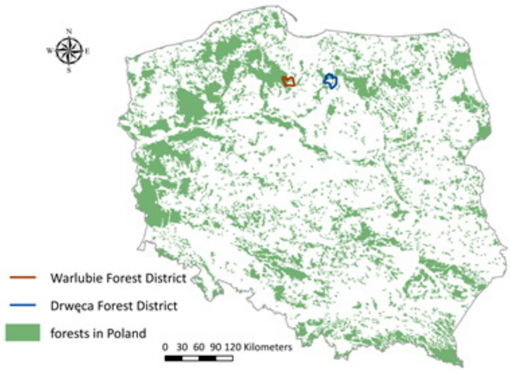

Figure 1: Location of the research areas.

Figure 2: The research areas are important also for recreational activities (forests in the lakelands).

Figure 3: Clear-cutting performed with harvesters (Warlubie F. D.).

In Warlubie Forest District clear-cuttings are performed with harvesters (Figure 3) while in Drwęca Forest District timber is harvested using chain saws (in all types of cutting) (Figure 4). Simultaneously the main forest site type in Warlubie Forest District is fresh coniferous forest (45%) while in Drwęca Forest – fresh mixed coniferous forest (44%). This two aspects influence on work consumption which was calculated regarding particular “research fields” (forest districts were divided into 43 and 46 “research fields”).

The base for the calculation was forestry work data (for 5 years, then average per 1 year; sources: Information System of The State Forests and “Catalogue of Working Time Standards”) – concerning timber harvesting (most time consuming), silviculture and forest protection. Obtained results were compared with recreational traffic in particular “research fields” – Pearson correlation coefficients were calculated. The base for the calculation of recreational traffic were one−to−one questionnaire interviews with representative group of 947 adult Poles – questions: length of time spending in forests within research areas; usually visited places ("research fields"). During interviews respondents were asked also about: frequency of encountering forest operations (statistical analysis using G function – χ^2 in logarithmic form) (Stupnicki, 2003), boards informing about timber harvesting, ruts caused by timber transportation; reasons because of which respondents don't rest in forests; the most disturbing factors during leisure time. All questions have concerned the period of "last 5 years" – period long enough for analysis and taking into account limited possibility of remembering (Babbie, 1995).

Figure 4: Timber harvested using chain saw (Drwęca F. D.).

The survey was conducted among the people living in the rural areas and holidaymakers spending their time in holiday centres or in private recreational allotments, as well as those who stopped at forest car parks for recreationalpurposes. The number of respondents in particular villages/places was relative to the number of inhabitants/holidaymakers (in particular villages/places). Following methods were used to select respondents (Sawiński et al., 2000): 1st stage – set path method (consists in interviewing a person in the nth facility); 2nd stage – the Kish method (in a given facility – the person celebrating their birthday recently). Methodology was consulted by sociologist.

3. Results

According figures 5, 6, 8 and 9 which present spatial variability of the intensity of forest operations and the intensity of recreational traffic in the summer (June-August), selected research areas vary in terms of this two aspects. Regardless of forest districts, the calculated Pearson correlation coefficients indicate the lack of correlation between spatial distributions of forest operations and recreational traffic in the summer (Figure 7, 10). Therefore there is no dependency 'the more forest operations, the less recreational traffic'. At the same time the lack of correlation was found for the rest seasons.

Little influence of forest work on leisure and recreation is confirmed also by tourists' answers to the questions about the frequency of their encountering forest operations (Figure 11) and access prohibition signs related to the felling of trees (Figure 13). Work consumption is higher in Drwęca Forest District, however there are no statistical differences between research areas (Figure 12).

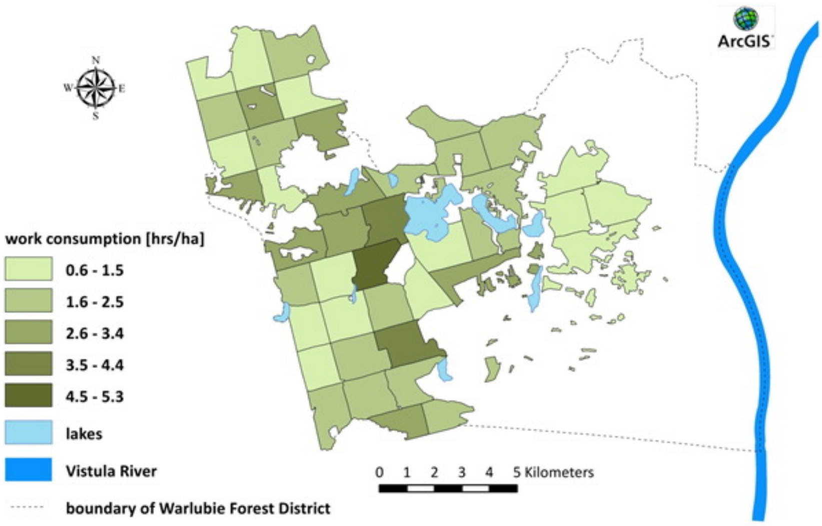

Figure 5: Spatial variability of the intensity of forest operations in the summer – Warlubie Forest District.

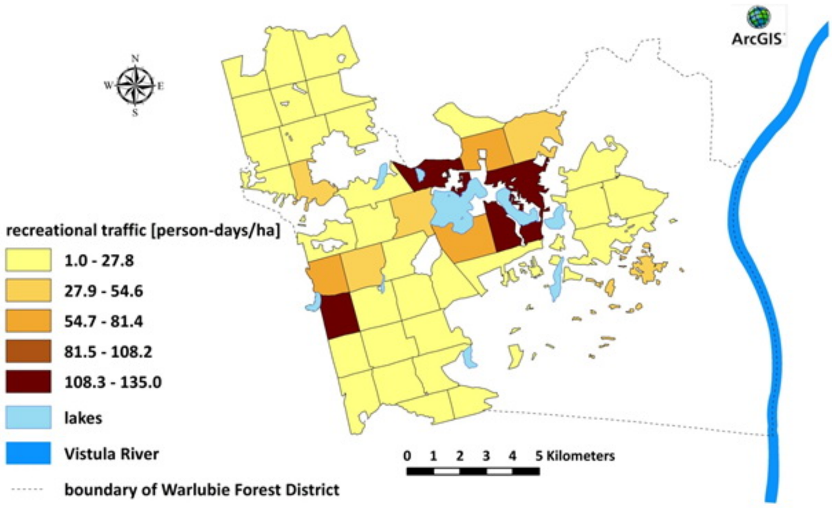

Figure 6: Spatial variability of the intensity of recreational traffic in the summer – Warlubie Forest District.

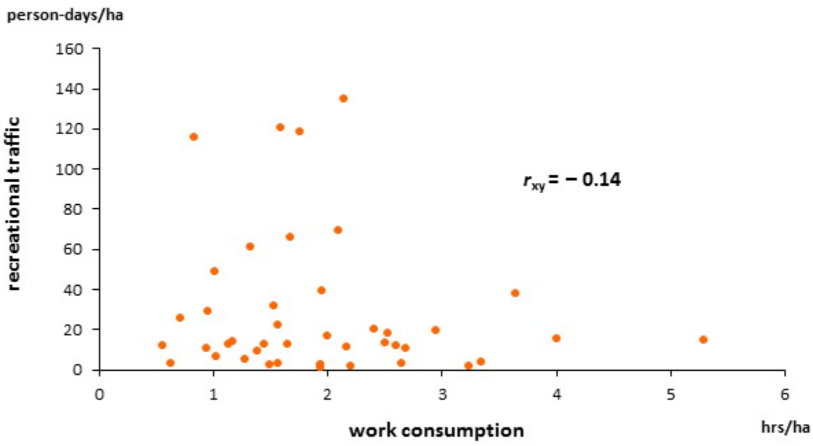

Figure 7: Relation between operations and recreational traffic – Warlubie Forest District.

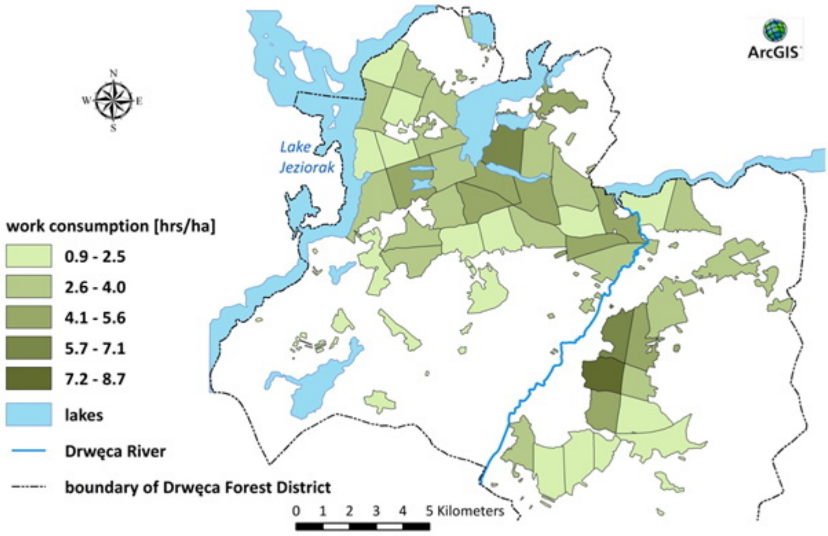

Figure 8: Spatial variability of the intensity of forest operations in the summer – Drwęca Forest District.

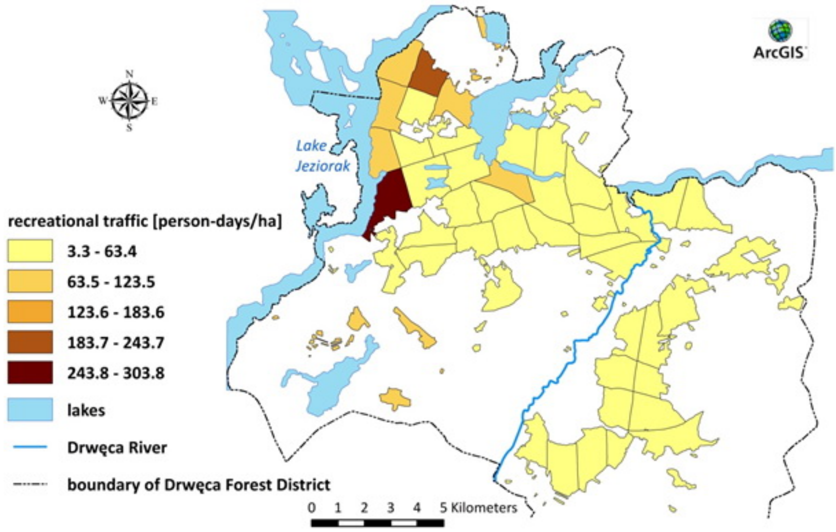

Figure 9: Spatial variability of the intensity of recreational traffic in the summer – Drwęca Forest District.

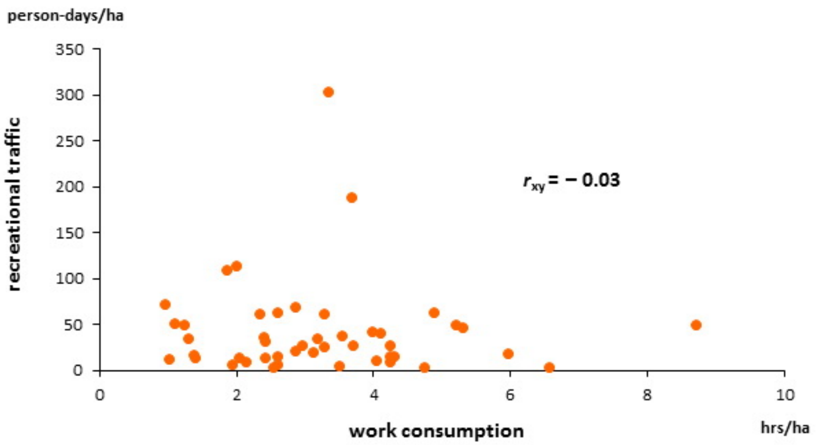

Figure 10: Relation between operations and recreational traffic – Drwęca Forest District.

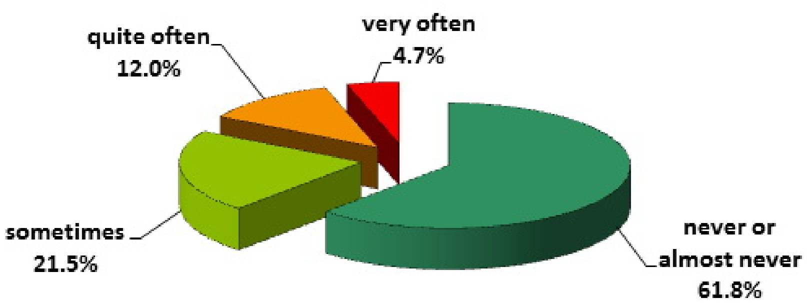

Figure 11: Frequency of encountering forest operations during recreation – the overall results.

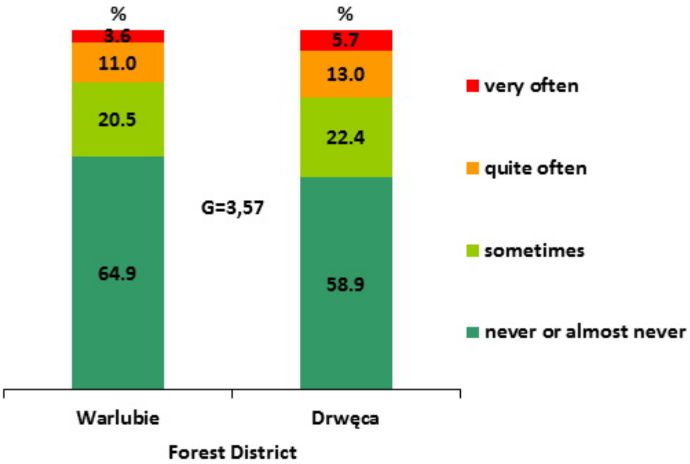

Figure 12: Frequency of encountering forest operations – depending on research area.

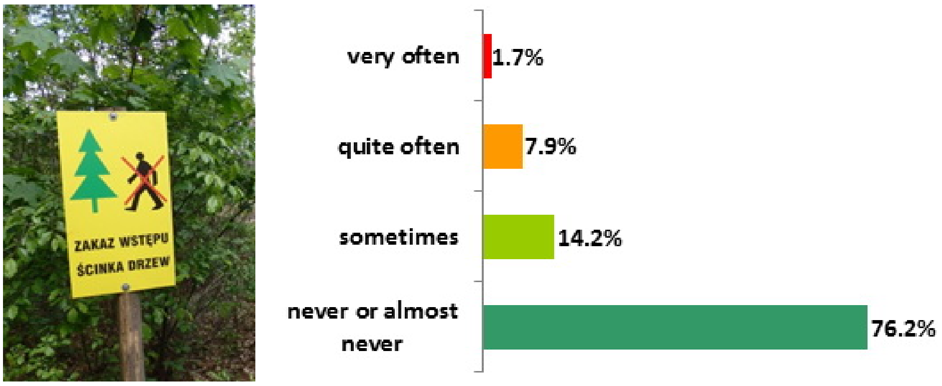

Figure 13: Frequency of encountering access prohibition signs related to logging.

The other results of the study:

- encountering ruts on forest roads caused by high tonnage vehicles (timber transport): never or almost never – 46.7%, sometimes – 21.5%, quite often – 20.3%, very often – 11.5%;
- among those who don't rest in "the surrounding forests" (25% of all the interviewees) – only 1 person has answered "due to forest work";
- share of respondents for whom forest work is the most disturbing factor during leisure and recreation – 5.2%.

4. Conclusions

1. Forest operations were found to be the factor slightly limiting the recreational use of forests in the research areas – regardless of the specifics and intensity of forest work.
2. Examined forest districts are good examples of proper multifunctional forestry.
3. There is no need to interfere with the accepted principles of forest management, both in relation to the intensity of forest operations, as well as their temporal and spatial distribution.

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Improvement of bogie tracks for wheeled forestry machines

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Abstract: This paper is concerned with development of a bogie track for forestry wheeled machines featuring extended service life, better grip and lower ground pressure as compared with the counterparts.
Today the logging companies both in Russia and all over the world resort to contemporary logging methods with increasing frequency. The world practice demonstrates that the cut-to-length method employs a team of machines, including a harvester and a forwarder. These machines feature good efficiency thanks to modern engineering equipment and automated control system. However, the machines suffer from one fatal flow. They are wheeled and their use on swampy, running soils and under subzero temperatures in such conditions as snow and glass ice makes them inefficient. Experience of their operation has shown that these machines are fitted with standard bogie tracks manufactured by Olofsfors, Clark and other companies. The use of those tracks slightly improves the situation but does not resolve the problem. The standard tracks become sagged and deformed under pressure of the machine load and ground deformation. It appears that in case the track is installed on the balance truck, the second wheel always suffers from increased travel resistance. The service life of the standard track with an open joint is around 3 to 4 thousand moto hours. The machine not equipped with the tracks affects the soil exceptionally negatively and this results in soil panning down to critical values, with that the ground pressure is very high and stands at around 75 kPa.
Thus, we had the following problems to solve: To decrease ground pressure. To reduce travel resistance factor. To improve track service life.
We have reviewed the existing technical solutions in this field and come to a conclusion that the most rational option to solve the task would be to use enclosed metal-rubber mountings in the track. This design is based on a silentblock. The rubber bushings and guides are cured and pressed fit into the joint housing on the press, then the ready joints are assembled into the links on the track.
We have made torsion and cranking resistance designs for the silentblock to reduce ground pressure. This allowed strength of the metal-rubber mounting that would strive to turn the track towards the ground contacting area. This also solves the task to reduce travel resistance as the ground contacting area enlarges, the metal-rubber mounting strength constantly levels the ground contacting area and the second wheel of the balance truck moves with least travel resistance. We have also made a dynamic force design of the track with the machine in motion.

Keywords: wheeled vehicles, metal-rubber mountings, bogie tracks, ground pressure

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1. Introduction

This paper is concerned with development of a bogie track for forest wheeled vehicles (forwarder, harvester) featuring extended service life, better grip and lower ground pressure as compared with the counterparts (Ksenevich et al., 2003).

These vehicles feature good efficiency thanks to modern engineering equipment and automated control system (Voskoboynikov et al., 2013). However, the vehicles suffer from one fatal flow. They are wheeled and their use on swampy, running soils and under subzero temperatures in such conditions as snow and glass ice makes them inefficient (Ageykin 1972; Klubnichkin 2010). Experience of operation of such vehicles has shown that these vehicles are fitted with standard bogie tracks manufactured by Clark, Olofsfors and other companies.

2. Material and Methods

Brush wood, roots, etc. often lay on the ground and help supporting a tracked machine. Tires usually press the ground and pack it. The main feature of the bogie tracks is that the tracks distribute load over greater area and do not concentrate it on two small flat spots (Fig. 2).

Soil is one of the crucial components of the forest eco-system (Kotikov et al., 2004; Eliasson et al., 2007). Forest vegetation depends on how soil feeds plants with nutrients, gases, moisture and supports roots. Soil formation process takes time and soil structure may be week.

The advantage of using properly selected bogie tracks: soil damage protection; less ground pressure and better ground grip; less soil packing; better propulsive thrust; reduced fuel consumption; increased cargo capacity; better stability during loading and unloading; better movement stability.

The vehicle not equipped with the tracks impacts the soil exceptionally negatively and this results in soil packing down to critical values.

The standard bogie tracks represent tracks inter-connected with a ring, i.e. open joint. An open joint degrades very quickly as a result of contact with soil abrasive elements such as sand, ground, etc. (Fig. 3).

After a while a track gets extended and becomes sagged and deformed under pressure of a vehicle load and ground deformation. It appears that in case the track is installed on the balance truck, the second wheel always suffers from increased travel resistance, i.e uphill movement.

Taking into consideration a large number of vehicles with different load and methods of use, it is very difficult to specify exact service life of the tracks. Great tension and load affecting the tracks shall also be considered. The average service life of a standard track with an open joint is around 3 to 4 thousand moto hours.

Considering the above, we have decided to improve joint elements of standard bogie tracks in order to: decrease ground pressure; improve track service life; reduce fuel consumption; improve maintainability; reduce travel resistance factor.

3. Results

We have reviewed the existing technical solutions in this field and come to a conclusion that the most rational option to solve the task would be to use enclosed metal-rubber mountings in the track (Potau et al., 2011) (Fig. 4). Metal-rubber mounting include: rear gasket; case; metal bushing; elastic insert (rubber IRP-1357); metal bushing; front gasket; washer; nut; bolt.

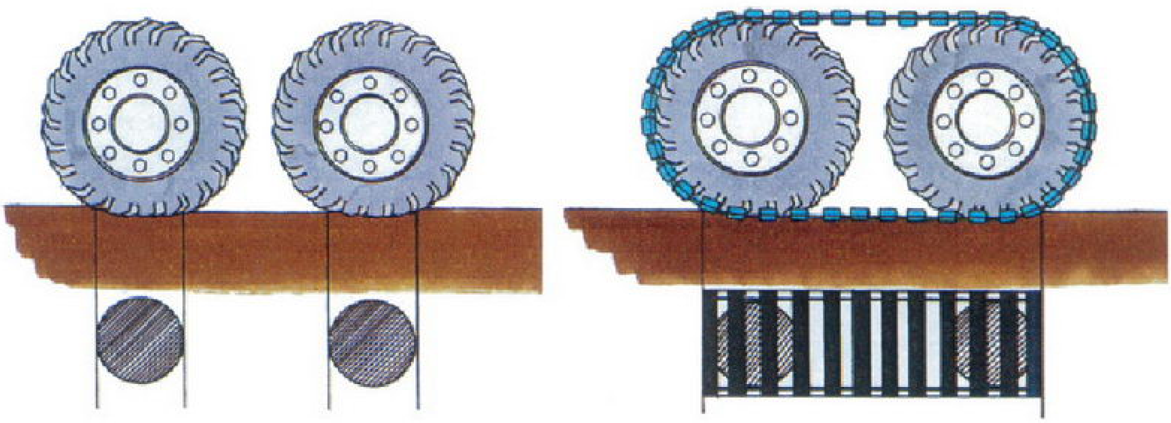
This design is based on a silentblock. The rubber bushings and guides are cured and pressed fit into the joint housing on the press, and then the ready joints are assembled into the links on the track.

Figure 5 shows a bogie track being developed , which includes 1. Grouser; 2. Track; 3. Metal-rubber mounting; 4. Side support.

We have made torsion and cranking resistance designs for the silentblock to reduce ground pressure. This allowed strength of the metal-rubber mounting that would strive to turn the track towards the ground contacting area. This also solves the task to reduce travel resistance as the ground contacting area enlarges, the metal-rubber mounting strength constantly levels the ground contacting area and the second wheel of the balance truck moves with least travel resistance that shall significantly improve fuel consumption.

We have made and tested a prototype bogie track (Kotikov et al. 2010; Klubnichkin et al. 2010). The bogie tracks with metal-rubber mountings were tested on timber harvesting machine Ponsse in Murashinsky logging company of Kirov region from February to April 2014 (Klubnichkin et al., 2015). Figure 6 and 7 shows some results of the tests.

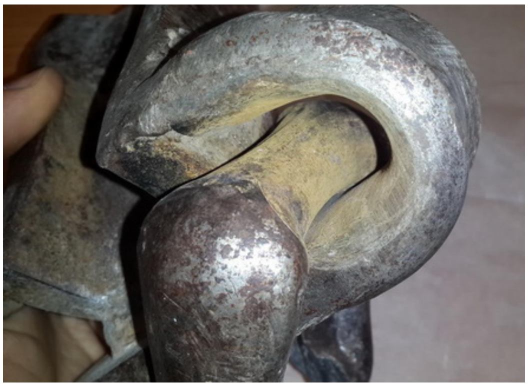
Figure 1: Vehicles which may be equipped with bogie tracks.



(a) (b)

Figure 2: Diagram of ground pressure: (a) without tracks; (b) with tracks.

(a)



(b)

Figure 3: (a) Standard bogie tracks; (b) wear of connecting link and track lug.

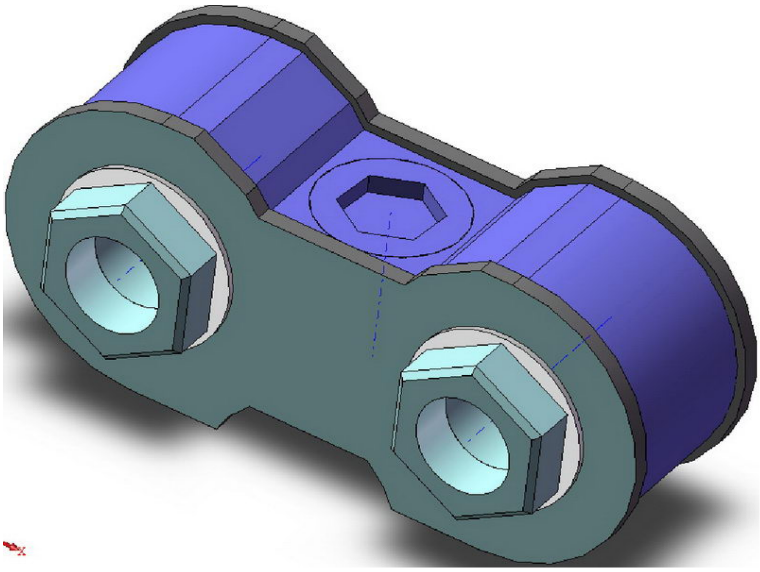


Figure 4: Metal-rubber mounting.

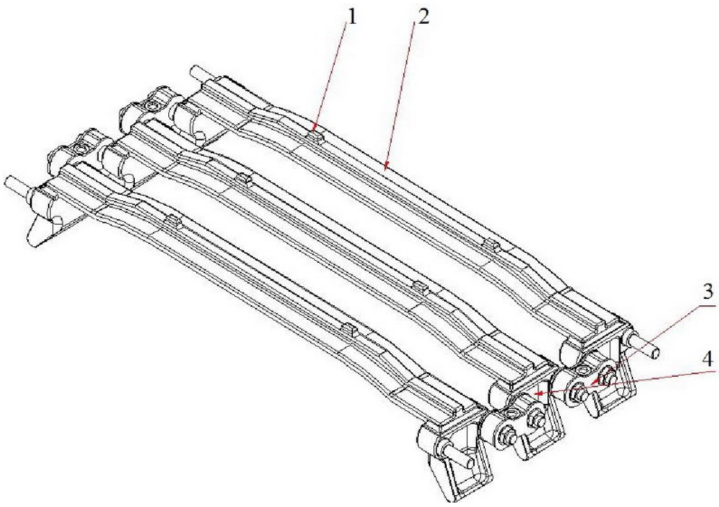


Figure 5: Developed bogie track.

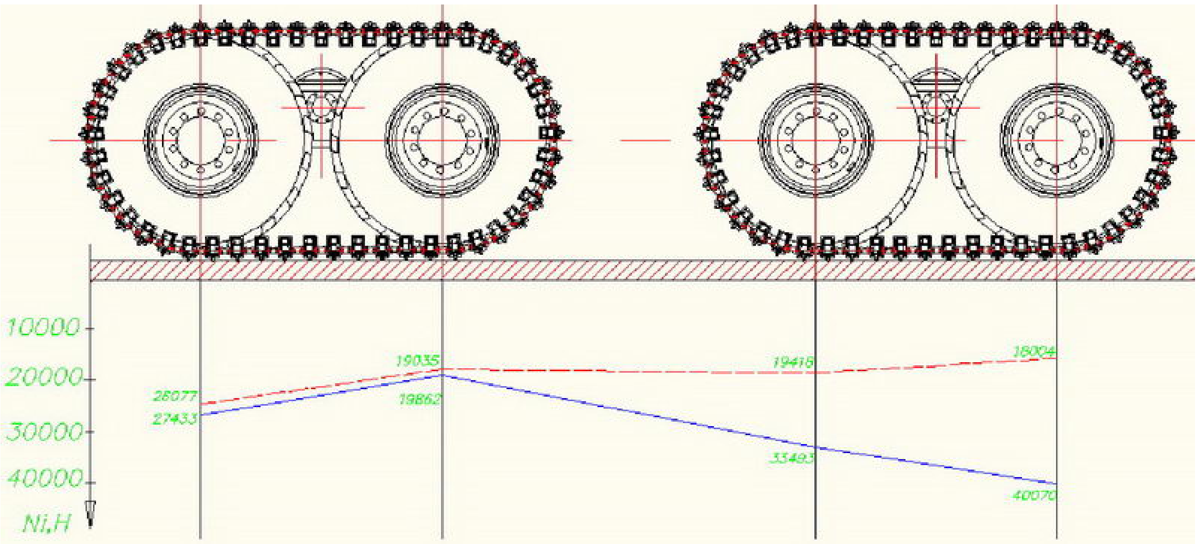


Figure 6: Diagrams loads on the ground from the forwarder, equipped with developed bogie tracks
- Laden forwarder; - An empty forwarder.

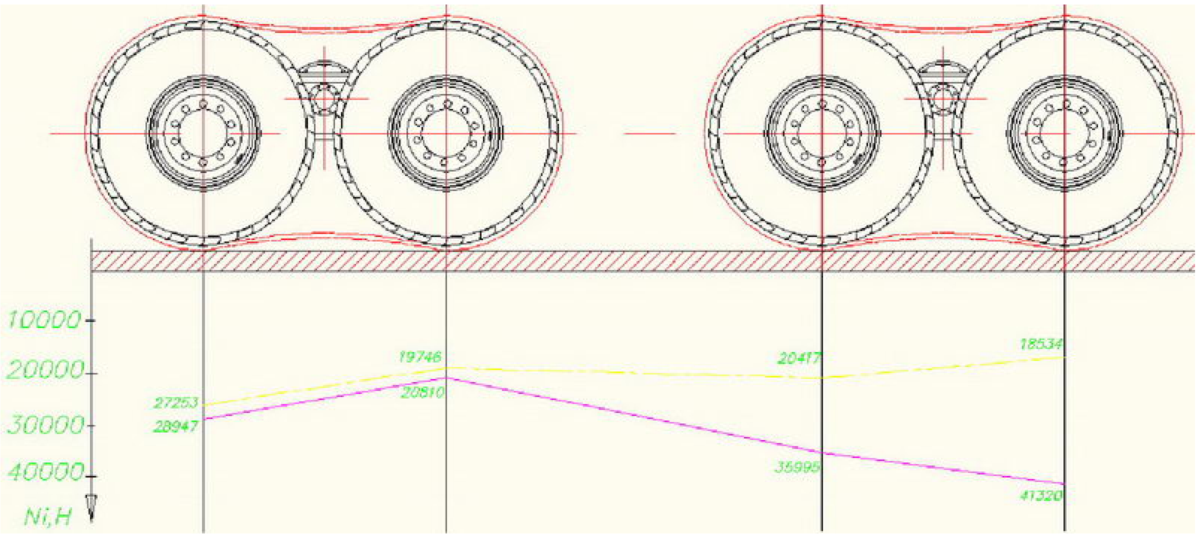


Figure 7: Diagrams loads on the ground from the forwarder, equipped with standard bogie tracks
- Laden forwarder; - An empty forwarder.

4. Conclusion

During operation on very soft soil it is necessary to use metal-rubber mounting along with tracks of special form which protect soil and subsurface cover against damage.

Use of bogie tracks in the structure as joint elements of the metal-rubber mountings makes it possible to reduce ground pressure, travel resistance factor, fuel consumption, improve track service life and their maintainability.

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Health and safety – forestry machine operators status and point of view

Wiesława Ł. Nowacka

Abstract: Mechanized wood harvesting is fast developing in many former planned economies East Europe Countries. Good examples of that process could be seen in Estonia, Czech Republic, Slovakia and Poland too. In Poland strong and lasting mechanization of wood harvesting has started almost two decades ago and rapid growth is noted. Significant influx of cheap, used machinery with low level of technological component brought into Poland is listed too.

The importance of working conditions, their compatibility with people needs and expectations grows, as the population is moving forward. Modern employees need safety and health conditions of work just close to their working environment.

This study is a result of prolong project started more than decade ago, aimed to collect data regarding mechanized forest harvesting operators status and development in Poland. The knowledge is based on diverse data coming from questionnaires, team of specialist meetings, scientific review. Within an extended case-study research collected information is based on interviews with operators and contractors. Twenty seven forestry machine operators were investigated.

Health and safety aspects of work were covered by information on work organization, typical work day, sick-leave, accidents at work data, occupational diseases, ache, pain and discomfort symptoms related to work.

Keywords: ergonomics, occupational safety and health, machine operators, mechanized harvesting

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Introduction

Forestry from thousand years until now is perceived as a source of variety of goods used by people. Today, the role of forests as a supplier of wood unabated since the consumption of wood raw material in its varied forms is steadily growing. In the last two decades of the wood consumption by the average Pole has increased two and a half and is 1 m^3 (Trębski, 2014). The importance of our country in the global wood production is high. Among the twenty-five largest world producers of industrial wood Poland occupies the eleventh position. According to research results, forests is nowadays perceived as very demanding profession with extremely hard work, special requirements regarding strength and physical endurance, with a specific physiological burden. Utilisation of wood in Polish forests is man-machine systems dominated. The situation is changing regularly. Mechanization of Polish forestry is very rapid now. Machine logging operations nowadays account around ten percent of wood utilised in Polish forestry.

As part of the social and economic transformations that have taken place in Poland after 1989. privatisation of forestry services took place in all production activities in the field of forest utilization. A prerequisite for the profitability of a forestry service companies (Zakłady Usług Leśnych) operating in the Polish forestry is a systematic increase in labor productivity, that is made primarily through the implementation of machine systems. In recent years, mechanization of work seems to be also one of the most important factors of stabilizing employment in forestry, since operating specialized machinery is becoming a new, attractive profession. This example of progress and modernity in forestry is also preventing the escape of young people to the cities (Marchlewski 2015).

Progress and social development bring about an expectation on the part of the contemporary worker for appropriate safety level and convenience on the job. Due to it, work conditions in forestry have improved markedly. One of the elements of the production chain are human resources. Foresters together with scientists take over the responsibility for existing, planning and creating new working place in the best contexts. Crucial to the quality and effectiveness of the work are, among others simultaneous organization of the work of the machinery taking into account the needs and expectations of their operators. Modern employees with their growing expectations need ergonomics just close to their working environment. New jobs are conducive to the improvement of working conditions, reduce the hitherto dominant and significant health risks, at the same time introduce such a threat, which until now had no significance.

The main pros of mechanization in forestry are: independence from the influence of weather, relatively low risk of accidents at work, low energy expenditure at work, significant reduction of risks to the operator's ear, high demands on the skills and knowledge to support, high autonomy in decision-making, ability to organize and matching in the working groups (Bostrand 1984, Nowacka, Moskalik 2012).

The main cons are: monotype of the work, forced automation movements, long-term, uninterrupted activity of almost always the same muscle groups, high static load, whole body vibration exposure over long periods of time, prolonged exposure to inappropriate conditions of the microclimate in the cabin (domination of used and not fully equipped machines in Polish forestry enterprises), the complexity of the performed work activities (specific requirements for cognitive and perceptual characteristic of operators), psychological stress combined with the phenomenon of monotony, long working hours or shift work (Jacob et al. 1994, Lidèn 1997, Nowacka 2009).

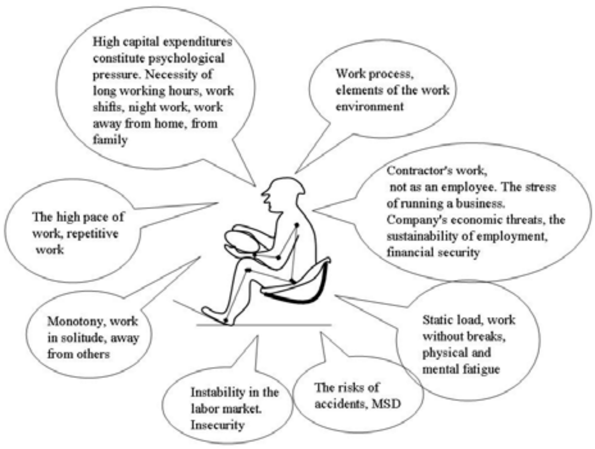

Figure 1: The complexity of harvesting machine operator's situation working in the forest.

Work on modern machines like harvesters of forwarders is a particular challenge because of the existence of both old threats and new emerging threats (Figure 1.).

Existing scientific studies, done also by the author, show clear evidence of the appearance of new health risks, indicate the existence of significant differences in diseases and health problems among chain-saw operators, representing typical working group of the former forestry and machine operators who create a new image of forestry worker (Johnson, Sharit 2001, Nowacka 2011). In a much greater extent, operators are at risk of diseases of the stomach, shoulders, back, neck, shoulders and forearms, overweight problems, psychological problems, allergies, skin diseases, insomnia (Pontén 1983, Gillberg 1995, Vik 2005, Østensvik et al. 2005).

The paper presents selected results of research started in 2002 and carried out by the author as continuous research. For the first time an attempt is made to estimate the health status of the forest logging machine operators in Poland, from the general practitioner (GP) point of view.

2. Material and Methods

This study is a result of prolong project started more than decade ago, aimed to collect data regarding mechanized forest harvesting operators status and development in Poland. The knowledge is based on diverse data coming from questionnaires, team of specialist meetings, scientific review, medical (GP) examination and physiological tests. Within an extended case-study research collected information is based on interviews with operators and contractors.

All subjects were asked to answer the questions enclosed in the Individual Medical Anamnesis Questionnaire (IMAQ). Medical anamnesis was applied towards general condition, current complaints, symptom history, previous sicknesses, medication, heredity, alcohol consumption and smoking habits etc. Subsequently the physical examination was conducted according to the study protocol.

Health status of operators was checked in such aspects as:

- Cardiology (Diseases of the heart and vessels),
- Pulmonology (Diseases of the respiratory tract),
- Gastroenterology and hepatology (Digestive tract and the liver),
- Urology (kidneys and urinary tract),
- Rheumatology (locomotory - back bone and joints diseases)
- Endocrinology (Endocryne glands diseases),
- Hematology (blood diseases),
- Central nervous system (neurology, ears, eyes),
- Dermatology (skin and mucosa diseases),
- Psychiatry (Mental Diseases),
- Family anamnesis,
- Habits.

3. Results with elements of discussion

The subjects of this study were twenty-seven male forest machine operators (FMO) from the different regions of Poland. The subject age ranged between 22 and 58 years. Average age was 39.81 ± 9.44 years. Their mean length of the job experience (in years) was 2.9 for harvesters 3.53 for forwarders and 3.92 for skidders, respectively. About 70% of FMO was working in the private sector. Their job requirement was more than 8 hours, mostly 10-12 hr. per day.

Distribution of age groups is shown on Fig.2.

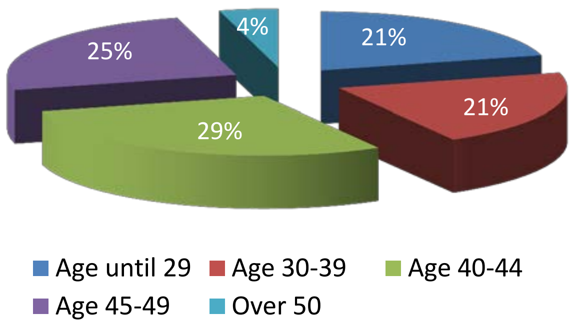

Figure 2: Age distribution in the investigated group.

Body mass Index (BMI) distribution shows that the forest machine operators have been mostly overweight (in nearly 70%) and in that group more than 25% has the obesity. So nearly 70% of the operators have to be the higher healthy risk included. Body Mass Index is a factor giving information on overall health (Fig 3.).

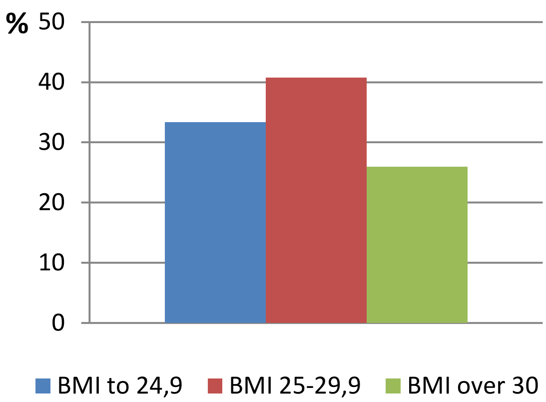

Figure 3: Body Mass Index (normal, overweight, obesity).

Elevated BMI has been considered mainly in the forth decade age groups (as high as 72.22%) (Fig. 4)

Although all of the subjects from the studied group denied prior diagnosis and treatment of a cardiovascular and pulmonary diseases, eight of them has declared subjective reduced exercise tolerance.

If we compared this disorder with the some other complaints one can see that the radio of the number of cases to the number of those with elevated BMI, a chest pain and the heart palpitation is among the most frequent in that group (Fig 5).

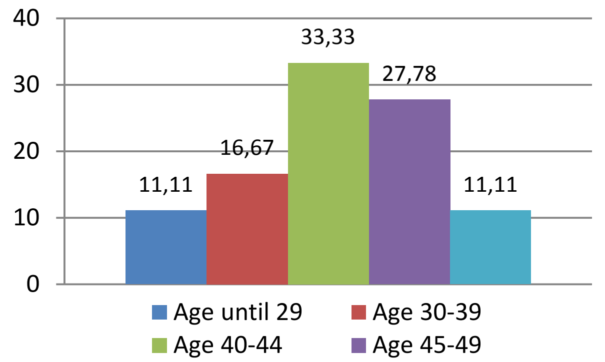

Figure 4: Distribution of BMI higher then 25 in age groups (%).

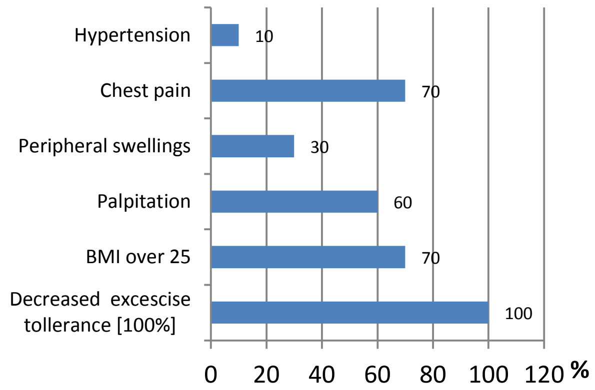

Figure 5: Relationship between decreased exercise tolerance and some other pathological health factors.

Among the studied group – the 10 men had the 12-month lasting muskuloskeletal upper limbs complaint. The pain has been localized in the upper limb (without specific localization) in 44%. Other frequent related location were: wrists (26%) and shoulders (17%). The pain incidence in the upper limbs was not age related (Fig. 6).

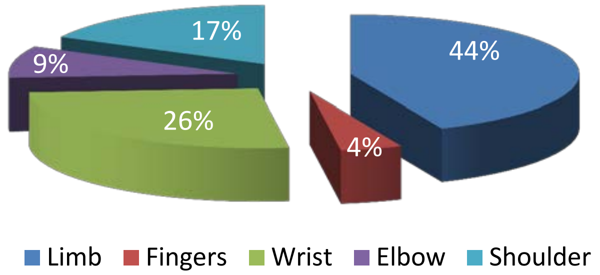

Figure 6: The pain incidence in the upper limbs.

The are significant differences of the reported pain localizations with the prevalence in sacro - lumbar part (67%) and in the neck (30%) parts of spine (Fig. 7).

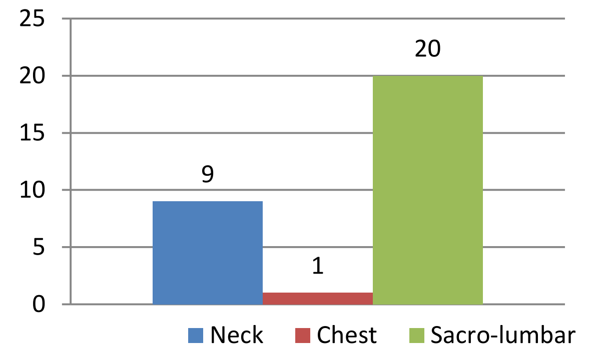

Figure 7: Localizations of the back pain in the different parts (N=27).

Incidence of more serious muskuloskeletal symptoms like muscle tingling, (10/27operators) movement restriction (7/27 operators) and back stiffness are shown in Figure 8.

The subjects from the studying group, affected with these complaints were only occasionally seen by a doctor but no one had been regularly diagnosed or treated because of the serious musculoskeletal troubles.

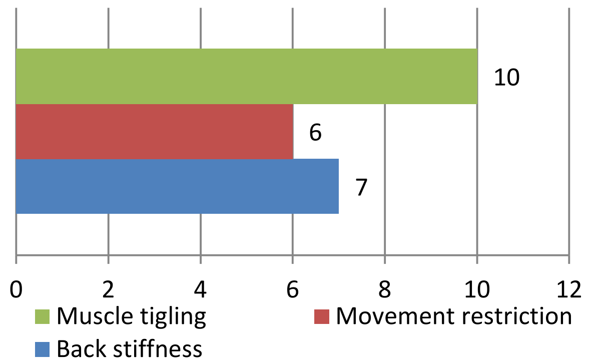

Figure 8: Prevalence of musculoskeletal disorders among the forest machine operators (N=27).

4. Conclusions

Work – related musculoskeletal disorders (WRMSD), repetitive strain injuries rank first among the health problems in the frequency with which they affect the quality of life. It was estimated from the foregoing results and the time study that in more than 90% of the machine operators the daily exposure time (i.e. working hours) exceeded the allowable exposure time of fatigue-decreased proficiency boundary, and in about one-third of the machine operators the allowable exposure time of exposure limit was exceeded.

Continuous static muscle tensions can be broken also by taking frequent breaks and mini-pauses taken during the workday, by shorten daily working time, by changing work tasks or by the job rotation (which decreased the time of exposure to static work).

Forest logging machine operators should be motivated to change their faulty habits (to stop the negligence of hygiene norms) and also educated repeatedly on the long-term hazards of poor life style factors. Wrong long lasting dietary and exercise habits had effects on increasing BMI. It is well known that improvement in dietary habits has been more influential than that in exercise habits on the reduction in BMI. Healthy dietary habits should be more effective in alleviating the overweight condition than physical exercise.

The people who are obese should than get corrective diet program with a view to reduce total calories amount to 1000–1500 per day and especially guided to avoid the simple sugars and animal derivative fat, “fast-food” as well as caffeine and alcohol excess.

During intensive work insufficient replacement of the excreted water and salts causes dehydratation and adversely affects the person’s physiological condition. The supply of sufficient fluid at work is recommended.

In summary, undertaking not frequent but regular exercises and relaxation methods , modification of diet are responsible for the symptom free working and better work performance and lead to the better quality of life. It seems however difficult for most individuals to change their life style. Workers believe that most occupational hygiene, health and safety training recommendations are difficult to implement and negatively impact productivity.

There is a need to monitor the health situation of forest machine operators continously.

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Mechanization in forestry from local communities point of view

Wiesława Ł. Nowacka*, Paweł Staniszewski

Abstract: Currently, we observe the strong trend of forest mechanization implementation in Poland. Social and economic changes that have taken place in Poland after 1989 have also affected forestry. Almost 100% of production activities concerning forest utilization is in private hands now. The constant increase of productivity as the main condition of profitability is driven by mechanized forest activities.

The fast growing mechanization of forestry in Poland is perceived by rural communities with a great interest. It is one of the leading forces of local growth. Analysis of the acceptance of mechanization in forestry by local communities was the purpose of the present study.

An interview has been applied as a research method, using standardized questionnaire as a research tool. The content of the final questionnaire was revised based on the pilot studies results.

Completed one hundred sixty two questionnaires enabled authors to present some detailed information touching upon acceptance of mechanization in forestry by citizens of nearby forests.

Keywords: forestry mechanization, rural communities, forest goods

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1 Introduction

Polish forestry is now implementing the principles of sustainable management in all parts of its activity (Rykowski 2001, Paschalis-Jakubowicz 2010). The contemporary concept of sustainable and balanced development of forests (SFM-Sustainable Forest Management) is based on the management and use of forests and forest areas in a manner and at a rate ensuring also the preservation of their social potential in a long run. The relevance of social aspects, including labour was highlighted in the declarations and resolutions adopted at the Ministerial Conferences on the Protection of Forests in Europe (MCPFE), convened in Helsinki in 1993, in Lisbon in 1998 (Resolution L1-People, Forests and Forestry-Enhancement of the Socio-Economic Aspects of Sustainable Forest Management) and strengthened in resolutions V2, V3 in Fourth Ministerial Conference - Vienna 2003. The implementation of the principles of this concept entails formulation and fulfillment of the following requirements and activities:

1. guarantee that socialization of the decision-making process in forestry will proceed,
2. promote the development of education and training programmes, especially directed to forest owners and managers, focusing on new opportunities and techniques for the production of goods and services from forests under sustainable management,
3. developing to their full value the potential contribution from the forest sector to rural development, direct and indirect employment,
4. developing the potential to generate new job and income opportunities mainly in rural areas in such diverse business as non-traditional small scale industry (e.g. SMEs), especially through diversification of activities related to forestry,
5. human resources development policies should stimulate the adaptation to changing job opportunities related to forests, broaden the competence of forest owners and managers and forestry workforce in forest management, and to strive to offer equal opportunities in employment, income, training and careers,
6. adapt education and training systems and programmes contributing to the development of a highly skilled, multidisciplinary workforce,
7. promote the improvement and application of appropriate safety and health standards and practices, professionalism of forest owners, forest workers, and contractors, and skills certification.

Primary function of forests was to guarantee production of wood as an important source for other people activities. According to research results, forests are nowadays treated by the urban population primarily as a place for recreation and tourism. Residents of small rural communities living nearby the forest do have different point of view. A forest creates an important financial support for them, particularly due to the availability of plentitude of goods, such as forest fruits, edible mushrooms, medical herbs, decorative plants etc. Moreover, forest creates the ability to run private business (i.e. forest enterprises, agritourism activity), providing full-time employment or part time job (Nowacka, Woźnicka, Staniszewski 2014, Staniszewski, Nowacka 2015). Social and economic changes that have taken place in Poland after 1989 have also affected forestry (Moskalik et al. 2006). Almost 100% of production activities concerning forest utilization is in private hands now. The constant increase of productivity as the main condition of profitability is driven by mechanized forest activities.

The main pros of mechanization in forestry are: independence from the influence of weather, relatively low risk of accidents at work, low energy expenditure at work, significant reduction of risks to the operator's ear, high demands on the skills and knowledge to support, high autonomy in decision-making, ability to organize and matching in the working groups (Nowacka, Moskalik 2012).

The main cons are: monotype of the work, forced automation movements, long-term, uninterrupted activity of almost always the same muscle groups, high static load, whole body vibration exposure over long periods of time, prolonged exposure to inappropriate conditions of the microclimate in the cabin (domination of used and not fully equipped machines in Polish forestry enterprises), the complexity of the performed work activities (specific requirements for cognitive and perceptual characteristic of operators), psychological stress combined with the phenomenon of monotony, long working hours or shift work.

The mechanization of forest work within Poland, begun during the late eighties of the last century, and now is becoming a reality. The mechanization of forest work in Poland is very rapid nowadays (Fig. 1)

The fast growing mechanization of forestry in Poland is perceived by rural communities with a great interest. It is one of the leading forces of local growth. Analysis of the acceptance of mechanization in forestry by local communities is interesting from the scientific point of view, as the citizens of little hamlets, small towns are the main workforce for growing private firms, SMEs.

2. Aim and methods

Analysis of the acceptance of mechanization in forestry by local communities was the purpose of the present study.

Structured questionnaire interview was chosen for investigation method, and standardized questionnaire was a tool (Appendix1). The questionnaire was containing closed questions (as a rule there were questions with cafeteria alternative answers, and partly with dichotomy answers) and half-open. Closed questions belonged to questions with multiple choice, one of them was question with five-step scale (Oppenheim 2004). Planning investigations one decided also about kind of information, which were to obtain. In this manner outline of a questionnaire came into being.

The verification stage for questionnaire inspection was planned. Testing was done with a help of twenty two volunteers participated in separate ergonomic investigations done by authors. The content of the final questionnaire was revised based on the pilot studies results.

Questionnaire contained 11 questions and explanation sentences regarding aim of investigations, instruction for respondents.

Questionnaires were distributed by forestry students among citizens of little hamlets and inhabitants of nearby forest small towns. Filled questionnaires flowed by mail or email. Thanks the way of dissemination the turning rate was very high, more than 95%. Not more than 0, 2% of questionnaires were not fully answered.

Next step of the research was coding the data in accordance with prepared Excel sheet -„coding template”. Coding was made just before calculations. As data are not large enough yet to use more sophisticated methods of statistical analysis, Excel software was used. For future needs and full statistical inference, special SPSS sheets are prepared.

This paper discusses the preliminary results of the studies carried out in the beginning of 2016. Moreover, it outlines a plan for further research activities planned for the period of 2016-2018.

3. Results and discussion

Completed one hundred sixty two questionnaires enabled authors to present some detailed information touching upon acceptance of mechanization in forestry by citizens of nearby forests.

Near 60% of respondents are living in little villages and towns with not more than 5000 inhabitants. More than 65% of respondents are employed. Only 11,7% of them are unemployed. The average age of questionnaire participants was 24 yr. (range 15-77yr.). Almost half of the investigated people were women (female - 49%, male - 51%). Education profile of respondents is shown in table 1.

Table 1: Education profile of respondents (in percent)

Primary school	Secondary school (forestry)	Secondary school (non forestry)	University level education
6,1	13,0	38,9	42,0

Forest is a source of family growth and improvement for 75% respondents. Mostly picking mushrooms and berries in a forest (respectively 57-45%) increases the family income. Forest is a place of employment for 47% families (one or more person employed in forestry).

87% of respondents have seen logging activities in the forest (77% - chain-saw operations; 62% - working tractors, machines with a crane, machines with trailers; 25% - harvesters). In the opinion of respondents (40% of them) logging activities, working machines are the main perpetrator for the forest, trees, shrubs and undergrowth.

The respondents were asked a question: *Do you find machine operations in forests an issue? Do they bother you?* The results are shown in table 2.

Table 2: Opinion of respondents regarding machines in the forest (in percent)

Problem	Opinion (%)
Machines in the forest bother me	31,5
In it:	
excessive noise produced by forestry machines	78,4
exhaust fumes	60,6
machines pollute the environment (waste packaging, oils, machine parts, other debris)	53,0
machines are artificial and unnecessary element of environment	39,0
logging operations are poorly planned and constitute an obstacle to forest visitors	21,6
using specialized forest machines reduces employment possibilities for chain-saw operators	13,7

Almost 54% of investigated persons declare that in their opinion using machines during logging in forestry is necessary. Only 2,5 % of respondents stated that machines are completely unwanted.

Obtained data confirm the assumption that there is agreement for cutting trees in the forest. Only less than 10% of respondents declare disagreement for cutting down trees in the forest.

4. Conclusions

Obtained initial results of investigations confirm need of continuation. The obtained results indicate the importance of widening a good practices in the forest mechanization. For more than 30% of respondents, machines are the unneeded element of the forest scenery.

Despite the quantity of filled in questionnaires, the results show that there is a considerable sense of disagreement with the presence of machines in the forest. There is present a general consciousness regarding the necessity of cutting trees. In the opinion of respondents, machines pose a problem with their presence in the forest as they are producing excessive noise, pollute the environment.

Although the results are based on 162 questionnaires, the study indicates that a considerable improvement of the situation is needed.

5. Ackowledgements

The authors would like to thank all forestry workers supporting investigations, colleagues and students helping with obtaining questionnaires. Without their enthusiasm this paper would not have been possible.

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Appendix 1.

ML-locally

MECHANIZATION IN FORESTRY – THE LOCAL COMMUNITIES POINT OF VIEW

All responses, opinions will be treated as confidential. Please mark with a cross your reply in the chosen place. Delete unnecessary alternatives. Add your comments in the place named „Other”. The personal ID will be filled in by the pollster. Thank you very much for your participation.

Personal ID .... date..........................

1. I live in a village/town with: ☐ less than 100inhabitants ☐ less than 5 thousands inhabitants ☐ less than 100 thousands inhabitants ☐ more than 100 thousands inhabitants

2. Age: ☐☐yr.

3. Gender: Female☐ Male☐

4. Education: ☐primary ☐secondary (forestry) ☐secondary (other than forestry)
☐ higher education. If so, what?……………………………………………..

5. Employed ☐ officially unemployed☐ undertake some activities from time to time☐

6. The forest is a source of improved living conditions, improve the family budget, enriches nourishment in your family,
☐no ☐yes
If so, what? I have the knowledge about mushrooms and I collect them ☐
I have the knowledge about forest plants and berries and I collect them ☐
I am employed in forestry ☐
Family members are employed in forestry ☐
I am a forestry entrepreneur ☐
Running agritourism farm ☐
Working as machine operator ☐
Casual work in forestry (e.g. for ZUL-Forest Service Company) ☐

Other……..

7. Did you meet signs of destruction of forest undergrowth, or trees, or shrubs in the vicinity of your activity in the forest?

☐ no ☐ yes

If so, who in your opinion, is the perpetrator of those acts?
☐ mushroom, forest plant/fruit pickers
☐ chain-saw operators activities
☐ logging machines (tractors, harvesters, forwarders etc.)

Other……

8. Did you see logging activity during your visits to the forest?

☐ no ☐ yes

If so, what ?
☐chain-saw operators activity
☐machine operators activity
☐tractors/other machines with trailers
☐tractors with crane
☐specialized machines (forwarders, skidders, etc.)
☐harvesters

Other……………………………………………………………………………….…………………………..

9. Using machines during logging in forestry is:

Necessary ☐ ☐ ☐ ☐ ☐ completely unnecessary

10. Do you find machine operations in forests an issue? Do they bother you?

☐ no ☐ yes

If so, what ?
☐excessive noise produced by forestry machines
☐exhaust fumes
☐machines pollute the environment (waste packaging, oils, machine parts, other debris)
☐machines are artificial and unnecessary element of environment
☐logging operations are poorly planned and constitute an obstacle to forest visitors
☐using specialized forest machines reduces employment possibilities for chain-saw operators

Other ………..

11. I am against utilization/cutting trees in the forest

☐ no ☐ yes

Thank you very much for your cooperation
dr hab. Wiesława Ł. Nowacka
dr hab. Paweł Staniszewski

Legal and economic aspects of private forestry enterprises activities

Jarosław Oktaba, Jarosław Sadowski*, Tadeusz Moskalik, Dariusz Zastocki

Abstract: After the year 1989, social and political changes in Poland gave birth to economic programmes leading to privatisation and restructuring of state-owned enterprises. In forest management, a crucial role had the enacting of Forest Regulation in 1991. The regulation focused on continual sustainable forest management, based on general forest protection. Forest management has specific conditionals, therefore State Forests chose their own path for economic and structural changes. Transition into service-type forest work execution was a very diversified process. The elementary indicator of development of the forest inspectorate economic activity privatisation process was work privatisation degree, presenting percentage participation of foreign entities in execution of the assignments. In years 1992−1996, participation of outside contractors reached 70% . The highest increase of contractor participation was observed in logging. At a later time, work with the highest level of privatisation were cutting and sortiment production (almost 100%). Today, the majority of economic undertakings for State Forests are performed by private forestry enterprises.

Keywords: State Forests in Poland, forest economy, private forestry enterprises

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1. Introduction

The activities of the State Forest Enterprise "State Forests" (PGL LP) are regulated by the Act of 28 September 1991 on forests. Forests being in possession of the Treasury are managed by State Forests. State Forests consist of the following organizational units:

1) General Directorate of State Forests,
2) District Directorate of State Forests,
3) Forest districts,
4) other organizational units.

Forest district managers run unaided forest management in a forest district, based on a forest development plan and are responsible for the condition of forests. The managers manage forest districts as elementary organisational units of State Forests, and represent the Treasury in civil and legal relations, within the scope of their activities. An important provision of the act on forests refers to the activities based on financial independency and covering of expenses from own income. The forest district's organisational framework precisely defines the statute of the State Forests (Lasy Państwowe) (Regulation No. 50 of Minister of the Environment, Natural Resources and Forestry, of 18 May 1994). Each year, forest district managers prepare economic and financial plans and are responsible for their execution. Basic plans include forest utilization, forest cultivation, protection and fire protection of forests, side utilisation of forests, and forest development plans.

2. Legal and economic conditionings of the activities of forestry firms

After 1989, social and political changes in Poland initiated economic programmes aiming to the restructuring and privatisation of state enterprises. As soon as in 1990, the State Forests began to improve economic situation of its organisational units. In forest management, crucial was the aforementioned Act on forests in 1991. This Act put on the permanently sustainable forest management based on widespread forest protection. Forest management has specific conditionings, therefore State Forests have chosen their own way of structural and economic changes. Switching to service-based forest work execution proceeded in a very diverse way. This led to increased economic efficiency, and at the same time, forest management remained within the competence of the Treasury. In 1991, Supreme Management of State Forests issued „*Primary guidelines – forest work privatisation*" which put into order privatization transformation processes, and were based on the experiences of forest districts of Dobrocin and Olsztynek (Trybuna Leśnika 1990). However, only the subsequent guidelines, prepared by General Directorate in 1995, regulated the principles of privatization of economic activities. According to the agreed assumptions, external economic entities were entrusted the execution of work within basic and side activities on the basis of service contracting. The general assumptions specified the purpose of privatization and guidelines concerning the selling off and availability of tangible assets to service contractors, as well as setting minimum rates for the services. Their subsequent sections regulated the procedure of contractor selection, taking into consideration the comparison of costs of ordered work with the costs of executing of work within one's own scope of activities. Firms were selected on a tender basis or through negotiations. The guidelines also regulated transfer of tangible assets from the organizational units of State Forests to external contractors, as well as legal and organizational forms of their availability. The guidelines recommended yearly negotiations of minimum rates. They preferred economic entities that employed former forest district personnel, and envisaged the possibility of resignation from the tender-based selection of contractors in their case. An integral part of the guidelines were the enclosed document templates being of substantial help to forest districts and private firms. Another internal regulation, specifying the role and responsibilities of State Forests in the development of forest service enterprises was Regulation No.36 of Director General of State Forests of 16 May 2002. Directives implemented by this regulation defined the tasks, role and participation of State Forests in the development of service firms. One of more important consequences that this regulation brought to improve cooperation with forest enterprises was the establishment of permanent advisory committees at the level of district directorates of State Forests, whose responsibility was to resolve problems concerning the functioning of the forest services market at a local level, and in particular organisational units of State Forests. The activities of State Forests and forestry firm representatives have also been focused on the implementation of a permanent educational system and the improvement of qualifications of owners and employees of forestry firms. The result of such cooperation was the creation of Training Centre for Entrepreneurs in the Trial Plant in Siemianice.

Poland's accession to the European Union in May 2004 created a situation where State Forests were forced to stop providing public assistance to forest service plants. The provisions of regulation No. 36 of Director General of State Forests of 16 May 2002 have been abolished. They have been adjusted to the mandatory conditionings by means of the regulation No. 79/36A of Director General of State Forests of 14 December 2004. The regulation primarily considered EU normalisation referring to the activities creating the forest services market, as well as ordering of services as well as Polish legislature, the Act *Public Procurement Law* [Journal of Laws 2004 No. 19, item 177 with further amendments] in particular.

The advisory team for State Forests cooperation with forest entrepreneurs, created for the purpose of development of forest services, appointed by the No. 20 of Director General of State Forests of 10 March 2008, initiated the issuance of the next regulation by Director General of State Forests No. 36 of 11 August 2011, concerning cooperation of organizational units of State Forests with the forest services sector. This regulation was to normalise the most important current problems appearing during cooperation of State Forests with service providers that may include: utilization and, apart from the price, other criteria of offer evaluation (allowed by public procurement laws), broader implementation of long-term contracts, implementation of forest work-time standard catalogues for making order cost estimates, and preparation of specifications of crucial order conditions (SIWZ) for forest services, and for forest service payments, the aforementioned catalogues or other already proven solutions.

Table: 1. The number of private forestry firms and volume of employment.

Year	Nuber of firms	Nuber of 1-person firms	Number of firms employing permanent staff				
			2-5	6-11	11-20	21-50	>50
1993	377	38	134	64	51	39	6
1996	815	151	336	141	127	53	7
1999	3261	1902	575	176	97	30	2
2003	7539	3287	3004	796	330	120	2
2006	4728	1233	2133	866	415	67	14
2010	4231	1016	1812	845	435	115	8

The basic indicator of development of forest district activity privatisation was the level of work privatisation, presenting percentage share of external entities in task accomplishment. In 1992-1996 the share of external contractors reached the level of about 70%. The highest increase was observed in the participation of timber logging. Later, work with the highest degree of privatization was felling and product assortments (almost 100%). Currently, the majority of activities are performed for State Forests by private forestry firms (Kocel 2013).

A characteristic feature distinguishing the initial period of the process of setting up new private forestry firms in the first years of Polish transformation was assistance offered in various forms to newly created entrepreneurs by State forests. It allowed forest companies to survive the hardest initial years of operation. Practice showed that in a market economy after the first year of economic activity only about 50-60% of companies continued their activities, and after five years only about 30%. A mature company is considered a company that survived on the market for more than 5 years (Entrepreneurship in Poland 2010, 211).

A specific feature of most private enterprises of forest services is to limit their scope of activities to a single recipient - State Forests. The result is that the financial condition of the enterprise and the condition of State Forests are closely related. Worsening situation in the wood market causes worsening of financial situation of State Forests, and this results in critical financial condition of forestry firms.

The number of companies operating in the forestry sector may prove its level of development and the degree of competitiveness (Gudkova, 2008). Basic criteria for separation of the size of enterprises include the number of persons employed, as well as the size of financial turnover and balance sheet total (Łuczka 1995).

The dynamics of development of the forest sector in Poland may be traced on the basis of the number and structure of employment in companies providing services to State Forests. Data presented in table 1 are partially the results of monitoring of forest services sector, carried out by the Forestry Research Institute, and partly are data of the General Directorate of State Forests (Koceľ 2013).

At the initial stage of development of the forest sector, the number of forestry firms was affected by both the changes that occurred in forestry under the influence of structural transformations across the Polish economy (Kłosiński 1996), as well as regulations introduced in State Forests itself, mainly the guidelines from years 1991 and 1995. It should be noted that among entities providing services to State Forests, dominated small businesses employing from 2 to 5 workers. There were only few forest service enterprises employing more than 50 permanent employees. There are many reasons affecting the reluctance of entrepreneurs to increase employment.

The problem is the need to act in a large area, the distribution of forest complexes and places of residence of workers, which increases organizational costs (Kocel 2013). The choice of a legal and organizational form is most important when creating a new enterprise, but it may also occur at other stages of its development. This decision often determines the way of development of the company, because further on the changes usually are lengthy, difficult and costly.

The basic organizational and legal form was to run business activities by privately owned forestry firms (individual enterprises). The dominance of this legal form is shown by the results of studies on monitoring of the services sector presented in Table 2 (Kocel 2013). It's share amounted to 73.5% on average in the total number of firms that provided answers,

Table: 2. Organisational and legal form of private forestry firms

Year	Number of multiplayer private firms that provided answers,	One-person enterprises	Civil partnerships	General partnerships	Limited partnerships	Limited liability companies	Joint-stock companies	Cooperatives
1993	377	325	37	2		13		
1996	815	662	138		1	14		
1998	1344	906	365	2		7		
1999	1344	933	393	1		8		
2003	1573	1178	377	9		8	1	
2006	1009	808	185	8		5		1

The legal form preferred by entrepreneurs, based on the individual ownership, prejudged by the advantages of this solution, such as easy start-up and wind-up of an enterprise (avoiding troublesome and often costly negotiations with partners and related legal advice), and small founding capital, considerable freedom in the management of the company (limited only by law), and less need for the use of expert advice, as well as simplified accounting rules.

For a forest district, usually appearing in the position of a creditor, the forms of an individual enterprise or civil partnership were more advantageous because their owners were responsible for their companies with their personal property (Markowski 2011). Commercial Code introduced in 2001, partially limited the participation of commercial companies in the structure of organizational and legal forms of forestry firms. This was because the minimum amount of share capital of limited liability companies was raised. A limited liability company requires bookkeeping, which is equivalent to the employment of an accountant or a bookkeeping company. Moreover, before 2004, in connection with the planned Poland's accession to the European Union, entrepreneurs began to fear the provisions of Commercial Code concerning the principle of free access of external limited liability companies to operate in the territory of our country.

The way of choosing contractors in the organizational units of State Forests was influenced by the changing economic law during the period of Polan'd transformation. Decisive was the implementation of the provisions of the Act on Public Procurement Law. Before its entry into force, forest districts more often used the possibility to conclude long-term contracts. It should be noted however that long-term contracts are more profitable for the parties. They are one of the stabilizing factors and allow to adopt a specific development strategy, to accumulate financial resources for further development, and make it easier to apply for bank loans. The procedure and criteria for choosing contractors performing services in the field of forest management, often brings controversies among entrepreneurs forced to participate in tenders. It is certain however that this does not cause destabilization of the forestry market, and the competition forces better quality of offered services.

In a market economy many small and medium-sized firms close down rather quickly, which is the result of the presence of a number of barriers and risks impeding their functioning and development. In the case of forestry firms, in addition to general problems they face in their economic activities, comes the "monopolistic" position of State Forests. Surveys (Koceľ 2013) indicated that the rates for the services offered by forest districts are the most often mentioned barrier limiting the development of private enterprises. Another difficulty in the activities of these firms is the necessity to participate in tenders. Many entrepreneurs mention short-term contracts as a significant barrier to the development of their firms. Another reason to limit the development of forestry firms may be managerial skills of their owners as well as their education, which may entail a limited ability to conduct business and lower organizational skills.

Difficult to verify is also the level of knowledge in terms of organization, management, decision-making theory and economics. The lack of market recognition and over-optimistic approach as to its absorbency can also reflect negatively on the functioning of the firm.

Apart from structural changes, a measurable result of privatisation of economic activities of forest districts was the reduction of employment in State Forests. Structural changes in forest districts primarily entailed closing of redundant organizational units (e.g. farming transport, workshops, warehouses, fuel stations). In the years 1989-2011, employment in State Forests decreased by some 78% (91 726 people), including workers on permanent employment contracts by approximately 96% (Kocel 2013). Services provided by external contractors contributed to improved efficiency of forest management. It appeared that the services ordered by forest districts were cheaper than those performed with the participation of their own workers, with the same completion quality.

3. Summary

Privatisation of economic activities of forest districts brought a number of benefits to State Forests. Fixed costs have been replaced by variable ones, depending on the needs. Purchasing services in the market causes elimination of fixed costs, associated with maintaining their own contractors. In addition to that, the lack of them reduces the risk of economic and economics-related unfavourable periodic phenomena, for example, wood market weakness. A certain drawback of the privatization processes is the necessity to organise tenders. This causes overloading of forest district staff. The analysis and verification of tenderer applications, and checking the reliability of business partners, may affect punctuality and quality of work.

Verification of private forestry firms should include the cost of services. The value of a service however should not be the only and the most important factor taken into consideration in the competition assessment, but also the aspects of nature should be taken into account. The increased implementation of long-term contracts will allow owners of forestry firms to purchase specialist equipment and raise qualifications of their employees. Creating of clear criteria concerning tenders, entered by entrepreneurs, where the owners would provide information about human resources and equipment at their disposal, will strengthen cooperation with forest districts and create favourable conditions for further development of the forest service sector.

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EU Forest Strategy – implications for forest utilisation at operational level in Poland

Jarosław Oktaba*, Piotr Paschalis-Jakubowicz, Dariusz Zastocki, Jarosław Sadowski, Grzegorz Jednoralski

Abstract: The paper presents an analysis of certain aspects of forest policy of the European Union directly addressed to the utilisation of forests. It assessed the potential impact of suggested by EU policies activities to practices the utilisation of forest at the operational level and the needs for additional actions.
We analysed two key regulations directly addressed to forestry: A new EU Forest Strategy: for forests and the forest-based sector and Innovating for Sustainable Growth: a bioeconomy for Europe.
The work includes activities associated with the operating level of Polish forestry in response to political demands and indicates areas that are not implemented and the reasons for this state of affairs..

Keywords: EU Forest strategy, Bioeconomy, utilization of forest, Polish forestry

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1. Introduction

The European Union has no competence to elaborate a common forestry policy, but some of the Union's policies may have implications for national forestry policies such policies eg.: Climatic policy, Nature and biodiversity protection policy, Research and development, innovation and competitiveness, Common policy agriculture and Development of the agricultural area and many others.

Due to the fact that forest management covers approx. 35% of the European Union surface, an important element in the functioning of the whole community is to identify importantly or priority actions in this area. Because of legal requirements, this can be done only by adopting a common position of the EU countries which determines the main activities and priority areas. Such an agreement is called a sphere of soft law. The adopted position does not have legal force, however, it makes support for the administration of the member states in the creation of national forest programs. The area of forest management is regulated directly by the two regulations first is a new EU Forest Strategy: for forests and the forest-based sector (New Forest Strategy) and the second ones are Innovating for Sustainable Growth: a Bioeconomy for Europe (Bioeconomy Strategy).

New Forest Strategy adopted in 2013 is the second after the adopted at 1998 Forestry strategy and 2007-2011 Forest action plan [2].

Bioeconomy strategy adopted by the Commission in 2012 is addressed to the primary production areas. The primary production in the context of this communication includes agriculture, forestry, fisheries and aquaculture.

2. A new EU Forest Strategy: for forests and the forest-based sector [1]

The New Forest Policy was elaborated taking into account the substantial achievements of Forest Europe process including the acceptance of a definition of sustainable forestry.

The guiding principles of New Forest Strategy are:

- Sustainable forest management and the multifunctional role of forests, delivering multiple goods and services in a balanced way and ensuring forest protection;
- Resource efficiency, optimising the contribution of forests and the forest sector to rural development, growth and job creation.
- Global forest responsibility, promoting sustainable production and consumption of forest products.

An important element of the new approach is to bring together the forestry and Forest-based industry (FbI). The definition of FbI covers not only primary processing but whole chain covered primary production – recycling – and waste utilisation. Such chain is called cascade principle. The cascade use of wood under those principles means that wood is used in the following order of priorities: wood-based products, extending their service life, re-use, recycling, bio-energy and disposal.

The New Forests Policy defines eight linked priority areas which are value for everyone:

- Supporting our rural and urban communities
- Fostering the competitiveness and sustainability of the EU's Forest-based Industries, bio-energy and the wider green economy
- Forests in a changing climate
- Protecting forests and enhancing ecosystem services
- What forests do we have and how are they changing?
- New and innovative forestry and added-value products
- Working together to coherently manage and better understand our forests
- Forests from a global perspective

Among of those areas the first three significantly affect forest utilisation at an operational level.

The challenges posed to the utilisation of forests by the area connected to supporting rural and carbon communities that are:

- continuously improve the level of technical culture of all forestry employee,
- the development of scientific but practical (simple) methods of multifaceted technology assessment sourcing of raw materials,
- the implementation of mechanisms for continuous modernization and improving the quality of work performed by contractors,
- revision of the methods for determining the size of the harvested different forest resources,

- looking for new forest products – not only the wood.

The introduction strategy at competitiveness and bio-economy areas in addition to providing demand for forest raw materials shows that:

- forest biomass will continue to be an important element of both CO2 storage and used for energy purposes,
- machines and technology of harvesting will have to be included in the full account of the environmental costs of the operation of forestry,
- Live Cycle Assessment (LCA) will be one of the most important elements of the system of forest technology assessment.

3. Innovating for Sustainable Growth: A Bioeconomy for Europe [3]

The Bioeconomy strategy is the second most important for utilisation of forest practices.

The European commission believes that establishing an economy in Europe holds a great potential among others: it can maintain and create economic growth and jobs in rural, coastal and industrial areas, reduce fossil fuel dependence and improve the economic and environmental sustainability of primary production and processing industries.

The Bioeconomy Strategy and its Action Plan aim to pave the way to a more innovative, resource efficient and competitive society that reconciles food security with the sustainable use of renewable resources for industrial purposes while ensuring environmental protection.

From the point of view of forest utilisation the key actions of that strategy are action 2 and 9:

- action 2. Increase the share of multidisciplinary and cross-sectoral research and innovation in order to address the complexity and inter-connectedness of societal challenges by improving the existing knowledge-base and developing new technologies. Provide scientific advice for informed policy decisions on benefits and trade-offs of economy solutions,
- action 9. Provide the knowledge-base for sustainable intensification of primary production. Improve the understanding of current, potential and future availability and demand of biomass (including agricultural and forestry residues and waste) across sectors, taking into account added value, sustainability, soil fertility and climate mitigation potential. Make these findings available for the development and review of relevant policies. Support the future development of an agreed methodology for the calculation of environmental footprints, e.g. using life cycle assessments (LCAs).

However, within the other action, we can also find some activities affect forest utilisation technology such as the introduction of biolabeling, building up a network of demonstratives factories including the necessary logistics and supply chains for a cascading use of biomass and waste streams or the green procurement supporting policy.

4. Conclusions

Forest Policy of the European Union points to the need for greater recognition of the paradigm of sustainable development in the functioning of the forestry and timber sector.

The greater recognition mean the necessity of starting the evaluation currently used technology, technics and machines from workers point of view, local societies, environmental footprint and off course economical but the real challenge is how to find a balance among them.

The second is, encouraged to work on a comprehensive assessment of machinery and technologies used in forestry from the point of view of employment and the impact on the natural and social environment at both Forestry and Forest-based Industry. We know some tools for it but we are not ready to use those tool because of lack of knowledge about some elements. Never mind in the future we should be ready to the implementation of LCA for applied technology and we should be focused on developing the scientific base for the selection of BAT (Best Available Technology) for contracting the services within the cascade wood use.

5. Case Poland effects we reach and challenges we see

- As an answer for the greater recognition of the paradigm of sustainable development, we have started to certify our forest under sustainable forestry management criteria. The majority of Polish forests (all managed by State Forests - National Forest Holding) are certified by both leading worldwide certifying systems: the programs FSC and PEFC [4,5]. The content of the strategic EU documents shows that the better solution is a certification under the PEFC system which is directly connected with the process of Forest Europe referenced by the forestry strategy and we still need separate certificates for the forest contractors.
- We have put into effect new method of contracting services [6]. Tenders awarded by State Forests shall contain provisions on the technology of work, equipment used, employee qualifications and employment at the contractor. Protocols transferring surfaces for harvesting contain descriptions of the protected elements of nature occurring on the surface of the work. Any damage -if occurs- constitute the basis for calculating fines.
- We have started works on the inclusion of forestry into carbon emissions trading [7].

Beside undertaken and carried out the commitments we still have challenges ahead.

- We still have no scientific method for choosing the Best Available Technology.
- We have no the LCA analysis for different harvesting technology.
- We have poor base for describing multifunctional utilisation of forest and balance between functions - within the area of quantification effects.
- We are still financial depending only on wood.
- We have not sustainable procurement policy.
- We have no idea how to manage cascade model of using wood.

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Economic and Life Cycle Assessment of integrated wood and chips harvesting from hybrid poplar plantations in the Genil Valley (Spain). Comparison with chips harvesting from Poplar SRCs

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Abstract: Integrated harvesting of a hybrid poplar (Populus x. canadensis) plantation for extracting timber for a local sawmill and woodchips for energy is analyzed under the economic and environmental point of view. To perform the environmental impact assessment the methodology of LCA has been selected, using as main tool the software SimaPro 8.0, following the method ReCiPe 2008, having into account the capital goods, such as the machinery fabrication processes. The harvesting operations and fertilization were the most impacting processes, while gravity irrigation does not have such environmental relevance. The most important normalized impacts were marine ecotoxicity, freshwater ecotoxicity, freshwater eutrophication, human toxicity and metal depletion. The ultimate reasons of these impacts are discussed, besides some ways of reducing them. The economic analysis was performed using actual costs and indicators such as the Net Present Value NPV and the Internal Rate of Return IRR. The 10% IRR is overpassed when the wood price is greater than 79,0 € per green tonne, assuming a 45 €/green tonne price for the chips delivered to a power plant. Under both environmental and economic points of view, in the studied case, producing chips for energy from a harvesting system integrated with wood from hybrid poplar plantations with 10 years rotation is preferable to the chip production from the same species´short rotation (3 years) coppices. Base case scenario has been analyzed considering hectare as the functional unit. Nevertheless, if the chosen functional unit were the chips dry tonne (ODT), assigning the impacts among wood and chips in the integrated harvesting case using a mass criterium, the environmental impacts of chips production are quite reduced if they come from integrated conventional plantation than from SRCs.

Keywords: poplar, Life Cycle Assessment (LCA), environmental impact, cost and profitability analysis

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1. Introduction

Despite its high water requirements, industrial production of poplar is particularly well established in Southern and Northern Spain, primarily for veneer production (Tolosana et al., 2011). Poplar plantations for veneer production are managed in rotation periods that usually span 10-15 years, with tree densities typically ranging between 350 and 700 trees/ha and stump removal at the end of each rotation (Barrio-Anta et al., 2008, Cañellas et al., 2012, Perez-Cruzado et al., 2014). For last 10 years new works systems incorporate branches, tops and stump collection for bioenergy purposes.

Modern bioenergy is expected to play a key role in the transformation of the energy sector (European Commission, 2009, IDAE, 2010, IEA, 2012). At present, most of the solid biomass employed for energy purposes is generated as a by-product of the forest, agriculture and wood-processing sectors. Poplar is known for its capacity to re-sprout from its stump and its fast growth rates when cultivated under adequate climatic and soil conditions. Adding, short rotation coppice of poplar is attracting scientific and commercial interest for bioenergy. In many areas of the world including the Mediterranean basin SRC-poplar is been considered (Cañellas et al., 2012, Sixto et al., 2010, Testa et al., 2014).

This study deal with environmental and economic comparison between these two crops. In contrast to timber plantations, SRC option requires higher densities (> 15.000 tress/ha) and faster rotation cycles and yield can increase to values in excess of 35 tDM/ha·yr (Sixto et al., 2007, Testa et al., 2014). Recent publications state that poplar plantations have the potential to supply up to 1.0 % of Spain's energy demand by the year 2020 (Perez-Cruzado et al., 2014).

On the other hand, the economics of biomass supply chains based on integrated wood and chips harvesting from conventional plantations or on Short Rotation Coppices (SRCs) have also been investigated in a number of recent publications. The results are highly variable due to differences in biomass yields (which depends on many parameters like soil type, climatology, water availability, species and clone, etc.), land rental costs, wood chip and timber market prices and the availability of public subsidies (Ericsson et al., 2009; Tolosana et al., 2011; Hauk et al., 2014; Testa et al., 2014; San Miguel et al., 2015).

The general aims of LCA are improving systems reducing environmental impacts, providing information for decision makers, improve information's available to people. LCA has been widely used to analyze the sustainability of biosystems (Cherubini and Stromman, 2011). As well as, Spanish poplar SRC plantations for the production of power (Butnar et al., 2010, Gasol et al., 2009, Gonzalez-Garcia et al., 2014) have been studied. However, an economical and environmental comparison between timber and bioenergy oriented or exclusively bioenergy oriented has not been performed.

The goals of this paper is to study the economic and environmental performance of the roundwood and bioenergy plantation, and secondly, comparing it to a poplar crop (Short

Rotation Coppice) studied previously (San Miguel et al., 2015) in the same area.

2. Material and Methods

The LCA analysis was performed according to standard methodology ISO 14040-14044:2006 considering the following phases: Soil preparation and conditioning; Cultivation; Harvesting and transportation; and Stump removing. ReCiPe 2009 Europe H (Midpoint) v1.09 was used to calculate aggregated impacts on selected environmental categories. SimaPro v8.0 software was used to build the models and perform calculations.

The Functional Unit (FU) employed in this analysis was 1.0 ha. Furthermore, in order to compare with SCR system, this functional unit has been change to dried tonne of wood chips.

2.1. Description of the system

Base scenario is a poplar plantation of 714 trees/ha, a 10 years period located in Granada, where the average rainfall is 497 mm. The round wood yield considered is 17,6 dried tonne per year and ha and 3,6 dried tone per year and ha of branches and tree top (chips).Table 1 shows process included in the studied system.

This paper provides up-to-date information about current practices, machines employed and prices in Southern Spain. Harvesting phase has been well documented. Felling is mainly performed by a chainsaw-operator. A light backhoe excavator (105 kW) with processing head supports directional felling. This machine also handles trees, crosscuts and piles logs. A 152 kW farm-tractor, adapted with high crane and 25 m^3 trailer, loads logs and transports them from crop to mill, within an average distance of 15 km. Branches and crowns are piling by a telescopic boom loader with raking implement (figure 1). A chipper attached to 155 kW PTO process debris. Then, a tractor with 35 m^3-trailer hauls chips off. Finally, this paper considers a 25 km distance transport from crop to mill by a 184 kW walking floor semi-trailer truck.

2.2. Technical and environmental inventory data

Table 1 provides a summary of all the processes considered in the LCA of the biomass supply chain. Diffuse emissions of phosphates/nitrates into natural waters associated with the use of NPK fertilizers were calculated according to Powers (2005) and Cherubini et al. (2009), and diffuse emissions of N_2O, CH_4 and NH_3 into the atmosphere were calculated according to guidelines published by IPCC (2006).

Background inventory data was obtained from Ecoinvent v3.0 database. Energy and material input values (kg/ha), electricity use and the specific characteristics of the machinery (size, weight, capacity, life span) were adapted from Ecoinvent v3.0 considering the information obtained from an experimental plot in Granada (Spain).

Base case scenario is a multifunctional system. To allocate environmental impacts to wood or chips a mass criteria was adopted. The following elements were left out of the scope of the analysis: Production of poplar cuttings, carbon sequestration by plant roots, energy conversion of biomass at the energy plant and indirect changes in land use.

Table 1: Phases and proccesses of LCA.

OPERATIONS/MACHINERY		**YEAR**									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Soil preparation and conditioning	Plowing (30 cm)/ Moldboard plow attached to 74 Kw farm tractor	1									
	Scarifying / Rotovator attached to 74 Kw farm tractor PTO	1									
	Marking plantation points / Crossing points of 59 Kw farm tractor passes	1									
Plantation	Shallow (90 cm depth) plantation/ Spiral drill attached to 59 kW farm tractor PTO	1									
Silvicultural treatments	Irrigation / 2.750 m^3/(ha·year) in 12 doses during summer vegetative period, every 15 days	12	12	12	12	12	12	12	12	12	12
	Surface fertilization (550 kg/ha 15/15/15 NPK) /centrifugal broadcaster on 59 kW tractor		1	1	1	1					
	Mechanical weeding / Chain brushcutter powered by 74 kW farm tractor, crossed passes		2	2	2	2					
	Pruning / workers with pneumatic knives on lifting platforms moved by self-propelled 24 kW tractors with telescopic booms.		1	1	1	1					
Harvesting	Roundwood and biomass harvesting. Biomass chipping										1
Transport	Roundwood and chips transportation										1
Stump removal	Stump drilling / Spiral drill attached to 118 kW farm tractor PTO										1

2.3. Economic inventory and methodology

The economic viability of the system is also calculated using the same phases defined in Table 1. The interest of the economic analysis is not only to assess the operational profitability, but also to compare the analyzed integrated harvesting procedure with other more intensive solid biofuels productive systems.

The costs were analized on a surface basis (per hectare). Operational unit costs were derived from the hourly costs calculation using standardize methods described by Ackerman et al. (2011), Savoie et al. (2012) and Spinelli et al. (2009) and the operational productivities. The last ones were estimated basing on the data collected in a time study recently performed in Granada (Spain) in the case of harvesting operations. Some data were gathered during 2014 from local companies and associations, consultants and distributors. Transportation costs were calculated using the online simulator produced by the Basque Regional Government (Spain) (Gobierno Vasco, 2014), considering the actual transport distances of 15 km for roundwood and 25 km for chips.

Other costs were also gathered from local sources and Spain's Environment and Agriculture Ministry (MAGRAMA), mainly refer to land rental - 757 €·(ha·year)$^{-1}$ -, anual irrigation cost, – 132,47 €·(ha·year)$^{-1}$ -, 5 m seedlings for planting – 1,0 €·plant^{-1} – and 15:15:15 NPK fertilizer – 350 €·tonne^{-1}.

Indirect costs, associated with the coordination and supervision of subcontracted activities were assumed to account for 5% of all direct costs.

The incomes were obtained from 2014 local poplar timber and chip prices (68,42 €·fresh tonne^{-1} for roundwood at the sawmill gate and 45,0 €·fresh tonne^{-1} for chips at plant, with 40 wt% moisture), having into account the above defined production per hectare.

Investment profitability was evaluated through estimation of Net Present Values (NPV) and Internal Rates of Return (IRR). Cash inflows and outflows were actualized for 2024 (end of cultivation period) assuming a 5.0% annual discount rate and 0.0% inflation rate for the duration of the project. For using the NPV to compare with SRCs, its value was annualized dividing into the rotation period of 10 years.

Table 2: 1.- Harvesting, 2.- Fertilization, 3.- Transport, 4.- Mechanical weeding, 5.- Stump drilling, 6.- Plowing, 7.- Plantation, 8.- Pruning, 9.- Irrigation.

			%								
Category	**Units/ha**	**Total**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Climate change	kg CO2 eq	2.338	53	26	7	5	4	1	2	2	x
Terrestrial acidification	kg SO2 eq	15,2	56	26	4	4	4	1	3	2	x
Freshwater eutrophication	kg P eq	0,4	60	22	4	4	2	1	1	5	x
Marine eutrophication	kg N eq	0,8	61	19	5	5	5	1	3	1	x
Human toxicity	kg 1,4-DB eq	523,2	58	25	4	4	3	1	2	5	x
Photochemical oxidant formation	kg NMVOC	20,5	70	8	5	5	5	1	3	2	x
Particulate matter formation	kg PM10 eq	6,3	61	18	4	6	4	2	2	2	x
Terrestrial ecotoxicity	kg 1,4-DB eq	0,2	51	22	7	3	11	1	3	2	x
Freshwater ecotoxicity	kg 1,4-DB eq	13,5	62	20	4	4	2	1	1	6	x
Marine ecotoxicity	kg 1,4-DB eq	16,3	54	28	4	3	3	1	1	5	x
Water depletion	m^3	9.496	34	6	2	2	1	1	1	3	49
Metal depletion	kg Fe eq	384,7	72	10	2	5	2	1	1	7	x
Fossil depletion	kg oil eq	636,9	57	17	9	5	4	1	3	3	x

Figure 1: Telescopic boom loader with raking implement.

3. Results

3.1 Environmental analysis

Characterized impacts are show in Table 2 for scenario referred to as the base case. The life cycle phases contributing the most to all categories (except water depletion) is harvesting, that includes felling, crosscutting, debris piling, chipping and hauling off. Surface fertilization is the other remarkable phase that contributes to all categories.

Normalized impact values (according to ReCiPe Mindpoint (H) V1.10) are shown if Figure 1. The graph shows that the category most significantly affected by far is marine ecotoxicity, followed by freshwater ecotoxicity. Climate change is comparatively less significant.

To fulfil a goal of this paper, to compare LCA of SRC-chips to chips from the studied base case, environmental impacts should be referred to the same functional unit and previously, adopt an allocation criteria. In this case, a mass criterion has been adopted. Table 3 shows values to compare. Strong differences have been found in the main impact categories. The use of herbicides and more fertilizers explain this.

3.2. Economic analysis

The results, concerning the Present Values of Costs and Incomes and the NPV of the investment are shown in Table 4. The annualized NPV is 271,18 €·ha^{-1}·year^{-1}.

The Internal rate of return was estimated using the IRR() function in MS Excel®, accounting for every costs – including 5% of indirect costs – and incomes. The obtained IRR under the assumed costs and incomes scenario was 7,29%.

The most costly year was the first one, due to the soil preparation, conditioning and planting costs. The remaining years of the first half of the 10 years rotation have similar costs because of the pruning and fertilizing operations, while the remaining last rotation years – from 6th to 9th – do only have land rental and irrigation costs. The only year with positive NPV is the last one, when selling incomes are introduced.

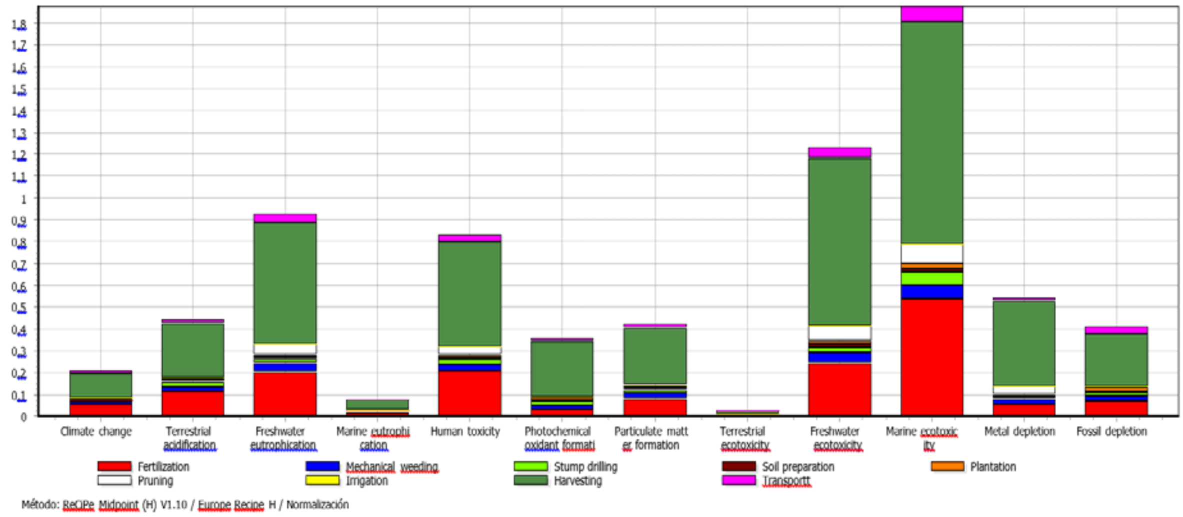

Figure 2: Normalized analysis of the environmental performance of poplar plantation.

Table 3: Environmental comparisson chips from different crops.

	Per dried tonne of chips	Integrated Plantation	SRC	Ratio
Climate change	kg CO2 eq	10,9	24,0	2,2
Terrestrial acidification	kg SO2 eq	0,07	0,35	5,0
Freshwater eutrophication	kg P eq	0,002	0,006	3,0
Marine eutrophication	kg N eq	0,004	0,081	20,3
Human toxicity	kg 1,4-DB eq	2,4	4,7	2,0
Photochemical oxidant formation	kg NMVOC	0,10	0,14	1,4
Particulate matter formation	kg PM10 eq	0,029	0,076	2,6
Terrestrial ecotoxicity	kg 1,4-DB eq	0,001	0,004	4,0
Freshwater ecotoxicity	kg 1,4-DB eq	0,06	0,16	2,7
Marine ecotoxicity	kg 1,4-DB eq	0,076	0,091	1,2
Water depletion	m^3	44,2	178,9	4,0
Metal depletion	kg Fe eq	1,79	1,39	0,8
Fossil depletion	kg oil eq	2,97	8,47	2,9

Table 4: Machine productivity, cost and aggregate values per operation.

Operation/Material	Year	Machine hours/hectare		Cost/Income (€/ha)	Aggregated Present Value (€/ha)
Land rental	1-10		----	-756,97	- 9.521,09
Plowing	1		2,0	-79,4	-123,18
Scarifying	1		1,5	-70,93	-110,04
Marking plantation points	1		1,0	-33,5	-51,97
Seedlings (plantation)	1		----	-714	-2.028,55
Plantation	1		11,9	-593,62	
Irrigation	1-10		----	-297,11	-3.737,02
NPK Fertilization	2-5		1,6	-208,61	-1.147,55
Mechanical weeding	2-5		16,0	-161,76	-889,83
Pruning (1st)	2		45,9	-287,16	-1.781,63
Pruning (2nd)	3		45,9	-312,67	
Pruning (3rd)	4		45,9	-338,19	
Pruning (4th)	5		45,9	-363,71	
Harvesting & chipping	10	Chainsaw	13,7	-2.008,37	-2.008,37
		Processor	6,7		
		Loader (piling)	8,3		
		Tractor-chipper	8,3		
		Tractor trailer	2,7		
Logs loading & transport	10		----	-1.237,27	-1.237,27
Chips transport	10		----	-469,00	-469,00
Stump removal	10		10,5	-463,74	-463,74
Total costs present value					23.569,24
Indirect costs (5%)					1.178,46
Roundwood selling	10			24.173,47	24.173,47
Chips selling	10			3.285,00	3.285,00
TOTAL NPV (€·ha^{-1})					2.710,77
NPV (€·ha^{-1}·year^{-1})					271,18

4. Discussion

Normalized values (Figure 2) show how phases contribute to each impact category. Machinery use and its productivity should be the purpose of future research. Fossil depletion per ha give insights about fuel consumption associated. Almost 40% of the 636,9 kg oil eq are associated to branches and crown piling, it is the less productive operation. As it can be read onward in 4.2, harvesting phase has also a high influence in economic results. However, surface fertilization reduces its influence in economic balance, so market economy is not including this negative externality.

To compare these results with others from scientific literature, same scope, method and functional unit should be equal. Base case in only compare with San Miguel et al, 2015 and only for chips. It can be seen that SRC is more intensive in chemical substances (adding oxifluorfen, glyphosate for chemical weeding and N-fertilizers). The results of categories (Table 3) that assess toxicity to ecosystems and humans increase between 1,2 and times. Fossil depletion increase 2,9 times in SRC due to the increase of machinery utilization.

If present and aggregated values of the different processes or operations costs are compared, land rental is the most costly; it is almost three times as much as the irrigation cost and five times as much as the integrated roundwood and chips harvesting costs. The importance of land rental and irrigation costs has been confirmed in other studies about poplar cultivation to produce Wood (Aunós et al., 2002).

The NPV of the investment is positive, while the IRR is slightly greater than the assumed annual discount rate of 5,0%, so the estimated profitability is low.

The main reasons to explain this fact are the low roundwood price in the Granada province, due to the main destination in local sawmills, instead of veneer industries. Other explanations of lower profitability are the high cost of land rental and irrigation – the last one is not needed under other climatic conditions in other Spanish regions – and the assumption of the machine life spans provided by Ecoinvent 3.0. database, that are greater in the usual forest practice in Spain, so the depreciation machine costs may have been overestimated.

If the costs per operation and year and the values of IRR and annualized NPV estimated for the studied plantation are compared to the obtained in the same area for an experimental poplar SRC (San Miguel et al., 2015) under the chip harvesting scenario, preferable to the bale harvesting one, the results are reflected in Table 5.

Plowing cost in the studied plantation almost doubles the SRC's, because of the greater depth. The estimated values for the plantation are similar to the obtained by López et al. (2005).

Table 5: Economic comparisson between two crops alternatives.

Operation/Cost concept	Costs / Incomes (€·ha^{-1})	
	Integrated	**SRC**
Land rental	-756,97	-756,97
Subsoiling	-	-110
Plowing	-79,4	-40
Scarifying	-70,93	-
Marking plantation points	-33,5	-
Planting	-1.307,62	-650
Irrigation	-297,11	-297,11
NPK Fertilization	-208,61	-217
Mechanical weeding	-161,76	-40
Post-emergence chemical weeding	-	-42
Pre-emergence chemical weeding	-	-51
Pruning	-1.301,73	0
Harvesting	-2.008,37	-6.024,55
Chips transport	-469	-2.375,37
Roundwood load & transport	-1.237,27	0
Stump removal / Soil recovery	-463,74	-450
Roundwood selling	24.173,5	0
Chips selling	3.285	18.098,6
Annualized NPV (€·ha^{-1}·year^{-1})	271	-719
IRR (%)	7,3%	<< 0 %

The planting cost, including the seedlings and the operational costs, is more than twice in the conventional plantation case than in the energy crop. That is because in the first case the planting depth is much greater – and so is the required machine time – and the 5 m plants are 20 times more expensive than the 20 cm cuttings used to establish the SRC.

The cost of mechanical weeding is also higher for the conventional plantation than in the SRC, because a double machine pass is needed.

On the other hand, the total harvesting cost is higher in the SRC case than in the conventional plantation, because it is more frequent (3 years rotation) and uses more expensive machinery. Per hectare chips transportation cost is also smaller in the conventional plantation case, because the chips production per hectare is lower than in the SRC.

As the result of these differences, the conventional plantation for roundwood and chips production is economically preferable to the SRC option as a land use, as long as in the last case the annualized NPV is negative and the IRR is quite below zero, in front of modest but positive values for the studied plantation.

5. Conclusions

In the studied Spanish region, poplar plantations for its integrated roundwood and woodchips harvesting show less environmental impacts and better economic results that poplar energy crops.

It is important to remark than surface fertilizer showed strong influence in environmental issues but does not in economic balance. Irrigation phase has strong contribution to environmental and economic performance and it is a difference with northern European countries.

Harvesting phase is the most important one for environmental impact and economic analysis. Hence, the process optimization efforts should be addressed to the harvesting operations, which mechanization degree is low.

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Influence of strip roads on thickness of trees growing in close vicinity

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Abstract: The research was conducted in 2014 in a 33-year old stand of Scots pine (*Pinus sylvestris* L.) in Notecka Forest. The strip roads were cut 6 years prior to the study and the second thinning was carried out in 2013. The measurements were conducted on trees growing about 3 m away from the strip road and on trees deeper in the stand (control measurements). The strip roads were cut parallel to the rows of trees. The zone of first 3 m from the strip road was divided into three stripes: on the border (first row), up to 1.5 m into the stand (second row) and up to 3 m (third row). It was found that due to increased living space caused by cutting the strip road, trees growing in the vicinity were in general thicker than those growing deeper in the stand, but the differences were not always statistically significant.

Keywords: strip roads, thinning, diameter at breast height

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1. Introduction

Mechanized technologies using harvesters for felling and wood processing as well as forwarders for wood extraction are more frequently used in wood harvesting practice in Poland (Nowacka and Moskalik, 2012, Sowa et al., 2013). These technologies can rationally be applied to perform intermediate cuttings if the tree stands are opened by establishing a network of strip roads. This results from ecological considerations mainly, as each technology, and especially a fully mechanized one, which uses big machines has an impact on the forest (Sauter and Busmann, 1994, Gapšyté, 2003, Suwała, 2003). For many years using strip roads has been associated with transportation operations (wood extraction) and machines that are in general used for these operations (Rzadkowski, 1997). In the present wood harvesting conditions, however, with other operations, like e.g. felling, delimbing and crosscutting being realized on strip roads, they are more commonly called operational roads (Rzadkowski, 1995, Laurow, 1996).

In general, strip roads are characterized by two parameters: their width and distance between them. For various reasons, not least scenic beauty, their layout in the tree stand (roughly in the form of straight lines) and direction related to tree rows is also important. If the length of a strip road is easy to measure, its width is more problematic, as it is rather difficult to find the exact borderline between the stand and the strip road. Isomäki and Niemistö (1990) write that the width of a strip road can be considered from the viewpoint of wood harvesting or its production. From the point of view of wood harvesting, the strip road width determines the area that is necessary for effective movements of machines, and in this respect the area is closely related to the width of the strip road. However, from the viewpoint of wood production, the width of a strip roads is responsible for the reduction of the potential production of the tree stand. This reduction can be of a spatial or wood volume character, or it can refer to the number of trees (Stempski, 2013). Isomäki and Niemistö (1990) also specify the, so called, external width, which takes into account irregularities in the position of trees growing the closest to the strip road.

Cutting a strip road in the stand allows the crowns of trees growing at the edge of the strip road to use more light, which at least for a certain period of time changes the conditions of their growth and development. Theoretically speaking, these trees should grow more intensively in thickness. The literature indicates however, that this is not always the case. Results which confirm the theory of a more intensive growth of the edge trees were reported by Horák and Novák (2009), Wallentin and Nilsson (2011), however the opposite effect resulted from research by Yilmaza et al. (2010). One of the key factors that affect the edge effect is the width of the strip roads (Giefing et al., 2003).

The purpose of the research presented in this paper was to analyse the thickness structure of trees growing in close vicinity of strip roads six years after they had been cut and one year after the second thinning.

2. Research area and methods

The investigations were carried out in the spring of 2014 in a 33-year-old pine tree stand, 12,85 ha in area, growing on a fresh coniferous site in the south-eastern part of the Notecka Forest. The average diameter at breast height (DBH) was 11 cm, the average height was 13 m, and the growing stock reached 189 m^3/ha. The first thinning connected with designing and cutting 12 strip roads (along tree rows) was performed in 2008 and the second one in 2013.

The scope of the investigations covered all trees growing along all the strip roads, at a distance of 3 m from them, and halfway between them in the stand, as control. Designing and cutting the strip roads allowed to distinguish clear distance zones, on which the DBH measurements were taken: zone 1 – constituted by the first row of trees at the edge of the strip road, zone 2 and zone 3 – referred to rows 2 and 3, at distances from the strip road of 1.5 m and 3 m, respectively, and zone 4 – the control, referring to the tree row halfway between two strip roads. The zones 1, 2 and 3 covered trees growing on both sides of the strip roads, and the control zone referred to trees one side of the strip road only.

The diameters at breast height were measured twice on each tree, in the direction parallel and perpendicular to tree rows, and the average values (from the two measurements) were used for further calculations. The diameters were measured with a caliper, with an accuracy level of 0.5 cm. A total of 4564 trees were measured (about 1300 in zones 1, 2, and 3 and nearly 680 trees in the control zones).

The DBH measurement in 2014 was the second one in the stand, the first one was carried out in 2013 before the thinning. In the course of the 2013 measurements, 4 of the 12 strip roads were found narrower (2.9 m against 3.6 m in the remaining 8 strip roads), which was taken into account in the analysis of the results. These narrower strip roads were broadened in 2013, because they had to be adjusted to the 10t forwarder, used for wood extraction in the second thinning.

The results from the DBH measurements were analysed statistically. The consistency of the DBH distributions with the normal one were verified and then the significance of DBH differences between different zones were checked. Due to inconsistency of the DBH distribution with the normal one, the significance of differences was analysed with a nonparametric equivalent of ANOVA, the Kruskal-Wallis test. All calculations were performed by using the Statistica 12 package, the significance level adopted was α=0.05.

3. Results

The largest average DBH values, calculated for all the 12 strip roads, were found on trees growing directly at strip roads, while the smallest DBH values were on trees in the control zone, halfway between two neighbouring strip roads (Tab. 1). This rule was also true for the mean DBH values calculated from the data collected at the eight wider strip roads. In the case of the narrower ones (strip roads 9-12), however, the smallest mean DBH value was found for zone 2 (1.5 m from the strip road).

The regularities described above referred to mean values from all strip roads put together, as well as from the groups of the wider and the narrower ones. An analysis of the results conducted separately for particular strip roads however, gave a different view. In the case of two strip roads (7 and 11) the largest DBH values were found not on trees adjacent to the strip roads, but on those growing in zone 3 (strip road 7) or in the control zone (strip road 11). Their differences compared to the DBH values of trees adjacent to the strip roads were rather small, 0.1 - 0.3 cm, and they proved to be statistically insignificant. In the case of the remaining 10 strip roads, the trees growing directly at the strip roads were the thickest, and the average difference from trees in zone 2 was 0.58 cm (Tab. 1). Similar differences were found for the DBH values on trees growing at the wider strip roads (0.62 cm) and the narrower ones (0.61 cm). Only in the case of three strip roads (4, 9, 12) the trees adjacent to the strip roads were thicker by more than 1 cm than the trees from the more distant zones, and the maximum difference reached 1.36 cm (strip road 12). The smallest DBH values were found in the control zones, and like in the case of the largest diameter values, this was not true for all strip roads. In the case of strip roads 4, 11 and 12 the smallest DBH values were found for trees growing 1.5 m away from the strip road (zone 2) (Tab. 1).

As it was mentioned earlier, for the majority of strip roads, the thickest trees grew directly at the strip roads, and the thinnest trees were those in the control zones. Only in the case of one strip road (3) did the DBH values diminish as the distance from the strip road increased. For 8 out of 12 strip roads, the trees in zone 3 were thicker than trees in zone 2, and, in the case of the strip road 7, even thicker than the trees in zone 1.

Table 1: DBH of trees growing in different distance zones (in cm).

Strip road	Zone 1	Zone 2	Zone 3	Zone 4
1	14.27	13.70	13.90	13.51
2	15.37	14.68	14.73	14.34
3	14.57	14.23	13.89	13.60
4	15.53	14.52	15.10	14.84
5	14.15	13.65	13.36	12.48
6	14.85	13.99	14.42	13.69
7	13.09	12.73	13.37	11.72
8	12.32	12.07	11.78	10.11
1-8	**14.26**	**13.64**	**13.75**	**12.87**
9	12.80	11.68	11.73	10.98
10	12.32	12.07	11.78	10.11
11	11.95	11.63	11.71	12.07
12	12.06	10.70	10.99	11.16
9-12	**11.80**	**11.19**	**11.21**	**11.29**
1-12	**13.37**	**12.79**	**12.86**	**12.33**

Both in the case of all strip roads as well as in the case of the wider ones, the trees growing directly at the strip roads were statistically significantly thicker than trees growing in the other three zones, and also the differences between zones 2 and 4 as well as between 3 and 4 were statistically significant (Tab. 2). In the case of the narrower strip roads, trees adjacent to the strip roads were statistically significantly thicker than trees in zones 2 and 3 (Tab. 2), and these were the only significant statistical differences found for this group of strip roads.

Table 2: Test results for the significance of differences in DBH values between zones (calculated p values for α=0.05).

Zone	1	2	3	4
All strip roads				
1		**0.000002**	**0.000016**	**0.000000**
2	**0.000002**		1.000000	**0.003495**
3	**0.000016**	1.000000		**0.001026**
4	**0.000000**	**0.003495**	**0.001026**	
Wider strip roads (1-8)				
1		**0.000028**	**0.000347**	**0.000000**
2	**0.000028**		1.000000	**0.000011**
3	**0.000347**	1.000000		**0.000001**
4	**0.000000**	**0.000011**	**0.000001**	
Narrower strip roads (9-12)				
1		**0.000842**	**0.001360**	0.068646
2	**0.000842**		1.000000	1.000000
3	**0.001360**	1.000000		1.000000
4	0.068646	1.000000	1.000000	

For values in bold the differences were statistically significant

The statistical verification of the significance of differences in the DBH values between the distance zones for particular strip roads (Tab. 3) showed that these differences were significant for 8 out of 12 strip roads, and significantly thicker trees growing in zone 2 were found for four strip roads (4, 6, 9 and 12). Considering the smallest DBH values of trees growing in the control zone, most often the differences between this zone and zone 1 were significant, which was confirmed for as many as 6 strip roads.

Table 3: Test results for the significance of differences in DBH values between zones for particular strip roads.

Zone	**1**	**2**	**3**	**4**	**Zone**	**1**	**2**	**3**	**4**
Strip road 1 (p= 0.1411)					Strip road 2 (p = 0.0222)				
1		-	-	-	1		-	-	+
2	-		-	-	2	-		-	-
3	-	-		-	3	-	-		-
4	-	-	-		4	+	-	-	
Strip road 3 (p = 0.0602)					Strip road 4 (p = 0.0106)				
1		-	-	-	1		+	-	-
2	-		-	-	2	+		-	-
3	-	-		-	3	-	-		-
4	-	-	-		4	-	-	-	
Strip road 5 (p = 0.0040)					Strip road 6 (p = 0.0082)				
1		-	-	+	1		+	-	+
2	-		-	+	2	+		-	-
3	-	-		-	3	-	-		-
4	+	+	-		4	+	-	-	
Strip road 7 (p = 0.0005)					Strip road 8 (p = 0.000)				
1		-	-	+	1		-	-	+
2	-		-	-	2	-		-	+
3	-	-		+	3	-	-		+
4	+	-	+		4	+	+	+	
Strip road 9 (p = 0.0000)					Strip road 10 (p = 0.3728)				
1		+	+	+	1		-	-	-
2	+		-	-	2	-		-	-
3	+	-		-	3	-	-		-
4	+	-	-		4	-	-	-	
Strip road 11 (p = 0.6560)					Strip road 12 (p = 0.0001)				
1		-	-	-	1		+	+	-
2	-		-	-	2	+		-	-
3	-	-		-	3	+	-		-
4	-	-	-		4	-	-	-	

Sign “+” denotes statistical significance

4. Discussion

The investigations showed a differentiation of tree diameters caused by cutting strip roads, leading to larger diameters at breast height on trees growing directly at the strip roads. Similar to the investigations conducted prior to a thinning (Stempski and Jablonski, 2014), this rule was not true for all the 12 strip roads, but only for 10 (9, formerly). The results correspond to those reported by Kremera and Matthiesa (1997), Mäkinena et al. (2006), Horáka and Nováka (2009). In Poland, Stempski et al. (2010) in their investigations, conducted in tree stands similar to those described in this paper, also found larger diameters at breast height on edge trees, and those diameters were considerably larger, at a level of 1.5 cm.

Although the number of strip roads, for which the statistical verification proved significant differences in thickness, dropped from 9 before the thinning (Stempski and Jablonski, 2014) to 8 now, the number of strip roads, for which the edge trees were statistically significantly thicker than those growing in the next zone, 1.5 m away from the strip road, increased (1 then and 4 now). It is noteworthy as well, that comparing the former and the present investigations, out of the strip roads with no significant differences in thickness between zones, only one strip road (No. 11) remained. The strip road 2, for which in course of the investigations before the thinning a statistical difference in DBH between zones 1 and 2 had been proven, was not present in the group of four strip roads with such differences found valid (strip roads 1, 3, 10, 11).

In general, the investigations showed that the thickest trees grew in zone 1 and the thinnest ones in zone 4 (control zone). This situation was confirmed for 7 out of the 8 wider strip roads and for 2 out of the 4 narrower ones. In the investigations carried out before the thinning, all strip roads had the smallest DBH values in their control zones, and for 6 strip roads (including 3 narrower ones) statistical differences in relation to the trees growing at a distance of 3 m from the strip roads were proven significant (Stempski and Jablonski, 2014). It can hardly be argued that smaller DBH values on trees in the control zones back then and now resulted from the presence of strip roads in the tree stand. According to the scientific literature, the effects of strip roads apply to trees which directly make use of the free living space of the strip road (edge trees), and these effects seldom reach deeper into the tree stand, maximum to 3 m (McCreary and Perry, 1983, Isomäki and Niemistö, 1990). The reasons can rather be found in mistakes made during the first thinning, which was confirmed by the frequency analysis of tree diameters (Stempski and Jablonski, 2014). The analysis showed predominance of thinnest trees in the control zones. This phenomenon was clearly visible in the wider strip roads, but in the case of the narrower strip roads, due to the fact that the trees were in general thinner in all zones, also the differences were smaller. The second thinning, followed by the aforementioned measurements, reduced the disproportions in the diameter distribution between the control zone and all the other ones, especially zones 2 and 3. As a result, the DBH values in the control zone were statistically significantly smaller than the DBH diameters in zones 2 and 3 in three strip roads, compared to five strip roads before the thinning.

As it was mentioned before, in general, the thickest trees grew in zone 1 and the thinnest ones in zone 4 (control zone), and no distinctive drop in DBH values related to the growing distance from the strip road was found (except for one strip road). As the investigations showed, the second thickest group of trees, following the trees from zone 1, consisted of trees in zone 3, growing about 3 m away from the strip roads, and not by trees in zone 2, growing only behind the edge trees. This situation was true for 8 out of 12 strip roads, with one of them presenting the thickest trees in the whole experiment. It seems, the reasons for such a situation can be explained by the fact that an increased demand for nutrients by the edge trees reduced the supply of nutrients available in the vicinity, limiting the growth of trees in that area. As a result, these trees had smaller diameters than those growing further away from the edge trees.

5. Conclusions

1. The second thinning, carried out five years after cutting the strip roads, in general did not change the diameter distribution of the edge trees, compared to the situation before the thinning. For 10 (9 before the thinning) out of 12 strip roads, the edge trees were characterized by largest diameters, and in 8 cases the differences related to trees growing deeper in the stand were statistically significant.

2. Similar to the situation before the thinning, in most cases the edge trees were statistically significantly thicker than those in the control zone. Significant differences between the edge trees and those in zone 2 were found for four strip roads, compared to one strip road before the thinning.

3. For the majority of strip roads, the thinnest trees were in the control zone (halfway between two neighbouring strip roads). A direct drop in diameter with growing distance from the strip road was found in one case only. Most often, trees in zone 3, growing 3 m away from the strip road, followed the edge trees in diameter.

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An automated detection system for (forest) road conditions

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Abstract: Forest roads – or more generally speaking gravel roads – underlie permanent wear out. Due to erosion, influence of weather and traffic-based use the status of a road changes quite dynamically. Hence induced damages on the roadway may get quite severe when not being cured by (regular) road maintenance.
Particularly in the forest sector knowledge about the current road condition is required for an effective planning and execution of those road maintenance actions. At the moment damages on forest roads are very often registered only according to subjective assessment criteria. The registration process frequently only happens with much time delay, at huge costs and with low precision.
A novel approach is presented here, where a measuring instrument was constructed that automatically detects road conditions, particularly for gravel roads. The system is a setup of several hardware components, compiled in a lance like unit, which gets attached to a car at the towing hitch or alternatively at a truck. This part is supplemented by wirelessly linked sensor units, attached near the vehicle wheels.
Raw data collection may typically happen during other (routine) vehicle movements on forest roads. The data analysis is usually done after the measurement campaign in a subsequent later step. The data evaluation is integrated into the software package "iFOS", where an identification and categorization due to different road conditions is done. In particular the strong rules engine supports a versatile use of this tool.
Field tests showed the practicability and usability of the device. The measurement principle facilitates an objective evaluation of road conditions. Forest enterprises receive a transparent tool for the allocation of funds on road maintenance. Consultants may want to use it for road registration and valuations.

Keywords: Forest road; maintenance; automatic detection; road quality evaluation

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1. Introduction

Forest roads are an important asset in forest enterprises. This is true for both public and private owners; it is true for small and big forest enterprises as well as for close-to-nature management regimes and plantations. The dominating road type found in any of these categories is a road without a hard cover, such as bitumen, asphalt or concrete. These dominating unsealed roads need regular maintenance. This is necessary as effects from traffic, road usage, but also from erosion and weathering may create unwanted road damages, such as potholes, surface ruts or corrugations. Hence it is evident that the road status has to be understood as a rather dynamically changing attribute.

For digital road management systems a contemporary forest road description is necessary, in particular the setting up of road maintenance regimes and schedules will be built on such information. In order to fulfill these needs a procedure or tool is necessary, telling the status of forest roads in an objective, precise and easily to achieve manner at competitive costs.

As a key component for the description of a road status the characteristics of the roadway have to be considered first place. Here the longitudinal roughness is a first important element, which may be disturbed by potholes, bumps or corrugations. Another one is the deviation from an expected and wanted cross profile shape, like for instance a roof profile. Here disturbances may be the flattening of such a shape or, again, the forming of ruts, shoving or humps.

2. Overview on some existing systems and measurement principles for road status monitoring

In road maintenance of public roads, which to its majority are nowadays tar-roads, but also in the monitoring of rail tracks, there exit several different approaches for the automated collection of describing status attributes. Laser scanning offers a quick and precise *distance measurement* through light-return-time measurements. When integrated into a tool kit this may offer through its extremely dense measurement dots a rather precise 3D road surface model, respectively information on longitudinal or transversal evenness of a road. As a tool of this kind the PPS (pavement profile scanner) as developed by Fraunhofer IPM may be mentioned here (Anonymous 2013). When applied in favorable illumination and contrast conditions the *light-section principle* offers another way to collect (road) surface information. *Accelerometers* may be used as (indirect) sensors for collecting vibrations at wheels or vehicles, as induced though longitudinal road roughness. A sample setup is described in Johansson, Kosonen, Mathisen, McCulloch and Saarenketo T. (2005), a product built around a sensor of this type is Opti-Grade (Brown, Mercier and Provencher, FERIC 2002) and a newer version would use the g-sensor in a smart phone (Moussaoui, 2013, Forslöf and Jones, 2015). Furthermore *thermal cameras* may help to identify temperature differences induced by moisture differences in the road surface. Mantintupa and Saarenketo (2012) describe an application of this technology, a product solution is offered by e.g. FLIR (see Anonymous, 2011). The *ground penetrating radar* (GPR) finally offers the option to collect sub-surface structural information (Saarenketo, Matintupa and Varin, 2012, Saarenketo, 2016).

Considering the abilities of these measurement principles for their application on forest roads, some approaches have only limited usability: intensive light and shadow patterns must be expected under forest canopies. This will influence road surface temperatures as well as the visibility of light beams. As a consequence thermal cameras will have limited usability; the same is true for procedures relying on light-section. Accelerometers attached in the cabin of a car or truck will not directly measure road roughness, but reflect very strongly dampening elements such as wheels and shock absorbers from these vehicles (Moussaoui, 2013).

The majority of existing tool kits use dedicated measurement vehicles with firmly fitted sensor units or alternatively they are built onto trailers with sensors being mounted there. This results in the need to send out these dedicated vehicles or trailers for the data collection purpose, an integration of the measurement campaign with other transport movements is more or less impossible. This is a detrimental aspect, as the application will increase costs for data collection campaigns. Furthermore in the evaluation of these existing tool sets their investment costs must be considered. Last but not least the suitability to detect forest road typical damage patterns on the road bed may be limited. In particular single-sensor approaches seem to have some limitations (see Moussaoui, 2013; Conrad, 2013).

This resulted in the decision to develop a new measurement device, using a sensor fusion approach. The concept was constructed in a manner to be mountable at cars (or trucks) and meant primarily for unsealed roads, like forest roads.

3. Conceptual design and user interface of the developed road scanner

To ensure a preferably comprehensive road monitoring the three-part measuring system which is still a prototype version consists of different electronic sensors. Sensor data are transmitted (wirelessly) to a headless embedded computer on the measuring lance. Together with this measurement device comes a separate evaluation software “iFOS” (*integrated Forest Operations Software*) which does a road classification and interpretation based on the collected data.

The hardware is a set of several components. The **measuring lance** (Figure 1, A) is designed for measuring and logging the cross-sections of gravel roads. Several different sensors are integrated: five ultrasonic sensors in a certain arrangement on the lance as well as an acceleration sensor, a GPS (1 Hz) and a gyroscope in a separate box (Figure 1, B) on top of the lance. In order to improve the quality of the GPS based determination of position there is currently an option to fix an additional external antenna for instance on top of the roof of the vehicle. All collected data streams are merged by a data processing unit with a simple 2-button user interface for starting and stopping a measuring cycle. This unit coordinates the measuring process and manages the data output.

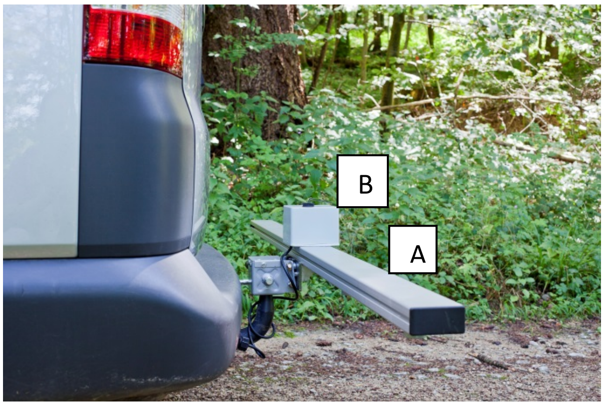

Figure 1: Measuring lance on a vehicle (source: R. Baula).

The measuring system is conducted in a way that it largely operates auto-calibrated. For example, a not exactly horizontal mounting of the measuring lance to the tow coupling is also registered and can be corrected as an unfavorably selected assembly point, such as one-sided inclined road. After calibration and fixation the measuring lance is ready for operation. At this stage the user has also the opportunity to get access to a real time surveillance option of the measurement via Bluetooth, e.g. with an Android smartphone.

To record the longitudinal road unevenness a 3-axis acceleration sensor at a sampling frequency of at the moment 50 Hz is used. Two **wheel sensors** are installed with a U-clip each at the right and left wheel suspension of the vehicle’s rear axle and transmit data wirelessly to the headless embedded computer on the measuring lance. In the course of data interpretation weak spots like potholes in the roadway can be detected.

The hardware system can be kept mounted on the vehicle as long as the batteries of the wheel sensors provide sufficient voltage for a proper data transfer. The readout of the embedded computer can be realized via Bluetooth right after the measurement - also in the field. The parametrization can be done time delayed to the data collection at the office during the analyzing procedure.

The post processing and the categorization of the determined road damages is done by using the specifically developed Windows-based **evaluation software** “iFOS” which includes the option to define own road categories. Depending on the probed parameter (depth of potholes, frequency of appearance of potholes, depth of bumps and lane grooves, etc.) different threshold values and damage ranges (e.g. good, middle and bad road condition) can be set and the results can either be plotted as a color coded map (Figure 2) or be saved as a geo-referenced attribute table for further calculations or documentation.

As long as the battery is on a non-recharge status the hardware keeps mounted on the vehicle which is in use in the forestry district. The user in the office additionally benefits from the fully automatic transmission and the pre-processing of the collected and stored data provided by the embedded PC. After a certain time, data should be readout. The result of data processing can be a road maintenance plan or an action plan for urgent reconstruction needs with consequent activities for the up-coming fiscal years (Figure 3).

4. Results - Road classification and steps of development

In 2014 Schuler evaluated and analyzed the usability of the described sensor setup in a field test. The aim of his thesis was to receive more information about the possibilities and limits in detecting road distresses of aggregate-surfaced roads using the first available road scanner layout. Therefor he describes the occurrence of distresses for 12 road sections, recorded at first in a visual manner, including one whole and two half road segments recorded by a separate laser scanner and compared them with the recorded data of the road scanner. The evaluation is split by ultrasonic and acceleration records. The list of investigated damages is limited by deterioration indicators that are most commonly observed like containing ruts, potholes, corrugations, initial vegetation and roughness (Schuler, 2014).

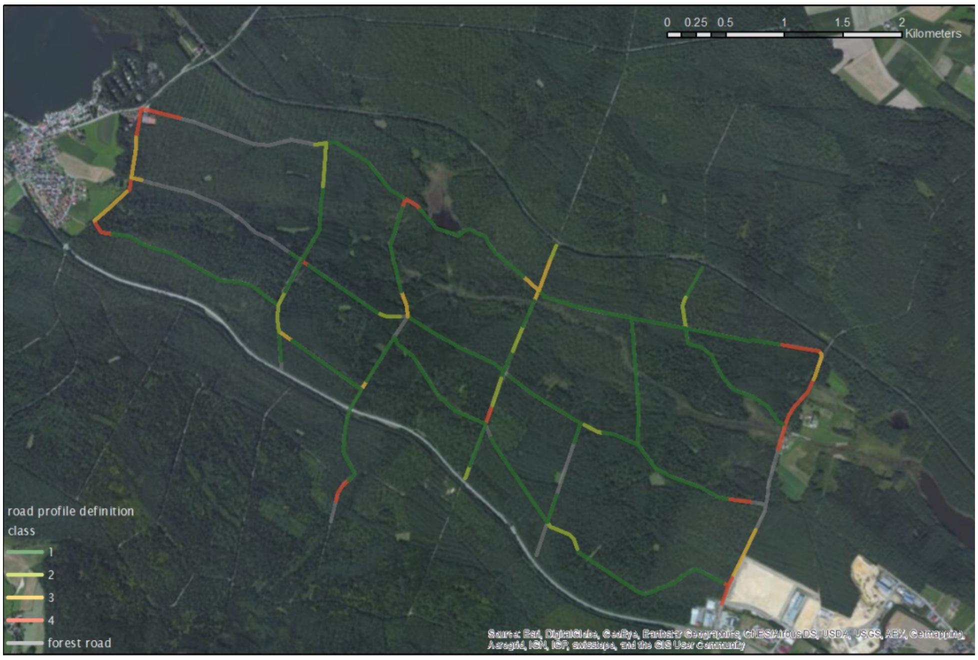

Figure 2: Road segment classification "ThüringenForst" (Starke 2016 based on Roos, 2015); created with ESRI ArcMap.

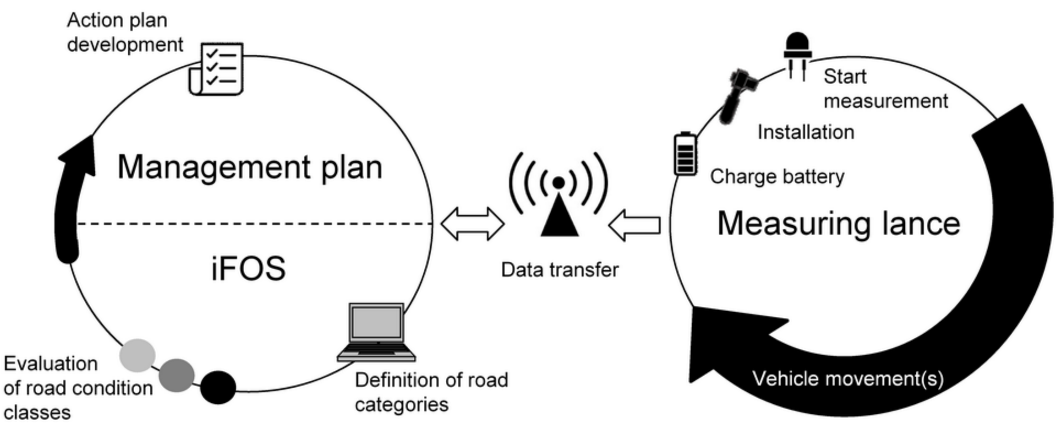

Figure 3: Possible forest enterprise work- flow (Rommel, Ziesak and Starke, 2015).

At this point the sensor layout of the five ultrasonic sensors followed a symmetric mounting design (five sensors in equal distances). A mean value comparison of the cross-section grading patterns between the laser records and the according ultrasonic-recorded profile showed that the ultrasonic recording delivers sufficient results for detecting wide ruts and geometric disturbances in the cross-section grading pattern. However, the detection of potholes as a local road distress, also partially related to the cross-section profile and the intense occurring of vegetation on the road surface, could not be recovered in the mean values of the ultrasonic dataset (ibid.).

The acceleration records, in particular the wheel sensor records, close the missing link for the detection of longitudinal road unevenness, induced by e.g. potholes or bumps. However, it must be clear, that only road bumps which are travelled over will cause signals in the accelerometers. Thus not every single pothole in the driveway may get tracked. Since there is a distinctive relationship between overall road bumpiness and collected accelerometer readings valid results for road unevenness for road segments are still guaranteed. A high variation of different amplitudes can also be related to a potential road roughness (ibid.).

Schuler (2014) mentioned a potential problem in the ultrasonic sensor layout for the rut detection. To make the system more effective towards significant accuracy of road distress discrimination, Starke (2015) designed a fitted concept for ultrasonic sensors with a smaller beam pattern as well as an asymmetric sensor layout, which were implemented in the system to ensure a better detection of slight changes in the cross-section profile and a higher probability of rut classification. The variables for this development were derived from the technical specification of ultrasonic beam patterns (MaxBotix, 2015), as well as from a potential occurrence of ruts, derived by mean track gauges of trucks and cars considering the uncertainty of staying in the track at different driving speeds (Kuonen, 1983).

The implementation in a first classified road validation for practical-use purpose was created by Roos (2015) for regional construction patterns, matching the needs and requirements of Thüringen Forst. He defines four categories of road damages equivalent to those used at Thüringen Forst (ThüringenForst, 2016). They are related to a disturbed water drain in cross-section grading profile, equivalent on Foltz and Elliots theory of the "short water path" to prevent erosion effects, being verified by Heinimann (1997). Hence, the optimal road cross-section profile is determined as a roof shaped grading pattern with a 5% slope (lateral) for the "class 1" characterization (Roos, 2015). For the categorization in "class 2", the road still has to provide a possible lateral water drain, but "class 3" shows the first severe disturbances, ending in "class 4", where a working lateral water drain can be generally excluded (Figure 4**Błąd! Nie można odnaleźć źródła odwołania.**) (Roos, 2015).

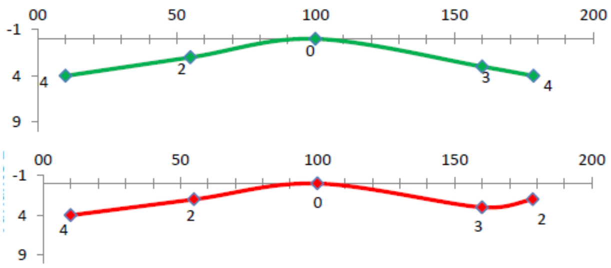

Figure 4: Cross-shaped grading pattern examples, including the measure points of the ultrasonic sensors (Roos, 2015): "ThüringenForst Class 1" (above) and "ThüringenForst Class 4" without working lateral water drain (below).

A field test, done on some 36 kilometers of forest roads, confirmed the matching of a visual classification compared with the designated classes from the road scanner results in sufficient accuracy. This was true when classifying road segments in single track recording and also for repetition accuracy of a 15 times multi track record on three forest road segments. For the single values a high variation of classes was observed for a single record visualization (Figure 5) (Roos, 2015).

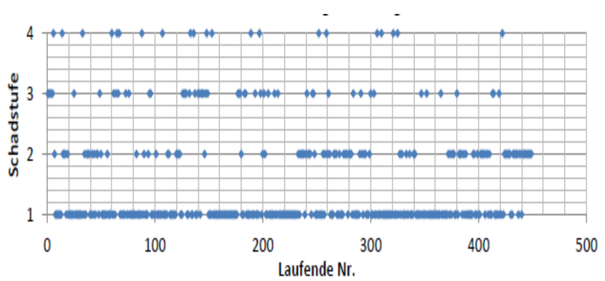

Figure 5: Single value classification of a road segment (Roos, 2015).

In a further thesis Hug (2016) investigated the features for the distance measurements, which are at this time realised by the mentioned ultrasound sensors. The accuracy and characteristics were tested under controlled laboratory conditions. For the measurements, Hug examined the varying side deviation of the ultrasonic sensor center beam and its probability to detect potholes, ruts, different solid objects and vegetation. Without any object placed in the center beam, the repeating accuracy shows no variation at all and thus ensures reliable measurements. The most important cross-profile distress, the rut, will be surely detected. At 2 cm precision level they are recognized at suitable significance of more than 95% (Figure 6).

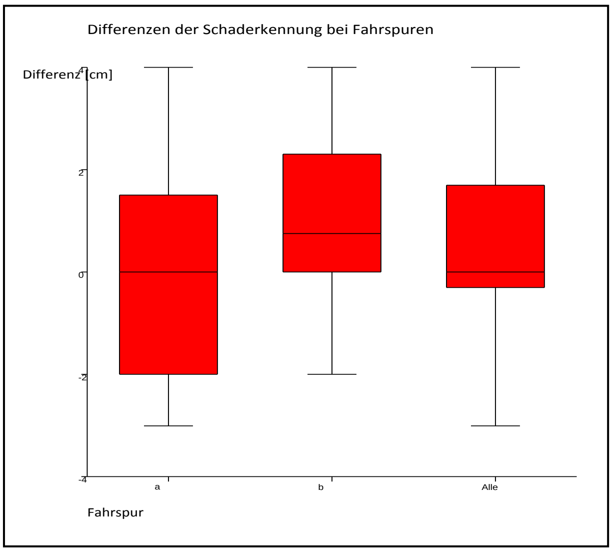

Figure 6: Difference between ultrasonic sensor measurements (a(n=19), b(n=16), all (n=35)) and reference measurements of two manually shaped ruts (Hug, 2016).

As expected, for potholes the detection is not guaranteed, for vegetation even significantly rejected, what confirms Schulers' notice that the ultrasonic sensors are limited in these aspects. Also the occurring of high variation of the single value classification Roos mentioned might be caused by the reflection of angled and rough surfaces and has to be kept in mind in case of implementing further classification variables.

5. Further development and discussion

Considering position data, sometimes the GPS accuracy seems not to be sufficient for a clear data evaluation. Especially in curves or at road junctions the data points could not be assigned to the correct road segment and even get further distorted by clipping algorithms during the post processing. Therefore two different kinds of GPS receivers were compared in Hug's thesis (2016). The "uBlox Neo 6M" that is currently in use and two different antenna setups in combination with a more powerful "uBlox Neo M8N" were compared and tested using an evaluation kit. The best readings can be achieved by the newer "Neo M8N", a receiver for both GPS and GLONASS signals, in combination with the roof top antenna (Figure 7).

The effect of shielding of the GPS signal, caused by an unfavorable low mounting point of the receiver, might cause the problem of a weak accuracy in some situations. For all observed records the positional dilution of precision (PDOP) stayed below the value 2, which can be seen as an indicator for sufficiently good satellite constellation during this measurement campaign. The driving speed has also an effect (between 10 and 30 km/h) on the accuracy of all records (Figure 8), but never led to a total signal loss (Hug, 2016).

At the moment the interpretation options as implemented in "iFOS" are being improved. This includes a classification of road sections based on user defined segment lengths. Furthermore a classification for the accelerometer sensors will be added, which will allow a much finer separation of road damage attributes.

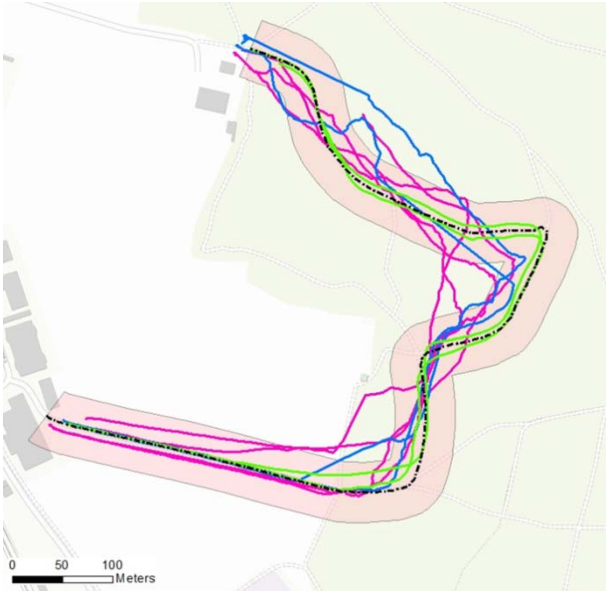

Figure 7: GPS tracks Neo 6M (red) current version, EVK-M8N intern antenna (blue), EVK-M8N extern antenna (green), 60m corridor alongside the road (light red) (Hug, 2016).

The experience of different verification and testing cycles (Schuler 2014, Roos 2015, Hug 2016) could proof that the realized approach for this "road scanner" with a fusion of different sensor types provides a suitable tool, which will detect damages to the road bed in an automated and precise way. Thus this tool can be an important element for digital road management systems. At the moment current work is also underway for implementing this tool in the day-to-day business at Thüringen Forst (Merten, 2016).

6. Acknowledgements

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7. Remarks

This paper has been submitted to the CROJFE - at the moment in the peer review process.

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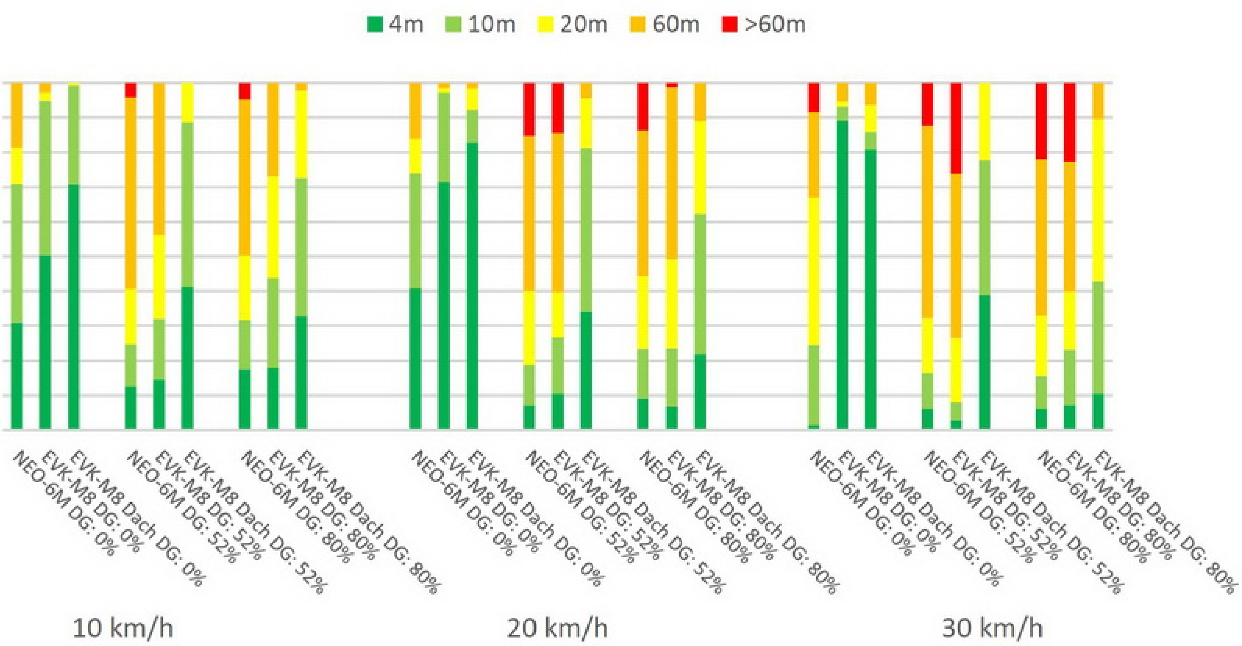

Figure 8: Point deviation in a 4, 10, 20, 60 and > 60 m wide road corridor for different GPS receiver setups including different forest canopy variants (0%, 52%, 80%) (Hug, 2016).

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Modeling of the soil compaction process and rutting by timber transport machines

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Abstract: An overview of approaches to the modeling of multiple surface compactions by mobile machines is given. The equivalent deformation modulus was taken for the characteristic of the forest soil surface deformity with an allowance for the stabilization with roots, turf or logging waste. Calculated and experimental data were compared to evaluate the modeling accuracy.

Keywords: forest soil compaction, rutting, repeated timber transport machines passages

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1 Introduction

The application of timber transport machines is connected with a number of potential ecological risks. The most critical risks imply soil surface damage, particularly compaction and rutting. It may result in erosion processes increase, woodland efficiency reduction, water flows quality deterioration and other ecological problems. The purpose of this work is to substantiate the methods of calculating compaction effect and rutting values during timber transport machines passages over deformed soil surfaces.

2 Current problem of soil compaction by timber transport machines

The mover's effect on soil causes deformations, which are considered to be (a) resilient*,* if soil particles return to their original position after external action is eliminated; (b) residual, if the particles position is different from the original one after the load elimination; and (c) plastic, if the residual deformation is equal to the total deformation. As a result of the repeated action of the mover, soil compaction deformations accumulate and ruts are formed; at the same time, the soil structure is damaged intensively.

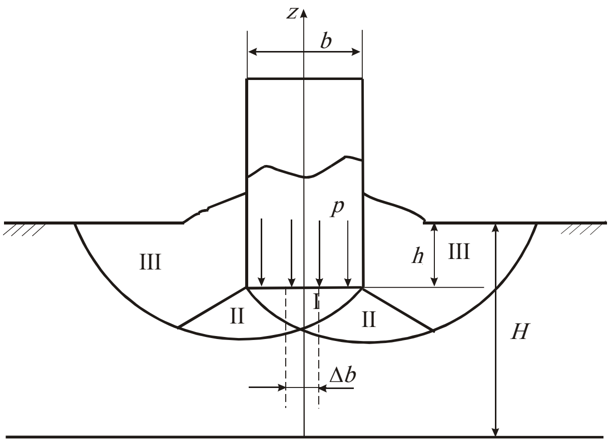

Figure 1: Scheme of soil failure under mobile machine mover.

The works by V. F. Babkov and M. A. Tsytovych (Babkov, Bezruk, 1986, Tsytovich, 1983) are basic researches into changes taking place in soil under load. In general, the process of soil compaction by timber transport, agricultural or other mobile machine movers occurs according to the similar patterns. Therefore, this problem is covered in the works of scientists in the field of agriculture, such as Y. S. Ageykin, V. V. Guskov, V. V. Katsygin, M. G. Becker et al., as well as forestry, such as G. M. Anisimov, V. M. Kotykov, N. I. Byblyuk, F. Seixas, M. Saarilahti, I. Wästerlund et al.

According to the results of those researches, the physical model of soil surface compaction and rutting is similar to soil stamping. In general, the rutting process consists of three phases (Fig. 1) (Guskov, 1988).

During phase one (section I), there is soil compaction only. Phase two (section II) is characterized by the formation of the compacted soil core, which acts like a wedge and not only consolidates the lower soil layers but also moves them sideways. During phase three (section III), the soil is deformed mainly due to the soil displacement and failure on the so-called sliding surfaces which bound sections II and III from below. The soil particles move in the direction of less stressed sections, which is indicated by local protrusions on the mover edges.

3 Modeling of the process of rutting by timber transport machines

The dependence between pressure p and settlement of stamp h during soil mashing is shown by graph (Fig. 2) (Karapetyan, 2010).

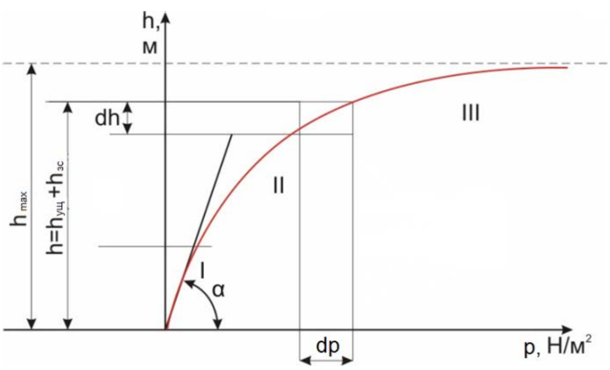

Figure 2: Stamp settlement dependence on pressure.

The same three phases (Fig. 1) can be seen on curve $h=f(p)$ (see Fig. 2), which differently represent the dependence between pressure and deformation rating. During the initial pressing phase (section 1), deformation is proportional to pressure. In section II, the dependence is non-linear because of shear deformations emerging in soil in addition to compaction. In section III, the soil compaction stops and plastic displacement begins: the soil reaches its ultimate stress limit or endurance limit.

Various formulas were offered for the mathematical expression of the dependence $h=f(p)$ in soil mechanics. The formula by V. V. Katsygin, which follows the law of hyperbolic tangent, is considered to be one of the most accurate (Byblyuk, 2004)

$$h=\frac{\sigma_0}{k}\frac{1}{1-p/\sigma_0}\,arcth\,\frac{p}{\sigma_0}. \quad (1)$$

The above formula is quite complex and requires the determination of a great number of empirical coefficients. The work (Karapetyan, 2010) provides dependences more convenient for practical calculations, based on the application of differential approach to the determination of homogeneous soil deformation.

$$h=\frac{\alpha\cdot p}{1-\frac{p}{p_b}}+\frac{\alpha^2\cdot p^2}{h_{\max}+\alpha\cdot p}, \quad (2)$$

where α is the coefficient of the homogeneous soil linear deformation, p_b is the bearing capacity soil, h_{max} is the maximum soil deformation.

The coefficient α is determined from the formula for the calculation of homogeneous soil deformation in section I (Fig. 2)

$$h=\alpha\cdot p=\frac{1-\mu^2}{E_0}\cdot\omega\cdot b\cdot p, \quad (3)$$

where E_0 is the cumulative soil deformation modulus in the compaction phase with an allowance for both resilient and residual deformations, μ is the coefficient of the soil lateral expansion, b and ω are the deformer width and shape coefficient accordingly.

The bearing capacity soil substantially depends on the initial values of soil consistency ρ_0 and humidity W (which changes several times according to our experimental researches data). Therefore, it is appropriate to determine the maximum soil compaction deformation by means of the equivalent layer method offered by M. Tsytovych (Tsytovich, 1983)

$$h_{max}=H_0\left(1-\frac{\rho_0}{(1-W)\rho_m}\right), \quad (4)$$

where H_0 is the equivalent soil layer thickness, ρ_0 is the initial consistency, ρ_m is the soil consistency with the most compact particles, W is the soil humidity.

Additional horizontal soil displacement is typical for the traction mode due to the mover skidding (Byblyuk, 2004); in this case, the expression for the determination of the rut depth following the single mover passage should be multiplied by value

$$\Delta=\frac{1+\delta}{1-\delta/2} \quad (5)$$

where δ is the mover skidding coefficient.

Repeated timber transport machines passages lead to an increase in the rut depth and soil consistency due to the deformations accumulation. Besides, the total deformation (depth of rut) is a sum of deformations compaction and displacement. To determine the soil compaction rating under a skidding tractor, V. Kotikov (Kotikov, 1995) offered an approach where forest soils are considered as plastic materials. The mechanical property values change for such soils only when stressed and remain constant following stress removal; the compaction deformations change in proportion to pressure. The nature of the accumulated compaction deformations is shown in graph (Fig. 3).

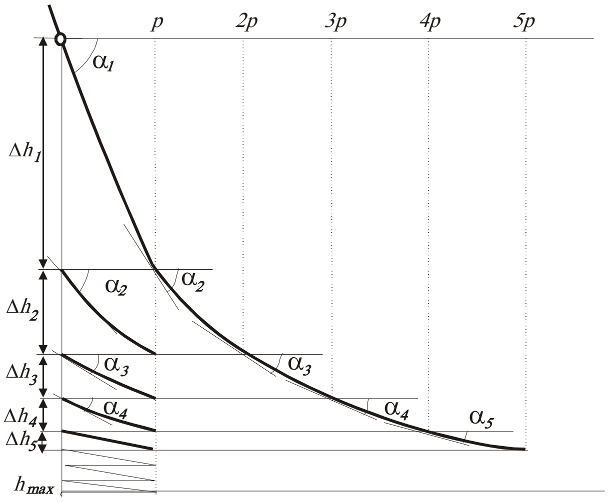

Figure 3: Scheme of compaction deformations accumulation during repeated passages of a timber transport machine.

Within these assumptions and taking into account the approach (Guskov, 1988), the accumulation of the soil compaction deformations during repeated passes of a skidding tractor is expressed by

$$\sum\Delta h=\frac{\alpha\cdot p\cdot n}{1+\frac{\alpha\cdot p\cdot n}{h_{\max}}}+\frac{\alpha\ \cdot p^2}{p_в-p}\cdot\frac{1-\chi^n}{1-\chi}, \quad (6)$$

where n is the number of passages; χ is the deformation accumulation coefficient.

The rut depth calculation using the above dependences for repeated compactions provides a good match of calculated and experimental data for agricultural lands (Karapetyan, 2010), i.e. previously scarified soil surfaces with a low bearing capacity.

According to our experimental researches (Styranivskyy, Styranivskyy, 2010) and the results set forth in the work (Wästerlund, 1989), the presence of turf and tree roots have a substantial effect on the forest soil deformation. In addition, skid roads are often covered with a layer of logging waste to reduce rutting intensity. Therefore, it is recommended in the work (Katarov, 2009) to accept the deformation equivalent modulus E_{eq} as the forest soil deformity characteristic and to calculate the rut depth with repeated passages of a timber transport machine by means of the following dependence:

$$H_n = \frac{\omega \cdot p_{\max} \cdot b \cdot (1-\mu^2) \cdot (1+\chi \cdot \lg n)}{E_{eq}}; \tag{7}$$

$$E_{eq} = \frac{E_s \cdot k_r}{1 - \frac{2}{\pi} \cdot \left(1 - \frac{1}{\left(\frac{E_{eq}}{E_s \cdot k_r} \right)^{n-1}} \right) \cdot arctg \left(\frac{h_w}{D} \cdot \left(\frac{E_w}{E_s \cdot k_r} \right)^n \right)}, \tag{8}$$

where p_{max} is the maximum pressure on the soil surface, E_s is the soil deformation modulus with no roots, k_r is the empirical coefficient defining the soil surface stabilization with tree roots, E_w and h_w are the deformation modulus and logging waste layer thickness accordingly.

However, according to our experimental data (Styranivskyy, Styranivskyy, 2010), the logging waste layer deformation modulus substantially depends on many factors (waste type and humidity, layer density and thickness etc.), which change in the course of timber transport machines traffic and thus complicate accurate determination of the value E_w. The effect of the forest soil surface stabilization with roots, turf or logging waste layer can be allowed for by means of empirical coefficients k_r, k_t and k_w with a satisfactory accuracy for subsequent calculations; their maximum values are determined experimentally, and current values are calculated using the following formulae:

$$k_{r,t,w} = 1 + \alpha_{r,t,w} \frac{H_{r,t,w} - H_{n-1}}{H_{r,t,w}} \quad \text{if } H_{r,t,w} < H_{n-1};$$

$$k_{r,t,w} = 1 \quad \text{if } H_{r,t,w} \geq H_{n-1}, \tag{9}$$

where $\alpha_{r,t,w}$ is the coefficient of the soil deformation modulus increase by means of stabilization with roots, turf and logging waste accordingly, $H_{r,t,w}$ is the soil layer thickness with roots, turf and logging waste accordingly.

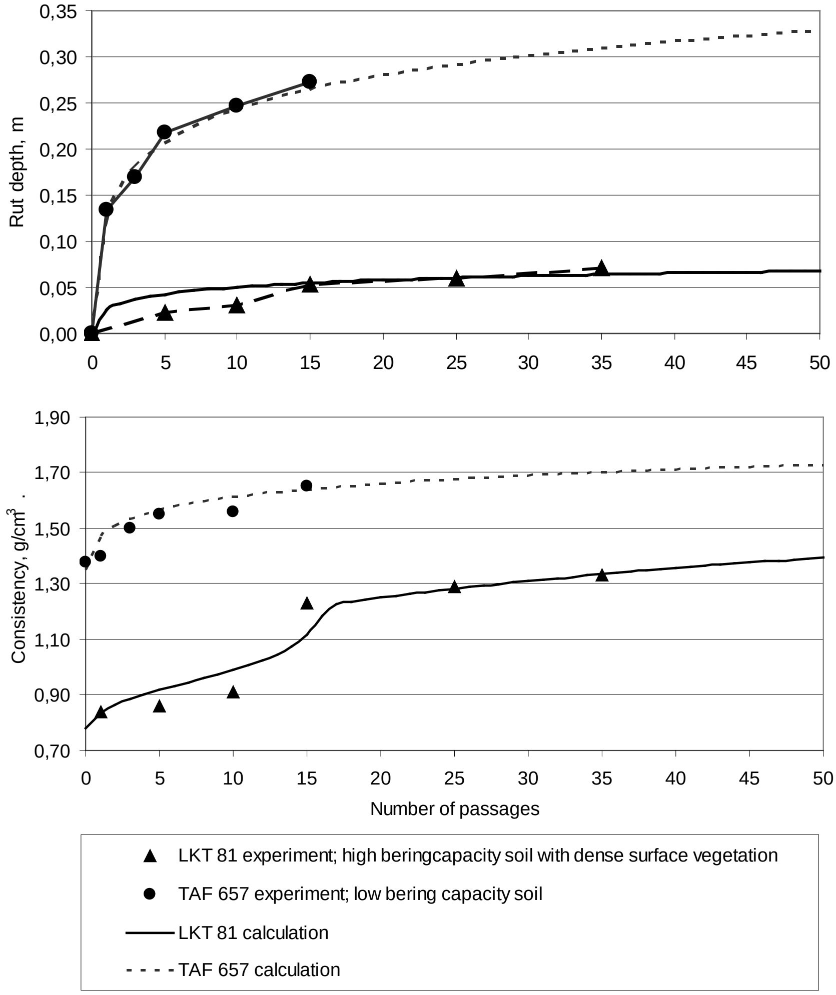

Figure 4: Calculated data as compared to experimental data of the rut depth change depending on the number of passages of timber transport machines

In this case, the dependence for the determination of E_{eq} will be

$$E_{eq} = E_s \cdot k_r \cdot k_t \cdot k_w \ . \qquad (10)$$

According to the work (Katarov, 2009), α_r=0.64 and H_r=0.3 m for mixed and coniferous timber stands on loamy soils; we have established (Styranivskyy, Styranivskyy, 2010) that α_t=1.5 and H_t=0.05 m.

The soil consistency increase with the repeated passages of a timber transport machine is calculated by means of the following dependence:

$$\rho_n = \rho_0 + \frac{\rho_0 \cdot H_n}{H_0 - H_n}, \qquad (11)$$

where ρ_0 and ρ_n are the initial soil consistency and the consistency following an n^{th} passage of a timber transport machine accordingly, H_0 is the deformation propagation depth.

4 Discussion

To estimate the rutting process modeling accuracy, Fig. 4 shows the results of field tests for wheeled timber tractors LKT 81 and TAF 657, as well as the calculation of the track depth depending on the number of passages on condition that the wheel is absolutely rigid and has a contact point *b* wide (wheel width) and *r* long (wheel radius) (Owende, Lyons, Haarlaa, Peltola, Spinelli, Molano, Ward, 2002).

Certain divergence of calculated and experimental data (Fig. 4) can be explained by a number of reasons, one of which is the inconsistency in the soil physical-mechanical properties on the way of a machine and in the course of repeated load. We have also found a substantial effect of the surface vegetation (LKT 81 experiment, Fig. 4) on the bearing capacity soil before this layer is damaged. Nevertheless, according to the statistical processing of the experimental data, the dependence (7) adequately reflects the general trend and the nature of rut depth increase depending on the accumulated compaction deformations in case of repeated passages of a timber transport machine. The divergence of calculated and experimental data is 2.6–11.5% for the rut depth and 0.7–10.2% for the soil consistency.

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Forwarder operating conditions in Norway as quantified through GPS tracking

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Abstract: Forwarder working conditions in Norway were assessed using a combination of GPS tracking and terrain analysis. We modeled distributions describing typical driving and working elements for forwarders and compared these with models available in international literature. Driving elements included driving empty, driving while loading and driving loaded, while unloading time, driving speeds, relocation distances and relocation sequences were also identified and measured. Average extraction distances were 980 m and average driving speeds were 3.2 km/h)

Keywords: Forwarders, productivity, terrain analysis

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1. Introduction

Forwarder extraction costs make up around 40% of the total harvested cost of timber delivered to roadside. For given load sizes, extraction costs are determined by forwarder cycle times. Apart from loading and unloading, time consumption is a product of extraction distance and driving speed. Extraction distance is influenced by forest road network density, while travelling speed is largely determined by topography and surface unevenness. Topographic features of relevance include slope length, inclination in and across the travelling direction, as well as bearing capacity. Surface unevenness or micro-topography is a measure of the intensity and size distribution of obstacles that have to be traversed.

Being able to more accurately predict forwarder cycle times would improve production planning and allow contractors to price tasks correctly. However, driving distances and conditions vary for each load, and methods for quantifying these in conventional productivity models are generally inadequate in capturing the variation experienced. As a result, only around 50% of the variation of forwarder productivity is described by such models (Eriksson & Lindroos, 2014). Less specific follow-up data can provide a useful basis for the calculation of general productivity models. Manner et al. (2016) describe how large data can be captured and interpreted from on-board software interpreting CAN-bus control signals. While exact load volumes cannot be determined without on-board scales, the methods described in that study provide robust work element models.

To get a better understanding of the operating conditions for forwarders in Norway and especially the variation in these conditions, we carried out a GPS based follow-up study of forwarders over a period of approximately two years.

2. Material and Methods

The work cycles of a varying number of forwarders was logged using iPad based GPS receivers over a time span of roughly 2 years. The GPS derived tracks were plotted against terrain models and forest maps and analyzed in SAS and a QGIS environment. Using a forest map background, extraction trails were classified into 4 segments (driving in the harvested stand, driving in terrain in the forest, driving on a skid trail, and driving on a forest road). Four work elements were also defined; driving empty, loading and driving while loading, driving loaded, and unloading.

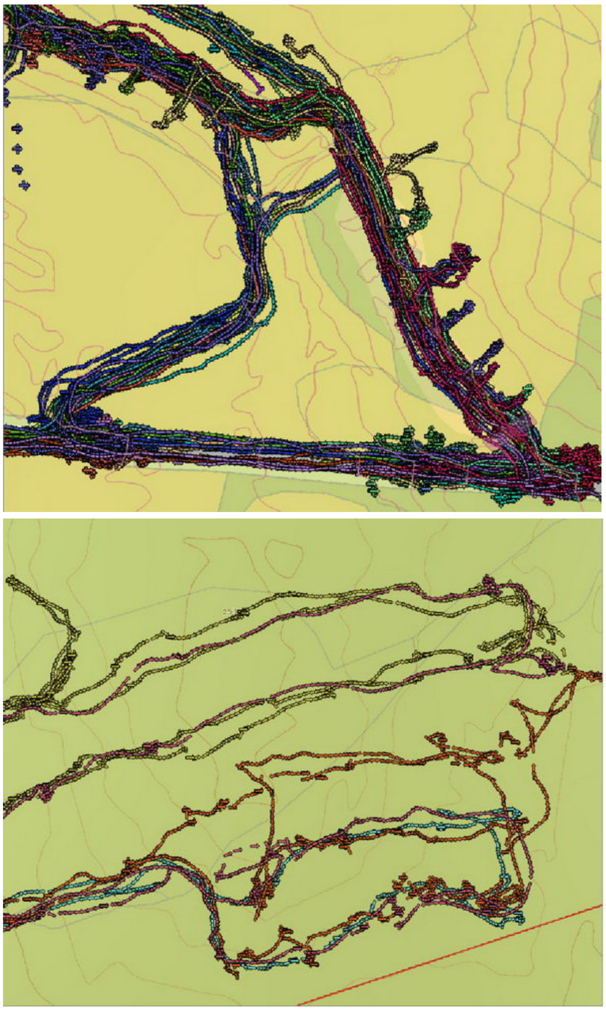

Figure 1: A graphic showing the many extraction cycles at the landing (up) and the less dense distribution of individual cycles in the stand (down).

Loading was assumed to be taking place when the GPS position remained stationary for longer periods while in the forest. Unloading was assumed to be taking place when the GPS position was relatively constant at the landing.

For each of the travel segments, initial and final altitude were recorded, allowing average slope to be calculated. Digital elevation models (DEMs) were generated at the highest resolution available for each area and the data used in determining slope at every GPS data point.

3. Results & Discussion

The mean extraction distance found in the study was 983 m. On average, this distance was made up of around 134 m driving in the harvested stand, 443 m driving in the terrain, 246 m on skid trails, and around 160 m on forest roads (figure 2). Corresponding mean slopes faced on the extraction trails were 10% when driving in the stand, 8% in the forest, 9 % on the skid trails, and 2% on the forest roads.

Driving speeds showed some variation but the median values were around 0.9 m/s (54 m/min or 3.2 km/h), which were slightly higher than expected. (figure 2).

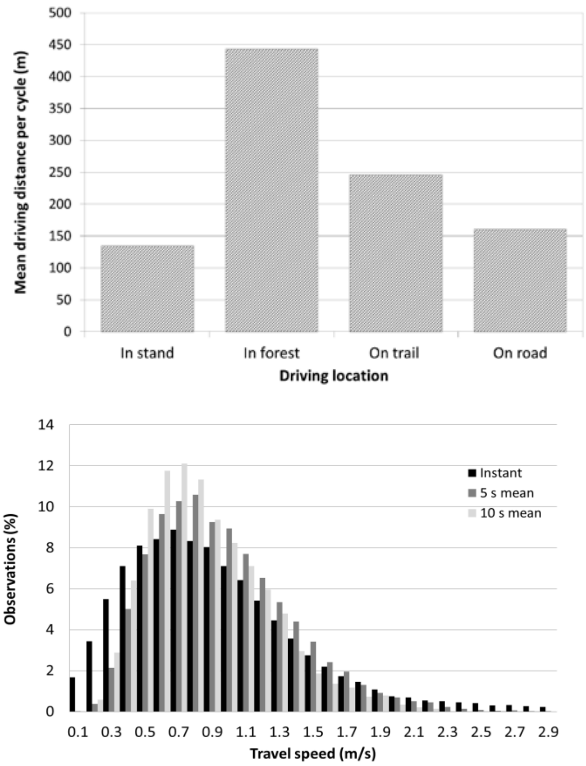

Figure 2: Breakdown of driving segments and distances on an average extraction cycle (up) and the distribution of travel speeds, measured as instantaneous speed (calculated per second), as well as average speeds for 5 and 10 second periods (down).

GPS data from forwarder trails provided a good basis for the calculation of basic statistics describing forwarding conditions. They also provide the basis for rudimentary time studies including machine utilization levels, work place time, breaks, driving time, loading time and unloading time. In addition, they can show both the sequence and distances the machine is relocated between work objects.

GPS data alone is not sufficient for detailed productivity analysis and they should be supplemented with other follow-up data sources such as CAN-bus (Manner et.al., 2016). This would make it possible to identify whether a stationary or bouncing GPS signal e.g. implies loading or unloading, or whether the stop is due to other reasons. Multi-path GPS error is a known problem in forest environments and can cause some problems when analyzing high resolution data (e.g. per second). The 'bouncing' signal will result in unrealistically high travel speeds and incorrect heading calculations between successive points. This can be partially addressed through smoothing over a longer time window, e.g. 5-10 seconds (figure 2).

The analysis of GPS data cannot be fully automated and carrying out a comprehensive study is labour intensive. The identification of unique forwarding cycles in the dataset requires the identification of a geographic cut-off point near the landing. This requires manual identification, and is complicated by the presences of multiple landings and extraction routes from a single source.

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Wound occurrence analysis and potential wound area damage probability of trees adjacent to skidding trails in Greek beech stands

Petros A. Tsioras[1]*, Zbigniew Karaszewski[2], Diamantis K. Liamas[1]

Abstract: Residual tree damage is an undesirable yet inevitable impact of forest operations. The objective of this paper was to analyze the damage attributes caused to the remaining trees during skidding in four different beech stands of Northern and Central Greece, where different wood extraction equipment had been implemented. All tree damages in a width of 2 m along both sides of the skidding trails have been recorded and analyzed after wood extraction was completed. The percentage of damaged residual trees ranged from 16.9 % to 28.2 %. Increased number of saplings were uprooted or destroyed in parts of the stands with high natural regeneration. The average number of wounds per tree ranged from 1.33 to 1.90 damages, with the majority of them inflicted up to the height of 1 m. In all sites mean wound size had high values (88.9 cm^2 - 1189.6 cm^2) indicating high risk for fungi infection. Ordinal Logistic Regression has been used in order to estimate the probability of different wound area categories. The type of the extraction equipment had a profound effect on the damage attributes. Better planning and implementation of the forest operations combined with training of the forest workforce could minimize residual tree damage.

Keywords: Residual stand damage, wood extraction, Ordinal Logistic Regression, forest operations

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1. Introduction

Selective harvesting, either single-tree of group selection, is the predominant method in Greece. Selective harvesting results in limited changes to the forest stands compared to other more intensive harvesting methods (Caspersen 2006). However, regardless of the method and the systems used, damaging of the remaining trees is inevitable. Excessive wounding of the residual trees may reduce future partial harvest benefits, such as a greater tree vigor and improved stand quality, as well as compromise the aesthetic and recreation values of some stands (Bustos et al. 2010). Injuries become an input port for fungi decays very often (Vasiliauskas 2001) resulting in further wood devaluation or even lower increments (Heitzman and Grell 2002). Thus, wounds on the residual trees suggest for the forest management a problem which appears in a long term (Dvořák and Cerny 2003).

Various factors affect the amount of skidding damage on the remaining trees. Such factors include the harvesting site, tree species and logging season (Froehlich 1976), the skidding period (Limbeck-Lilienau, 2003), slope (Stampfer et al. 2001), as well as the level of training and consciousness of working crews (Tavankar et al. 2013). Wound characteristics are related to the evolution of the wound and potential future losses. Wound dimensions, area and location on the trunk, are important with regard to the development of fungi infection, which differs among species. In beech, complete closure without infection has been correlated to the wound width (Hosius 1967). The area of the damage is also important. Wounds larger than 10 cm^2 increase the possibility of decay development.

Objective of this paper was to analyse wound occurrence on remaining trees in pure and mixed beech stands where different harvesting systems with regard to skidding operations have been implemented. It was hypothesized that a use of four types of different skidding operations would cause tree wounds of different areas. Ordinal Logistic Regression (hereafter OLR) has been used in order to estimate the odds of different wound area categories in the four sites. Our results provide new information into the residual tree damage levels along skidding trails of beech stands in Greece in an effort to minimize the environmental impacts of wood extraction systems.

2. Material and Methods

Field work took place in four areas in Northern and Central Greece: Arnaia (Site 1), Stefanina (Site 2), Karitsa (Site 3) and Perivoli Grevenon (Site 4) (Figure 1). Detailed description of the study sites and trail network attributes are described in Tsioras and Liamas (2015). The sites were chosen as characteristic for stand conditions and the differentiation of the implemented wood extraction equipment.
The trees were marked by experienced forest officers of the Forest Service Office for each site. In all study sites the trees were felled, delimbed and topped motor-manually. Fallen trees were cross-cut and processed with chainsaws into various wood assortments at the stump. Roundwood and fuelwood extraction to roadsides or landings took place with different combinations of forest machinery equipment (Table 2). The equipment types under study were very characteristic for Greek conditions; in most cases agricultural tractors were used for wood extraction, equipped with a single or double drum winch, with a cable length of 70-100 m. Mules were used in fuelwood extraction in sites 1, 2 and 3.

The tree wounds were investigated according to the method described by Meng (1978). All damages on the residual trees were recorded with regard to their characteristics, such as location and height on the stem and wound size. Wound depth was also recorded in the cases where wood tissues had been damaged.

Figure 1: Map of the study sites.

Harvesting works were conducted by Forest Worker Cooperatives (hereafter FWCs) assigned by the Forest Service Office in each area. Equipment operators used their own equipment, in order to control performance results and avoid higher residual stand damage due to lack of familiarity with new equipment. Furthermore, the workforce characteristics (age distribution, work experience) were examined in each area in order to eliminate performance differences between experienced and inexperienced forest workers. For this reason, all FWCs with members with work experience less than five years were excluded from further consideration.

Residual tree damage along skid trails (primary and secondary) was observed and recorded after felling. In order to determine the percentage and types of damage, all trees along the skidding trails at a distance of two meters from the end of each skidding trail side were examined. All damages on trees with a DBH ≥ 7 cm, as well as destroyed or uprooted saplings (young trees with a DBH < 7 cm) were recorded. The width of the skid trails was not fixed, but ranged from 3.4 m to 4.1 m.

One-way analysis of variance (ANOVA) and Duncan's post hoc test were used in order to find statistically significant differences of wound attributes means between the four study sites. Normality and homogeneity of variance was tested by applying Kolmogorov–Smirnov and Levene's tests, respectively. The SPSS Ordinal Regression Procedure or PLUM was used for estimating the wound area damage odds for the study. Significance was set at the level of $p < 0.05$.

3. Results

A total of 1789 live stems with a DBH ≥ 7 cm were sampled throughout the study sites of which 388 have been wounded (Table 2). The percentage of damaged residual trees varied from 16.9% (Site 4) to 28.2% (Site 3). The majority of the wounded stems belonged to beech in all study sites. The number of damaged saplings varied greatly, from 5 in Site 1 up to 141 in Site 4. This result is analogous with the stand condition, as, especially in Site 4 and to a lesser degree in Site 3, more saplings were wounded or uprooted saplings in parts of the stand with abundance of natural regeneration.

Trees suffered different number of wounds across the study sites (Table 3). This number varied from 1 up to 4 in the first three sites, and from 1 to 5 in Site 4. This resulted in a mean of 1.33 - 1.44 wounds per tree for the first three sites, while the respective value (1.90 wounds per tree) for the fourth site was found significantly higher ($F = 9.641$, $df = 3$, $p < 0.0001$). Finally, no significant differences were found between the number of wounds inflicted on beech and the other tree species, in any of the study areas.

The study was conducted in a buffer zone of the first two meters along the main and secondary skid trails (Table 4). Mean damage distance average from 38.2 cm to 81.4 cm ($F = 33.497$, $df = 3$, $p < 0.0001$). In all areas, the majority of the damages (74.2% - 94.6%) were found in a distance range of 0 - 100 cm from the edge of the skidding trails.

3.1. Damage characteristics

The majority of all wounds were inflicted at the height 30 – 100 cm (Table 5). However, in Site 1 damages on the root area were the most common, with a frequency twice as much compared to the other sites ($\chi^2 = 58.734$, $df = 9$, $p < 0.0001$). As a result of the different distribution of wounds between the various sites, mean height also varied, ranging from 33.5 cm up to 62.2 cm ($F = 9.973$, $df = 3$, $p < 0.0001$).

Table 1: Wood extraction equipment per study site.

	Wood extraction equipment				
	Fiat 70-90	**Bobcat 733**	**MBTrac 800**	**Landini Powerfarm 100**	**Massey Ferguson 565**
Site used	Site 1	Site 1	Site 2	Site 3	Site 4
Engine	3.6L, 4-cylinder	2.2L, 4-cylinder	3.8L, 4-cylinder	4.4L, 4-cylinder	3.9L, 4-cylinder
Power	70hp	46hp	78hp	102hp	60hp
Fuel	diesel	diesel	diesel	diesel	diesel
Rear lift (kg)	3350	-	3000	-	-
Torque (Nm)	-	143.0	263.1	416.0	230.0
Weight (kg)	3400	2500	3950	3642	2821
Length (m)	3.58	3.05	4.15	4.16	3.76
Height (m)	2.63	1.92	2.81	2.56	2.43
Width (m)	2.05	1.40	2.12	2.10	1.91
Cable length (m)	85	60	90	95	80

Table 2: Number and percentages of damaged trees and saplings.

Study area	Examined [n] [trees] (N)	Wounded trees [n] (N)	Damaged saplings [n] (N)	Damage percent All species (%)	Beech (%)	Other (%)
Site 1	760	151	5	19.8	66.2	33.8
Site 2	351	86	3	24.5	100.0	-
Site 3	322	91	28	28.2	82.4	17.6
Site 4	356	60	141	16.9	58.3	41.7
Total	1789	388	177	21.7		

Table 3: Wounds per tree statistics across the different study sites*.

		Wounds per tree species						
		Beech		Other species		All species		
Study area	Range (n)	Mean (cm)	Sd (cm)	Mean (cm)	Sd (cm)	Mean (cm)	Sd (cm)	s.e. mean¤ (cm)
Site 1	1-3	1.34	0.59	1.42	0.61	1.36[a]	0.59	0.05
Site 2	1-3	1.33	0.54	-	-	1.33[a]	0.54	0.05
Site 3	1-4	1.47	0.70	1.28	0.46	1.44[a]	0.67	0.07
Site 4	1-5	2.08	1.31	1.70	0.76	1.90[b]	1.10	0.14

*Same letter denotes no significant difference at the chosen level (5%)
¤ Standard error mean

Table 4: Percentage occurrence of residual tree damages according to distance from the edge of the skid trail.

	Distance 0-20 (cm)	21-40 (cm)	41-60 (cm)	61-80 (cm)	81-100 (cm)	101-200 (cm)	Mean distance (cm)
Site 1	35.3	26.5	18.1	14.7	-	5.4	46.1[a]
Site 2	45.6	23.7	13.2	2.6	2.6	12.3	38.2[a]
Site 3	28.2	28.2	19.1	13.0	3.8	7.6	48.6[a]
Site 4	9.2	15.0	28.8	7.5	13.8	25.8	81.4[b]

*Same letter denotes no significant difference at the chosen level (5%)

Wounds were unevenly distributed in area classes in the study sites (χ^2 = 109.794, df = 9, p < 0.0001). Mean wound size in Site 1, 3 and 4 ranged from 466.3 cm^2 to 1189.6 cm^2 (Table 6). The only exception is site 2, where the 78.1 % of wounds had an area between 10 - 200 cm^2 (mean 88.9 cm^2). A large number of exposed roots were evident on Site 1. For this reason, further analysis of the wounds on the tree stems was conducted (Table 7). Mean wound area values were found considerably lower, ranging from 80.5 cm^2 up to 552.4 cm^2 (F = 15.592, df = 3, p < 0.0001). The largest mean for wound width and length were found in Site 1, whereas the highest mean for wound depth was found in Site 3.

With regard to slope gradient, the large majority of wounds has been recorded to slope up to 20%. In the first three sites the frequency of wounds decreases as slope increases, starting from the 0 – 10% class, whereas in Site 4 the highest wound frequency was recorded at slopes of 10 – 20%, followed by slopes of 20 – 30%. Statistical analysis failed to reveal any association between the slope class and a) the number of wounds per tree and b) wound size class in any study area.

3.2. Ordinal Linear Regression

An Ordinal Linear Regression Model was built using the following predictor variables:

- HS: Harvesting system – (nominal variable with four categories, one for each system)
- SP: Tree species (nominal variable with four categories)
- DBH: Diameter at breast height (in cm) – continuous variable
- WH: Wound height (distance from the ground level in cm) where the wound started – continuous variable

The dependent variable was the wound area class (hereafter WAC), an ordinal variable of four levels.

The model fitting information suggested that the model can be used (χ^2 = 142,293, df = 5, p < 0.001). Furthermore the Nagelkerke Pseudo R-Square was found to be 0.338. The model parameter estimates are described in Table 8.

The odds of a wound caused by HS1 to belong to the largest wound area category (WAC=4) was too high, 2.721 (95% CI, 1.859 to 3.984) times that of a wound caused by HS4 (basis for comparisons) - a statistically significant effect (Wald statistic 26.478, p < 0.001) (Table 9). The odds ratios of HS2 and HS3 were also significant but with a substantial difference; the odds of a wound caused by HS3 to belong to the largest wound area category was 1.659 (95% CI, 1.092 to 2.520) times higher than that of HS4, whereas that of HS2 is considerable lower only 0.186 (95% CI, 0.117 to 0.296) times that of HS4.

According to the model parameter estimates an increase in DBH (expressed in cm) increases the odds of a wound belonging to the largest wound area category by 1.03 (95% CI, 1.017 to 1.043). Finally, increasing the distance of a wound from the ground level by 1 cm increases the odds by 0.995 (95% CI, 0.993 to 0.998) times.

Table 5: Distribution percentages of the damages according to their location on the tree.

	Location on the tree				
	Root (%)	**Bole (%)**	**30-100cm (%)**	**> 100cm (%)**	**Mean value (cm)**
Site 1	39.9	12.8	38.9	8.4	39.9[ab]
Site 2	16.7	34.2	43.9	5.3	33.5[a]
Site 3	20.8	20.8	47.7	10.8	48.7[b]
Site 4	20.5	19.7	40.2	19.7	62.2[c]

*Same letter denotes no significant difference at the chosen level (5%)

Table 6: Wound area statistics*.

	Wound area class				
	0-10 cm^2 (%)	**10-50 cm^2 (%)**	**50-200 cm^2 (%)**	**> 200 cm^2 (%)**	**Mean value (cm^2)**
Site 1	1.5	8.3	21.6	68.6	1189.6[a]
Site 2	8.8	37.7	40.4	13.2	88.9[b]
Site 3	0.8	14.6	29.2	55.4	466.3[c]
Site 4	2.9	24.2	30.7	42.2	468.3[c]
Total					610.3

*Same letter denotes no significant difference at the chosen level (5%)

Table 7: Wound damage dimensions for trees with DBH ≥7 cm. (Trunk measurements)*.

	Width		Height		Depth		Area	
Study area	**Range (cm)**	**Mean (cm)**	**Range (cm)**	**Mean (cm)**	**Range (cm)**	**Mean (cm)**	**Range (cm)**	**Mean (cm)**
Site 1	4-80	14.80	1-180	34.57	0.3-8	2.02	30 -3200	552.36[a]
Site 2	2-50	13.23	1-14	5.19	0.5-2.5	1.13	4-500	80.46[b]
Site 3	2- 4	11.32	3-116	26.99	1-6	3.57	9-1856	339.28[c]
Site 4	1-34	8.88	1-135	24.61	0.5-10	1.75	4-3570	288.08[d]

*Same letter denotes no significant difference at the chosen level (5%)

Table 8: Model parameter estimates.

		Estimate	**s.e.**	**Wald**	**df**	**Sig.**	**95% CI Lower Bound**	**95% CI Upper Bound**
Threshold	[WAC = 1]	-3.196	0.303	110.964	1	0.000	-3.791	-2.601
	[WAC = 2]	-0.767	0.223	11.842	1	0.001	-1.204	-0.330
	[WAC = 3]	0.774	0.221	12.233	1	0.000	0.340	1.207
Location	WH	-0.005	0.001	12.290	1	0.000	-0.007	-0.002
	DBH	0.029	0.006	20.114	1	0.000	0.016	0.042
	[HS=1]	1.001	0.195	26.478	1	0.000	0.620	1.382
	[HS=2]	-1.682	0.237	50.466	1	0.000	-2.145	-1.218
	[HS=3]	0.506	0.213	5.637	1	0.018	0.088	0.924
	[HS=4]	0[a]			0			

Table 9: The odds ratios for the model variables.

		Odds ratio	Lower	Higher
Threshold	[WAC = 1]	0.041	0.023	0.074
	[WAC = 2]	0.464	0.300	0.719
	[WAC = 3]	2.167	1.405	3.344
Location	WH	0.995	0.993	0.998
	DBH	1.030	1.017	1.043
	[HS=1]	2.721	1.859	3.984
	[HS=2]	0.186	0.117	0.296
	[HS=3]	1.659	1.092	2.520
	[HS=4]	1.000		

4. Conclusions

The study examines the impacts of skidding operations on the residual trees along skidding trails in beech stands. This is an important issue for forest management, as skidding damages may lead to degradation of the future forest products. The findings of this study agree with those in other studies with regard to the frequency of damaged trees and the damage area. However, these preliminary results should not be generalized for all the beech forests in Greece, since the study is still ongoing with data from different areas. This study should be further expanded to other species nationwide.

OLR can be of use in the analysis of residual stand damage. The type of skidding equipment was found to have a profound effect on the wound area in our study sites. At Site 1 the use of a BOBCAT 733 equipped with iron tracks, was, in many cases, responsible for excessive root damage that could have been avoided with the use of different machinery. The combination of continuous and categorical variables in OLR can help us gain more insight on the complexity of damage-inducing mechanism. Therefore, research efforts should also continue on the implementation of OLR with even larger datasets and more predictor variables.

Useful suggestions to reduce skidding damage include careful planning the trails, utilizing the optimum trail spacing, keeping the trails straight and directional felling of trees on an angle towards trails. It is also important to keep the skidders on the trails, limit skidding operations during wet periods, use the correct type and size of skidder (i.e. not too large and not too small) as well as utilize bumper trees where required. However, none of the above mentioned findings and conclusions will make a difference unless actions and initiatives, aiming at increasing the professional capacity of the people involved in forest operations, take place. In this study, the low level of residual stand damage in Site 2 could be attributed to the higher level of professionalism of the working team, which was reflected on its newer equipment, compared to the other working teams, and better coordination among its members. This suggests that more importance should be given on the human factors in forest operations. Well trained and motivated forest workers and machine operators can guarantee increased productivity, safety during work and reduced environmental impacts.

5. Remarks

Paper has been partially published in the: Tsioras, P. A., & Liamas, D. K. (2015). Residual tree damage along skidding trails in beech stands in Greece. Journal of Forestry Research, 26(2), 523-531. doi: 10.1007/s11676-015-0056-6

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Moisture sensitive rutting models for fine grain mineral soils

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Abstract: For vehicle mobility, a soil must have sufficient bearing capacity to prevent vehicle from sinking too deeply. Bearing capacity of fine grain mineral soils is heavily dependent on soil moisture content. In theory, the finer the grain size is, the greater is the effect of moisture on the mechanical properties of soil. Minimizing soil disturbance would be greatly aided by reliable high-resolution soil trafficability tools. Generating understanding about the resistance of soil to mechanical disturbance is therefore a key factor in soil trafficability assessment. The paper presents preliminary results of a driving test carried out on two fine grain mineral soil forest sites in Southern Finland in 2015. The project aims at developing moisture sensitive rutting models for fine grain mineral soils adequate for practical use in forestry.

Keywords: bearing capacity, cone penetration resistance, trafficability, VWC

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1. Introduction

Soil bearing capacity together with machine equipment properties are important parameters in preventing rut formation and soil compaction during terrain transport (Bygdén et al., 2004). Sensitive soils with low bearing capacity typically include peatland and fine textured upland soils. However, the behaviour of these soil types regarding weather conditions differ, but it can be partly predicted using different soil characteristics and methodologies. Forest soils are characterized by the presence of continuous vegetation cover and root network, stumps and stones and high rate of organic matter.

Upland forest soils usually have an organic top layer of 2-20 cm consisting of a mixture of living and decomposed plants. Tree roots are mainly concentrated to the uppermost soil layer. Particle size distribution is the most important characteristics of the mineral soil. Upland soil types are generally divided into sediment or till soils depending on origin, and according to particle size. Sediment soils is dominated by a single particle size while till soils have mixed particle size. Strength of fine grain mineral soils is very dependent on the moisture content while the strength of coarse soil types such as sand is poorly correlated with the moisture content (Freitag, 1987).

Cone penetrometer is widely applied tool in assessing compaction or rutting of forest soils (e.g. Saarilahti and Anttila, 1999; Eliasson, 2005; Poršinsky et al., 2006; Sakai et al. 2008; Siren et al., 2013). While the previous investigations have provided important information on the relationship between cone penetration resistance and trafficability of forest soil, the models can only be applied in circumstances similar to these studies.

As mechanical properties of fine-grained soils are highly depended on moisture content, it is important, that sensitivity of soil moisture content on mechanic properties could also be taken into account in predictions of soil trafficability. The idea of this type of modelling is earlier been raised and demonstrated by Hintze (1990). Vega et al. (2009) has presented a modular terrain model that link temporal variations into forest soil trafficability. This paper presents preliminary results of large scale driving tests carried out on two fine grain mineral soil forest sites in Southern Finland in 2015. The project aims at developing moisture sensitive rutting models for fine grain mineral soils adequate for practical use in forestry.

2. Materials and methods

Field studies were conducted on two separate test sites located in the municipality of Vihti in southern Finland. Both sites, called here A and B comprised Norway spruce dominated forest that were growing on fine-grained mineral soil. Site A comprised three blocks (numbers 1-3) and site B two test blocks (4-5) that all comprise three parallel test trails (1-3) 20 m in length and 5 m in width. In site A test blocks were placed successively to each other on the test trails and in site B test blocks were placed parallel to each other on the test trails. Each test trail was further divided into four study plots, 5 m in length and 5 m in width, placed successive to each other (named 1 to 4 from start of the test trial). As a result, each study plot was named with 3-digit code, the first digit indicating block, the second indicating test trail and the third indicating study plot (e.g.123=Block 1, trail 2, study plot 3).

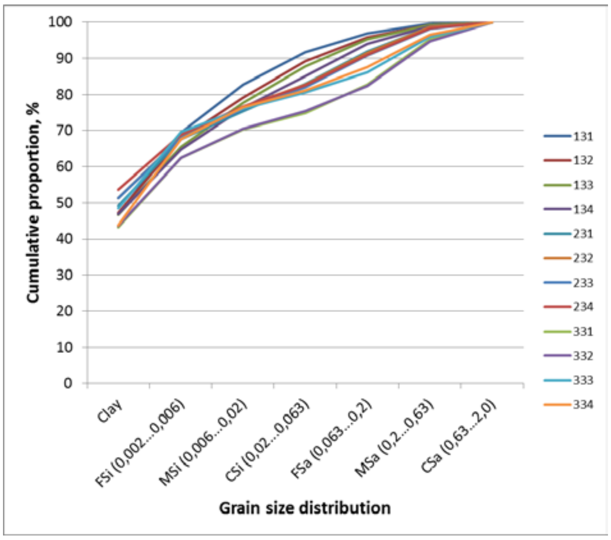

Figure 1: Grain size distributions of soil samples taken from study plots within block A along trail 2.

Prior to test trials, dbh of all trees within the sample plot was measured. Height was measured of selected sample trees. Stand characteristics for each sample plot were calculated using the KPL software. Stand density (N), average diameter at breast height (DBH), average length (H), basal area of trees (BA) and volume of trees (V) were calculated for each plot. The study sites were harvested prior to the first attempt in August with an 8-wheeled harvester with boom reach of 10 m. The harvester travelled outside the actual study trials to keep the test site intact. Trees were processed outside the study trails. Consequently, study trials had no ruts, no compaction nor branches protecting the soil prior to trials with forwarder. In site A, trees were planted on rows; distance between rows being roughly 2.5m. Trails were placed to enable forwarder tyres to run between the stumps of the cut trees. Site B was of natural origin which means that forwarder tyres travelled over certain number of stumps along the test drives. While harvesting, boundaries of the study plots were marked on the ground.

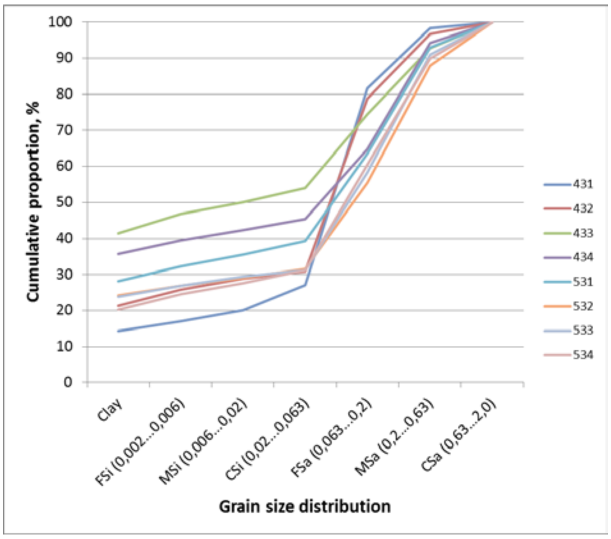

Figure 2: Grain size distributions of soil samples taken from study plots within block B along trail 2.

Test drives were conducted during three periods of the autumn; the first test in late August, the second in November and the third in December. In the first test on site A, the forwarder drove along the middle test trail (trail 2), in the second the trail on right and in the third test section the trail on the left (trail 1). On site B, tests were performed in August and November only, as bearing capacity collapsed. The test drives were carried out with 8-wheeled Ponsse Elk forwarder equipped with chains on the front bogie and universal Olofsfors Eco tracks on the rear wheels. The mass of the forwarder with the tracks and chains was 20 000 kg. In each test drive the forwarder was loaded with constant mass of pulpwood (9 800 kg) resulting in total mass of 29 800 kg.

Prior to each test drive, two soil samples were taken in the middle of each study plot with a round sampling tube having a diameter of 4.6 cm. The soil core extracted from the soil was divided into three sections, organic layer and two mineral soil subsamples 10 cm in length, the first starting from the upper level of the mineral soil. Thickness of organic layer was measured in the field while the bulk density, volumetric water content (VWC), organic content and grain size distribution were later analyzed in the laboratory.

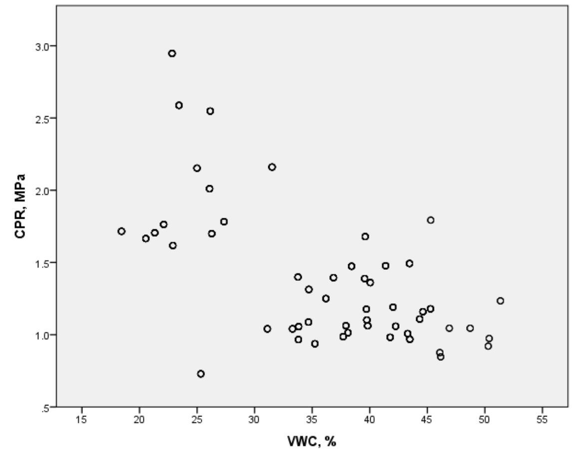

Figure 3: Relationship between CPR and VWC.

Cone penetration resistance was measured with the Eijelkamp Penetrologger 0615SA penetrometer consisting of a 11.28 mm diameter rod and a 60-degree cone. The penetrometer includes a load cell and an ultrasonic depth sensor that captures readings in 1 cm depth increments. The mean of the readings 5…20 cm below the surface of the soil were used as the final CPR value to describe strength of soil (CPR).

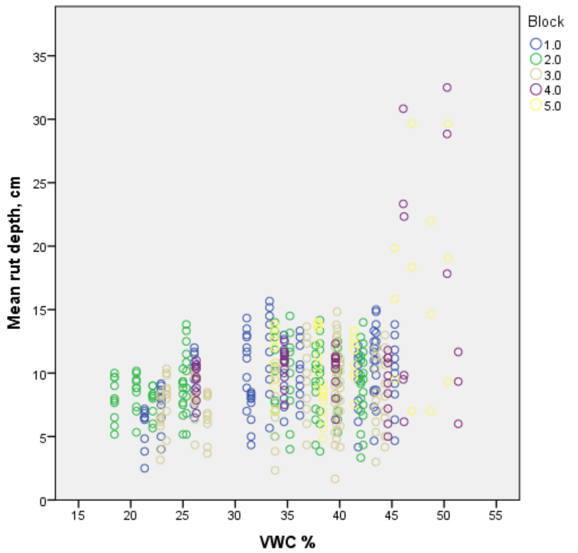

Figure 4: Mean rut depths of all test runs by block and their corresponding VWCs.

After each test run, the depth of the ruts caused by the forwarder on each trail 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 marked on the surface of a nearby tree. Sample line on the trail was marked to the ground in order to keep measuring point location constant. The reference level of the ground outside the wheel ruts was first measured to the left and the right of the wheel rut centre. 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 both wheel ruts 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 is the mean of the rut depths on both sides caused by the forwarder.

3. Results

Particle size distributions of the sample plots that was utilized in November test drives are presented in figures 1 and 2. Soil of site A can be regarded as fatty clay and the variation between blocks and study plots is very small. Soil of site B varies from clay to silt.

As expected, VWC rise from August to November markedly but only slightly from November to December (Table 1). VWC has moderately strong correlation with CPR (figure 3). Rut depth increased rather linearly after each test run. VWC had clear effect on rut depth. Relationship between VWC and rut depth is rather linear until VVW value of roughly 45%. The bearing capacity of soil collapsed on silty soil (site B) when VWC reached the saturation point, which with these bulk densities equates VWC of roughly 48-52% (Figure 4).

Table 1: Mean VWC by test drive (period) and block.

Test drive	Block	Mean	Std. Deviation
1	1	25.5	3.95
	2	21.5	2.42
	3	24.9	1.89
	4	36.3	6.85
	5	37.9	2.75
	Total	29.2	7.69
2	1	36.4	4.56
	2	33.1	4.82
	3	39.2	3.5
	4	48.5	2.48
	5	47.8	1.99
	Total	38.2	6.42
3	1	40.9	4.63
	2	40.4	1.87
	3	40.2	2.72
	Total	40.5	3.27

4. Discussion

Results regarding CPR in similar forest soils may be regarded reliable since they are at the same level as the results obtained by Sakai et al. (2008), Poršinsky (2009) and Vega-Nieva et al. (2009). Rut depths measured in this study are also in line with the rut depths simulated with a modular trafficability model of Vega-Nieva et al. (2009).

As expected, in fine-grained mineral soils, VWC of soil is strongly correlated with the rut depths caused by forest machines. This correlation seems to behave rather linearly until certain point which is rather close to the theoretically maximum saturation point of soil. In our soil types the theoretically maximum VWC varied 48-52%. At the saturation point, cohesive forces break, and soil loses it bearing capacity.

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Chapter 4. Abstracts

Sustainable Forest Products Supply Chains

Dalia Abbas

Abstract: The presentation discusses a sustainability understanding linked to forest products supply chains in the United States. It integrates life cycle and cost assessment as well as the sociological conditions surrounding the supply chain linked to forest operations and operator performance.

Keywords: Forest operations, supply and value chain, life cycle assessment and cost

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Implementing Computer Based Bucking Method in Producing Black pine (*Pinus nigra*) Logs in Bursa, Turkey

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Abstract: The forest resources should be managed by modern methods to ensure sustainable management of forest products and to yield maximum economic value from trees. After felling of trees, the second stage in forest harvesting is bucking which should be performed in an optimum way to increase productivity in timber production. Cross-cutting a tree into the sections that maximizes the total economic gain from a tree is called optimum bucking method. Large number of bucking combinations can be generated for a single tree; therefore, computer-assisted methods should be implemented for quick evaluation of these combinations. Some of these methods may include network analysis, dynamic programming, and heuristic techniques. In Turkey, bucking is generally performed based on loggers' experiences without using any scientific approach. In this study, capability of dynamic programming based optimum bucking method was evaluated to maximize tree value in bucking operation during timber production. Optimum bucking was implemented during a selective cutting of Black pine (*Pinus nigra*) stands located in the city of Bolu in northwest of Turkey. The optimum bucking approach was compared with traditional bucking method, and the approximate contribution of using optimum bucking approach was computed. The results indicated that using optimum bucking method increased the total value of harvested trees by 10.52%. It was also found that longer log lengths with larger diameter potentially increase capabilities of optimum bucking methods

Keywords: Forest products, Optimum bucking, Dynamic Programming, Black pine

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Remarks

Full paper has been published in the *European Journal of Forest Engineering*

Evaluation of selected energy and transport parameters of seed extraction remains

Monika Aniszewska, Arkadiusz Gendek, Witold Zychowicz*

Abstract: Fossil fuels were used for energy purposes For centuries, but from year to year the number of them are running short. The result is search for new renewable energy sources. A wood from forests that do not meet the quality requirements, among others raw materials from solid biomass, is one of main resources. For the energy production and transport purposes harvested wood is bundled or processed to chips. Seed extraction remains can also be used as a by-product for energy generation. The seed extraction waste consists of emptied cones, wings and damaged or empty seeds. Although volume of such waste is not significant in comparison with the amount of energy small-sized wood, but often troublesome for the owners of seed extraction plants, especially those who have to drive seed extraction units powered from the electricity grid. Currently, Poland has 16 seed extraction plants, which include both upgraded, old established before the Second World War, and new based on modern technologies. The latter are usually electrically driven, so that the storage are full of hollow cones. According to data from the years 2009- 2014 in Poland annually seed extraction amount to an average 360 Mg of cones of different species.

The paper attempts to identify oven dry and net calorific value of cones of three species: Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* L.) and European larch (*Larix decidua* Mill.). In order to assess the profitability of transport, specific density, bulk density and the conversion coefficient of empty cones of three most widespread species were determined.

A oven dry calorific value determined in accordance with the standard PN-ISO 1928:2002 was respectively for the Scots pine – 19.50 $MJ \cdot kg^{-1}$, Norway spruce – 20.60 $MJ \cdot kg^{-1}$ and European larch – 20.60 $MJ \cdot kg^{-1}$. Calculated net calorific value of cones of these species amounted to 18.10 $MJ \cdot kg^{-1}$, 19.30 $MJ \cdot kg^{-1}$ and 19.30 $MJ \cdot kg^{-1}$. Using a helium pycnometer density of the cone has been determined, which is in the range from 1097 to 1329 $kg \cdot m^{-3}$. It is lower than the density of wood substance reported in the literature. The bulk density of cones of tested species constitutes from 9 to 18% of a corresponding specific density (in accordance with the PN-EN 15103:2010 standard). The highest value is for the European larch cones, and the lowest for Norway spruce cones. Conversion factor for pine cones and spruce are respectively equal to 0.26 and 0.23, and for European larch cones – 0.55. The determined parameters can be used to estimate economically reasonable transport distance of empty cones of these three species.

Keywords: seed extracion, renewable energy, by-product, calorific value

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Productivity Analysis of Post-fire Salvage Logging Operations in Bursa, Turkey

Ebru Bilici*, Abdullah E. Akay, Didem Özkan

Abstract: Forest fires cause important ecological damages on forest ecosystems especially in Mediterranean countries (i.e. France, Greece, Spain, Turkey, etc.) with hot and dry weather conditions. In order to prevent long term ecological impacts of forest fires, fire-damaged timber should be immediately extracted from the stand since they are vulnerable to major deteriorating agents such as insects, decay fungi, and stain fungi. Besides, some of the economic value of fire-damaged timber can be recovered through post-fire salvage logging operations. Thus, it is crucial to estimate productivity of salvage logging operations and evaluate main factors that affect operational productivity. In this study, it was aimed to analyze productivity of post-fire salvage logging operations performed fire-damaged Brutian pine (Pinus brutia) stands in Mudanya province of Bursa in Turkey. In the study area, forest fire occurred in 29 August 2015 and damaged about 170 ha forested land. Mechanized CTL system was implemented in the field. Trees were cut and bucked by using single grip harvester, and then rubber-tired tractor was used for skidding logs from stump to landing area. The time study was implemented by using repetition approach in which chronometer was run for each work stage separately. The results indicated that the average productivity was 14.03 m3/hr for an average skidding distance of 181.46 m. Moving loaded from stump to landing was the most time consuming work stage (31.1%). The second most time consuming stage was loading logs on the tractor (27.7%) because the loggers often work on difficult terrain and slippery surface which increases the log handling time of operator especially for the turns with high number of pieces.

Keywords: Logging operation, Post-fire timber salvage, Tractor, Brutian pine

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Use of lignin solution in the road structure to increase the bearing capacity of forest truck roads

Jan Bjerketvedt

Abstract: About 75 % of the forest truck road network in Norway is older than 25 years and many of these roads are built with local materials of very varying quality. Forest road standard registrations shows that the bearing capacity is one of the major problems. The climatic changes with increased rainfall and a shortened season with frozen ground will additionally strengthen this problem.The common use of lignin (or lignosulfonate) solution is on the road surface as a dust suppressant and road stabilizer; it binds soil particles to provide a solid, hardwearing surface. Long term experiences from the Norwegian Public Road Administration indicated that the treatment also resulted in an increased bearing capacity. This study is aimed at measuring the effect on bearing capacity of applying lignin (Norwegian trademark Dustex) to the top/base layer (upper 20 cm) on existing forest roads and if this is an economically viable alternative to traditional methods.On two forest roads built with local moraine material in road structure and wearing course (2 and 3 km length) measurements of bearing capacity were carried out with a Falling Weight Deflectometer (FWD). Test sections of about 1 km length with low bearing capacity on each road were treated with Dustex. New measurements were carried out after one year (summer), one and a half year (wet autumn conditions) and two years (summer).The study shows increased bearing capacity on the treated test sections compared with the untreated sections. The difference is very clear regarding the changes from dry summer to wet autumn conditions. It turned out to be remarkably large bearing capacity variations along the road and not least between the road's two sides (cut and fill side).Whether this treatment is an economically viable alternative to traditional methods or not, remains an unanswered question, - so far. The lignin is compostable and the duration of the measured increase in bearing capacity is uncertain. A comparison of costs related to use of Dustex and traditional road building material will be presented based on possible duration of the Dustex treatment, Dustex maintenance spraying and different road building materials.

Keywords: Forest roads, bearing capacity

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Use of dust abatement chemicals to reduce sediment production from forest roads

Kevin Boston

Abstract: Forest roads can have a significant impact on the environment, especially aquatic systems. Their drainage systems can result in larger peak flows, they can accentuate landslides, and the road prism can be the source for chronic delivery of sediment. On the Pacific coast of North America, this chronic sediment can affect critical habitat for salmon, a significant commercial and sports fishery. The initial mitigation performed on these roads is to hydrologically disconnect the road's drainage systems from the stream. However, there always is a road segment that remains connected to stream. The question is can we reduce the sediment from the surface of the road on these remaining connected road segments.

Dust abatement chemicals add a chemical strength to cohesive particles by linking particles together. This project's goal was to explore whether dust abatement chemicals can reduce the sediment production from the surface of an aggregate forest road. An novel procedure to test the effectiveness of the aggregate treatments was developed in the confined of blocked experimental design that used two types of treatments, lignin sulfonate and polymer-based chemical along with a control were applied to two rock types, one soft, microDeval values greater than 20% with an abundance of fines while the other was much harder with a microDeval values leas 20%. The solutions were applied with no hauling for one week; afterwards an equivalent traffic of 200, 80 KIP log-truck loads were applied to test sections. Following the trucking, the test sections were exposed to sprinkler driven rain that produced 6.35 mm o (¼") of water per hour. The effluent from each test section was collected until 12.70 mm (1/2") water had been applied to the test section. The control produced the lowest amount of effluent from the treatments as the both the lignin sulfonate and polymer were both part of the effluent that may make them unsuitable to add an aquatic environment.

Keywords: dust abatement, sediment, forest roads

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Estimating rutting and soil displacement in skid trails by soil sampling and 3D Structure for Motion (SfM) photogrammetry modelling: first trial in Vallombrosa forest (Italy)

Martina Cambi*, Francesca Giannetti, Francesca Bottalico, Gherardo Chirici, Enrico Marchi

Abstract: Mechanization and skid trails network play a key role in the fast extraction of timber from areas affected by windthrown, especially for timber quality and worker health and safety. Nevertheless, heavy vehicle trafficking may have a strong impact on soil, due to soil compaction and rutting. Different methods have been applied for determining the effect of forest logging on soil. The most common are based on sample collection and/or field measurements. Recently, other methods such as terrestrial laser scanner (TLS) have been applied to construct 3D model of terrain (Digital Terrain Model) to assessing rutting and compaction of soil. However, TLS techniques require relatively expensive technologies and specialized users. With the evolution of Structure from Motion (SfM) photogrammetric technology, that reduces constraints by allowing the use of consumer grade digital cameras and highly automated, data processing acquisition of 3-D data has become easy, fast, automated and low-cost.The aim of this study was to test the use of SfM to assess soil compaction and rutting during logging operations in a windthrown area. The study area was a silver fir forest situated in Vallombrosa forest (central Italy) damaged by a windstorm in March 2015. For timber extraction both a forwarder (John Deere JD1110 D) and a skidder (John Deere 548H) were applied. In the logging area trails trafficked by both forwarder and skidder were selected for the study. On these trails two different methods were applied for determining the impact on soil: (i) soil sampling for determining soil physical parameters (bulk density, shear and penetration resistance) and (ii) temporal analysis of high resolution Digital Terrain Model (DTM) generated by SfM photogrammetric technology. Machine trafficking on the selected trail was carried out for 10 days and the data for assessing the impact on soil were acquired before, during (after five days from the beginning) and 5 days after the end of timber extraction. The two different approaches were compared for determining the difference in the assessment of the impacts on soil of the two vehicles used in logging operation. The two approaches are comparable and highlighted a significant difference between the trails trafficked by forwarder and skidder. Our findings showed that SfM may be easily used to produce 3D terrain model, thus allowing to assess soil compaction and rutting in a faster and cheaper way.

Keywords: forest operations, soil compaction, DTM, SfM photogrammetry

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ForstInVoice - Making better use of harvester board computers

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Abstract: The use of CTL-method in harvesting has fundamentally changed wood procurement in Central-European forests. Quality trusted measuring data generated by harvester during felling and sorting of timber is a profound source of information. To accelerate the logistics process and especially to optimize the information flow along the WSC, the KWF evaluated the data management chain within a R&D project. Additionally an IT solution was built up to squire the business process particularly for small and medium-sized forest entrepreneurs. The process routine is shaped by cloud computing and onboard communication for harvesters and forwarders according to StanForD 2010.According to ForstInVoice the procedure is as follows: The previously negotiated and agreed work order will be sent to a web-based platform by the applicant. This work order will be downloaded from the platform, confirmed and related directly to the harvester board computer and processed by the machine. After the harvesting process the delivery note and invoice will be sent from the machine to the platform to finalize the business interaction. Operating experiences and future prospects in the use of this system within the WSC will be presented and discussed.

Keywords: CTL-method, data management, onboard communication, trusted measuring data

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Trunk quality changes analyse in Latvia private forests

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Abstract: Private forests compose more that 50 % from common wood coverd area in Latvia. Private forests for the most part are small with area from 0.5 to 5 hectare. For private wood owners have more important sale of products, the more trunk quality, the better income in housekeeping money. For this reason, we to decide make to fulfil the research work about trunk quality determinant factors in private forests. Main attention in the research work was give to abiotic and biotic conditions why determinant changes of trunk quality. Therefor that tree growth and trunk quality in different types of forests are affected by mainly by abiotic and biotic conditions. However, sometimes it is observed that growing in outwardly the same conditions and in close proximity trees have different characteristics in their growth and sawn timber quality of the trunk. In our study we test connection of these changes not only from silvaculture cultivations works, but look over geo-bio-physical anomaly effects at exact place of growing tree, too. The study was carried out in the family forest property – Taurupe region, Latvian. Innovation – in biophysical anomaly detection use two technical measuring devices. First, IGA-1-M device, developed in Russia - Ufa by Yuri Kravchenko. Second, Lashanten antennae that is used in Germany. In determining "underground water or earth energy flow" the traditional methods biolocation or radiestesian were used for control of measurements. The possibility of drawing the underground water plan with use of the local GPS station is tested – in conditions of clearing of trees (glade), young forest stand (coppice) and seasoning stand. We are also working on recommended methodology for measurements and creating plan of results in forest conditions

Keywords: trunk quality, abiotic and biotic conditions

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The logistic potential of large chip trucks and chipper trucks in a combined system

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Abstract: Studies of high capacity vehicles in Sweden has shown that fuel savings of approximately 13% is to be expected when increasing truck capacity from 60 to 74 ton. 74-ton trucks has been tested on different segments of cargo transport in Sweden, including chip trucks and chipper trucks. In Finland 76 ton gross weight is a new standard (64 ton in Sweden). Chipper trucks, that both comminute and transport forest residuals from roadside is a common supply-system for bioenergy in Sweden. The system were a chipper blows directly into a chip truck is rarely used in Sweden but is more common in Finland. In this study a 74-ton chipper truck is collaborating with a 74-ton chip truck (only for transport) to maximize the performance of the system and minimize costs and emissions. The chipper truck fills up the chip truck as often as possible at the landing. When the chip truck is away the chipper truck chips into its own trailer. When filled the chipper truck can choose to transport the full trailer itself, if the option is to stay idle, or it can stay and switch trailer with the next chip truck to arrive. The idea is to use the chipper for chipping as much as possible, but at the same time have the full flexibility of a chipper truck. The extra weight capacity allows for high efficiency in both chipping and transport operation. A third chip truck (60 ton) were also engaged for transport to support the system. The aim of the study was to evaluate the system as a logistical solution and to find critical parameters and bottlenecks as a base for further development. Time-studies were performed and analysed in a simulation model to capture the dependence between the studied resources under different circumstances. Preliminary results has shown that the system has a big potential. But it is critical that the chipper truck can be used to ship most of the time. In the time study, only 50 % of the chipper trucks time were used for chipping. This naturally corresponds with the transport distance the volume at each landing and the number of chip trucks in the system.

Keywords: Chipper truck, logistic study, simulation, forest fuel

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Impact of yarding direction and silvicultural treatment on operation performance in whole tree cable yarding – an analysis based on plot level data

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Abstract: In forestry, work efficiency studies are employed to investigate the performance of harvesting systems. Shift level or plot level studies are suited to determine long term effects and provide more robust information due to a larger number of cases than in detailed work studies. The effect of yarding direction and silvicultural treatment on operation performance in whole tree cable yarding was studied based on operation data collected by the Bavarian State Forests. The data's special feature is its origin, as operations were carried out by one and the same four-man crew and machine (Koller K507) over a period of nine years. During this period, 223 operations were conducted within 12.852.7 h and 271.721 trees with a total volume of 71.742 m³ were yarded. Downhill yarding was less favourable, as installation took significantly more time. Likewise, productivity was significantly lower if yarding was conducted in downhill configuration, which can be assigned to the need for breaking the dangling load instead of operating at full speed like in uphill configuration. Silvicultural treatments inhabiting concentration effects (like slot and group cut method) increased the overall productivity significantly compared to treatments affecting the whole operation area (plus tree thinning, clear-cut-like types). The developed model (R^2=0.511, standard error=0.017 PSH15 per m³) provided reasonable estimates (8.57 x 10-19 PSH15 ± 0.02 PSH15 mean deviation from the observed curve) for time consumption during yarding of whole trees. Explaining variables included tree volume, yarding direction, span length and silvicultural treatment. Delay share was about 18.5 %, while the overall share of productive time in total operation time (installation, productive time, relocation, and other time) was 56.9 ± 10.7 %.

Keywords: cable yarding, productivity, yarding direction, silviculture, plot level

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Modeling multimodal roundwood transport in Norway

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Abstract: Structural development towards fewer and larger mills in the forest sector results in increasing transport distances and a subsequent need for more efficient transport systems. This study examines the potential for further efficiency improvement of the current rail network in south-eastern Norway.
The case models the main wood supply basin in southeast Norway where approximately 2 million m^3 of roundwood is transported by rail to 2 main markets (domestic and export). The base case represents the current situation with existing terminals distributed along two main rail branches. Terminals are fed from supply areas with varying limits for maximum vehicle weights, reflected by corresponding variation in average truck transport tariffs. Rail lines serving terminals also vary with respect to electrification, reflected by corresponding cost functions for the drawing power and load capacity of available diesel vs. electric locomotives. Two simple optimization models compare the minimum cost and capacity volume attracted to each terminal between alternative scenarios for development of domestic vs. export demand.
The system cost from forest to mill for the base case was modeled to just under 145 NOK/m^3 (approx.15 €/m^3). The resulting variation in costs, wood flows and terminal capacity requirements between scenarios is considerable. Increased electrification both reduced truck transport distances and resulted in a more stable use of the key terminals, regardless of demand scenarios. Further electrification and development of the indicated key terminals provides a more robust platform for competitive wood supply in the region.

Keywords: rail terminals, handling capacity, electrification

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Availability and utilization costs of forest woody biomass for bioenergy in Mexico

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Abstract: The potential for forest utilization for bioenergy supply makes this resource a driving force for the development of rural communities within the Mexican forest sector. Nowadays studies about the Mexican forest have generated new policies for the improvement of life standards, involving policies on conservation, sustainable management and sustainable utilization. Nevertheless, there have been no studies with special focus on management of forest resources, which integrate wood supply chains into bioenergy transformation within a framework of sustainability. This research focuses on analyzing the potential of available forest woody biomass for energetic use, with the objective of integrating and creating wood supply chains which support the development of rural communities. The main objective is to develop a methodology for holistically evaluating the sustainable potential of supplying energy from decentralized bioenergy plants using woody biomass. Considering its design, the methodology is based in three research modules: i) Availability and appropriateness of lignocellulose biomass, ii) Forest management for bioenergy supply and iii) Energy output. The research includes an analysis of forest biomass utilization coming from residues out of harvesting activities, non-extracted stands and sawmills using variables that affect the theoretical, technical and economic potentials. A regional case study focusing on tree species of commercial importance (pine, oak and fir) is analyzed involving 10 provinces with the highest timber production located in the north and central-south part of the country. A spatial approach is carried out delimiting the geographical area for analysis with i as the analyzed specie out of a n number of species in a j region or site based on land use and inventory data. At a theoretical and technical level, equations to account the availability of woody biomass as well as extraction limits equations are developed using statistical and geographical data. Digital elevation models (DEM), involving statistical analyses, are used to analyze terrain conditions in order to calculate sustainability constraints. For the economic potential, Monte Carlo simulations are developed in order to estimate production cost from harvesting and transportation.

Keywords: Bioenergy, Mexico, Wood supply chain, Forest management

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Integrated biomass and timber harvesting in pine plantations in Western Australia

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Abstract: Integrated biomass harvesting system is one of the conventional biomass utilisation methods applied in Australian pine plantations. This project studied the productivity-cost and yield of this harvesting system in 32 years old *Pinus radiata* plantations located in South West Western Australia. The harvesting systems consisted of a harvester and a forwarder. There were two study treatments; control plot (extracting saw log and chip wood) and fibre-plus plot (integrated sawlog, chip wood and fibre-plus (residue logs as source of biomass)). In the integrated biomass harvesting plot, 36.6 GMt/ha of Fibre-plus materials were utilised in addition to the normal sawlog and chip wood volumes. Extracting additional biomass materials reduced the productivity of the forwarder and increased the cost of extraction (2.7 $/GMt) compared to the control plot (2.2 $/GMt) but the harvester's productivity and cost did not change highly in both plots. DBH was significant factor influencing the working time of harvester while load volume, extraction distance and extraction type (sawlog, chip wood, chip wood and Fibre-plus) significantly impacted forwarding time. Additional biomass recovery in the Fibre-plus plot resulted in less residues left on the site (103.2 GMt/ha) than control plot (144.2 GMt/ha).

Keywords: Productivity, Cost, Integrated biomass harvesting, Extraction type, Yield, Harvesting residues

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Mapping the effects of rail system configuration on delivery precision, stock levels and lead times in pulpwood supply

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Abstract: Industrial wood supply often relies on a combination of road and rail transport. With structural development towards fewer and larger mills, growing supply areas require an increased proportion of rail transport to enable both sufficient capacity and minimal costs. Branch patterns and distributions of terminals and mills vary between systems and can therefore have consequences for system efficiency and service dimensions. The aim of this study was to map the effects of rail system configuration on key service dimensions such as delivery precision, stock levels and lead times in pulpwood supply. The modeling was done with discrete-event simulation. Pre-planning of system parameters was done in a linear programming model, formulated to mimic how planning is performed in the actual cases. System control during subsequent simulation was provided by an internal logic for re-allocating truck and train capacity based on system status variables such as a stock development trends and rate of deliveries compared to delivery plan. Two alternative system configurations were modeled based on existing cases in north and south Sweden. Each system was subjected to three scenarios (base case, spring break-up, unplanned mill production stops) and the key service dimensions were compared between these. Five runs were made for each system/scenario with stochastic variation in production parameters and seasonal event occurrence. Development of system control, system configuration and scenarios was done in discussion with company representatives to ensure a realistic model.The main challenge has been to reproduce a realistic response enabling high delivery precision at a monthly level. For the base case scenario (no system disturbances) simulated stock levels and lead times were found to be within typical intervals. Lead times for truck and rail deliveries were linked directly to road-side and terminal stock levels, respectively, resulting in a bipolar distribution of lead times for the system as a whole. The ability to absorb disturbances such as unplanned mill production stops varied with the system configuration modeled and this ability increased with the proportion of the total system volume handled by rail.

Keywords: discrete event simulation, multimodal transport, delivery precision, lead times, stock, wood supply, pulpwood

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Evaluating the debarking efficiency of modified harvesting heads on European tree species

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Abstract: Debarking can help maintain forest health and lower the spread of spruce bark beetle as it reduces the export of nutrients, which are mostly located in tree bark.
Existing purpose-built debarking harvesting heads are successfully used in Eucalyptus plantations. However, to maintain flexibility and lower investment cost, modifications were made to commonly used harvesting heads mounted on single-grip harvesters to assess their debarking efficiency under Central European conditions.
Different field tests, with varying tree species, summer and wintertime, diameters and age classes are established in Lower Saxony and in Bavaria, Germany. All tests are performed using the cut-to-length method. To quantify debarking ability originating from head modifications, measurements are performed with a photo-optical evaluation software.
First results demonstrate considerable differences in debarking efficiency between vegetation season and tree species. More specifically, when used within the growing season, innovative head modifications provided an efficient method of achieving in-stand debarking of over 80%.

Keywords: Debarking harvesting head, debarking efficiency, photo optical measurements, mechanized operations

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Aerial logging – state and perspectives

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Abstract: Off-road transportation has been a timber harvesting process that is technologically challenging and costly . Depending on terrain and road network conditions, there are three solution pathways: (1) ground-, (2) structure-, and (3) air-borne off-road transportation technologies. Whereas scholarly reports on ground-borne technologies have been numerous, contributions on (cable)-structure-borne systems are limited, and papers on airborne systems are very rare. Consequently, a considerable amount of knowledge on airborne logging systems has got lost, which now and then results in attempts to "reinvent the wheel". The purpose of the contribution is threefold: First, to review the knowledge of static, dynamic and hybrid aerial vehicles that were tested and/or used in logging operations; second, to derive the operational boundaries for aerial systems; third, to assess future applications of airborne systems.

The review identified three lines of research. Balloons as static systems were studied in the 1960s and operationally deployed in the 1970s in the US/CAN. They disappeared due to non-controllable wind conditions and huge rigging/dismantling cost. Helicopters as dynamic systems started to get used in logging operations by the end of of the 1960s, and have been used in specific areas of the world only, such as the Pacific Northwest, Central Europe, and Northern Borneo. Hybrid airships for logging operations were proposed in the 1960s, and the first prototype, the so-called "Helistat", crashed in 1986, resulting in a shutdown of further trials. More recently, we have been seen a revival of hybrid aerial vehicles, which could offer some potential for future forestry applications. Future uses of airborne systems in forest operations have potential, if combined cost of road network and off-road transportation are the decisive criterion, because airborne systems require less dense road networks.

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Vehicle-soil interaction – what can you learn from terramechanics?

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Abstract: The soil compaction phenomenon has been on the forest operations research agenda since the late 1950s. The predominant approach has been data-driven, measuring the consequences of vehicle traffic on different soil properties, such as density, porosity, permeability, etc. The description of the effects has been based on statistical methods, which yielded important results, but is lacking to describe the three-dimensional deformation of soil units due to both normal and shear stresses. Engineering mechanics and partially soil physics have been studying soil deformation, which poses the question what the forest operations community can learn if it looks at the soil impact problem from the deformation are on the than compaction point of view. The purpose of the present contribution is as follows. First, to revisit the scholarly work done in terramechanics. Second, to provide an analytical concept to describe acting and resisting for his on a single wheel, which is operating on a soft soil. And third, to apply those analytical concepts to evaluate the gradeability of vehicles on slopes, which is a very important to design safe winch -assisted ground-born operations on steep slopes.
The analysis provided three main results. The normal stresses between wheel and soil are acting in a non-vertical direction, whereas shear stresses are acting perpendicularly. This means that the "vertical view", which underlies the soil compaction approach, is inappropriate and does not appropriately describe the soil deformation caused by vehicles. Second, there are four forces that are describing the interaction of a single wheel/track on a soft soil: (1) the resisting force of soil, (2) the deformation resistance of the soil, (3) the slope action, and (4) the acceleration action. Terramechanics offers models to characterize the deformation resistance and the resisting force of the soil in terms of tire specifications and soil properties, which allows to estimate the gradeability of an axle/track configuration. Third, terramechanics approach offers the possibility to quantify the severeness of a tire/track on the soil by quantifying the deformation energy acting on the soil. Looking from a different perspective on specific problems has the potential to offer new insights and to pave the path for new research. The mechanical engineering point of view is focusing on soil deformation rather than on soil compaction only, and the author is convinced that soil impact research should go in this direction in the future.

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Contact pressure allocation under bogie tracks

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Abstract: At present forestry in Europe copes with an increasing demand for raw timber, both for material and for energetic use. In addition public is getting more sensitized for the impact of forest operations. Therefore conflicts arise with the requirements of a continuous supply of industry with timber, because forest operations sometimes have to be carried out at inappropriate weather and therefore soil conditions. The visible result is often soil compaction to the point of total loss of traffic ability. Soil compaction is seen as an outcome from high wheel loads at wet soil conditions. The pressure limits that can be applied to the soil without serious harm are widely discussed but often lack the real input pressure. A lot of formula is known to calculate the contact pressure but the knowledge for the allocation of pressure is leaking. Calculations of contact pressure from the contact patch area and the wheel load result in notably low values. Measurements with a spatial resolution of 0.7 cm² were done for typical tracks from Olofsfors covering the whole range of tracks between traction and carrying types. The measurements were done with a covering 20 cm sand layer for protection of the sensor system. Besides the variation of the track types, other factors like the tire sizes, the distance between the tires of a bogie and the tension of the tracks were varied. The results show that there is a reduction in contact pressure by the tracks, but the distribution of the pressure is not homogenous. The positions of the tires are delivering the highest pressure values while the area between the tires shows only a soft carrying. The influence of the track types (traction vs. carrying) on the pressure allocation is significant for the 600 mm wide tires but decreases for 710 mm.

Keywords: soil compaction, track types

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Optimising resource management in forestry through the use of qualified planning times and planning costs for standardised working procedures (RePlan)

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Abstract: Knowledge of the process times and process costs of forest operations has become increasingly rare in recent years. During the conversion of piece wage to time wage, most forest administrations and enterprises in Germany did not update the cost and time data related to their forest operations. This knowledge of process times and process costs is, however, necessary for the economic management and efficient use of resources. Forestry stakeholders require such data for planning, managing and controlling sustainable forest use. The lack of current data has since led to planning deficits; the joint research project "RePlan" aims to fill this gap. The objectives of the project include firstly the selection of relevant forest operations which would benefit most of actual process times (mostly with high degree of manual work); secondly, the derivation, development and, if applicable, the registration of process times and process costs for operation planning, monitoring and evaluation of selected forest operations. The forest operations have been selected on the basis of being representative of all such operations in Germany. A database will be designed and created within the project that will be made available for use by forest owners, enterprises, advisers and entrepreneurs. Other key project tasks include the development of a concept for continuous data collection and update, as well as the establishment of a network of interested actors of forest industry who will provide input on data and additional processes to be included in the database. By improving cost awareness, the efficiency of forest resource utilization will be enhanced, which will benefit actors in forestry and society as a whole. Project partners are the KWF (Board of Trustees for Forest Work and Forest Technology), the University of Freiburg (Institute for Forest Science, Chair of Forest Operations), the University of Göttingen (Burckhardt-Institute, Department of Forest Economics and Forest Inventory), the REFA (Sector Organization Forestry) and the DFWR (German Forestry Council).

Keywords: Soil compaction, Track types

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Fuel Quality Changes and Dry Matter Losses during the Storage of Wood Chips. Part 1: Field Trials to Examine the Storage of Wood Chips under Practical Conditions

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Abstract: The storage of wood chips is important for the biomass supply chain, as it compensates for temporal differences in production and consumption. Typical storage-related problems are a decline in fuel quality and dry matter losses due to microbial activity.

In field trials, the storage of spruce chips from forest residues (crown material) and from energy roundwood (thin delimbed stem sections of low quality) with and without rain protection (fleece) was examined. Trials lasted for five months each and were conducted both during winter and summer.

Sampling was done with balance bags, which were arranged grid-like within the wood chip piles when building up the experiment and pulled out during the storage period. This allowed for both temporal and spatial resolution as well as repeated measures. Overall, more than 1 000 bags were analyzed. In each pile, temperature measurements were executed at 3 positions to examine the influence on dry matter losses and quality changes. In addition to wood chip piles, both assortments were stored unchipped in piles without rain protection.

The results show that changes in moisture content and dry matter losses were significantly (factorial ANOVA, $p < 0.05$) dependent on storage duration, season, assortment and rain protection (fleece). With increasing storage duration, moisture contents decreased and dry matter losses increased. During summer there was stronger drying and higher dry matter loss than during winter. Forest residue chips (FRC) dried and decomposed more than energy roundwood chips (ERC). With fleece stronger drying and higher dry matter losses occurred than without. In total, the highest decrease in moisture content was 22.6 weight percentage points and the highest dry matter loss was 11.1 w-% (both during summer after 5 months of storage in FRC covered with fleece).

The change in usable energy content was primarily influenced by dry matter losses and changes in moisture content. In winter, loss of usable energy was low, except for the uncovered FRC pile (-11.3 %). This pile had high dry matter losses but showed no drying. In the other piles the energy loss was relatively low, because either there was only little dry matter loss (ERC) or the dry matter losses were widely compensated by the drying of the chips (FRC with fleece). In summer, even a slight increase in usable energy content occurred. This was a result of strong drying that compensated dry matter losses, which were higher than in winter. Ash content and net calorific value (on dry basis) only changed marginally during storage of wood chips.

Unchipped storage led to lower dry matter degradation in both assortments. Moisture content of unchipped piles changed only during summer. Unchipped roundwood dried very strongly to a moisture content of about 24 w-%. Additional to dry matter losses caused by biological degradation, the amount of biomass which fell to the ground (mainly needles and fine twigs) had a large effect on total dry matter losses in unchipped forest residue piles. Overall, the dry matter losses in these piles were comparable with the losses measured in forest residue chip piles, but mean decrease in energy content was somewhat higher. However, the ash content of the unchipped piles decreased distinctly because of the reduction in needles and bark.

In conclusion, forest residue wood chips should be stored with rain protection or as short as possible during winter. During a dry and warm summer, wood chips can be stored without restrictions. Unchipped storage can be mainly recommended for energy roundwood concerning energy content. For unchipped forest residues, however, ash content can be reduced by defoliation and thus the quality can be improved in this way compared to chip storage.

Keywords: wood chips, storage, dry matter losses, fuel quality, energy content

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Remarks

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The use of photo-optical systems for measurement of stacked wood

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Abstract: The study involved two photo-optical systems: iFOVEA (Fovea GmbH) and AFoRS (Scheller Systemtechnik GmbH). For the purpose of comparison traditional (manual) method of wood volume measurement was applied. The study made use four devices for each of the system.

The study was conducted in five locations: forest districts of Karwin, Nowa Sól, Przytok, Swieradów and Regional Directorate of Pila. In total, 539 piles were analyzed, representing the volume of 39,372.49 m^3(p) of stacked wood (according to manual measurement).

Measurement data obtained during the field work were analyzed statistically. The characteristics of different systems of wood volume measurement (wood volume and time consumption of measurement), were examined variables that were compared between the systems of measurement. In order to determine which systems differ from each other in terms of the mean size of the observed characteristics, each possible pair of the systems were compared using a multiple comparison test. Wilcoxon test with Bonferroni correction was used for this purpose. Friedman's ANOVA for ranks was used for comparisons between systems.

Volume measurement of stacks. The arithmetic means of the stacks measurement are as follow: 81.51 m^3(p) (manual measurement); 80.87 m^3(p) (AFoRS) and 82.33 m^3(p) (iFovea). The obtained mean value for the AFoRS is lower 0.79% and for iFOVEA is higher 1.01% comparing to the manual system. There were no statistically significant differences between the manual measurement and AFoRS. These differences were found for iFOVEA and both: manual measurement and AFoRS measurement.

Time consumption. The lowest measurement times of the average size of the stack were found for AFORS (7.38 min.), slightly higher for the iFOVEA (10,06 min), and highest for the manual measurement (15.84 min). The application of the Friedman test made it possible to show significant differences of time consumption of stack measurement for tested systems.

Most time is needed for measurement when using traditional system, just over 0.19 min/m^3(p). Carrying out this task using photo-optical systems time consumption is following: 0.12 min/m^3(p) (iFOVEA), 0.09 min/m^3(p) (AFoRS).

Keywords: wood volume measurement, photo-optical method, stacked wood

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Performance and costs for harwarder and harvester-forwarder systems in clear felling

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Abstract: Forestry development can be evaluated from social, economic and environmental points of view. Improvement in each of these areas is necessary in sustainable forestry. The conventional logging system for clear felling in Sweden is the harvester-forwarder system. The system is a mature and efficient system as a consequence of more than 30 years of development. Even so, the direct loading which becomes possible through harwarder technology, indicates a potential to decrease total time consumption in logging operations. Direct loading eliminates the loading time of the forwarder in the harvester-forwarder system. In the spring of 2014, a harwarder prototype for clear felling started in test operation in forest stands in northern Sweden. The prototype has tilt- and rotatable load carrier to enable direct loading, and a device for quick coupling enabling fast switch of working tools. The harwarder uses a harvester head while felling and processing and subsequently changes to a forwarder grapple to ensure effective unloading. The performance of the harwarder and a harvester-forwarder system was studied in clear felling by means of time study analysis and field measurement with two machine operators. The machine operators operated all machine types and had experience from both harvester and forwarder work. One of the operators also had experience from harwarder work. Variables such as transport distance, stem volume and number of assortment were collected from machine data. Functions for time consumption were created from statistical analysis of the data material. Logging costs were calculated for each machine based on available statistical averages for Sweden or northern Sweden, combined with observed performance data.The costs differed between the two systems. The harwarder system showed potential to decrease costs in clear felling in stands with smaller size trees, limited terrain transport distance and with fewer assortments handled. The harwarder needs equipment both from harvester and forwarder which makes it more expensive, which implies that the time consumption per produced wood volume must be lower than for the harvester-forwarder system. More detailed knowledge of pros and cons for the harwarder system are still needed, both concerning technology and methods. Further studies are planned for that purpose. The harwarder system is new in comparison with the harvester-forwarder system and is likely to display a considerable potential for further development. The future of the harwarder system is ultimately resting on decisions of machine manufacturers and buyers. Studies like this provides an important base for their decision making.

Keywords: time studie analysis, productivity, direct loading

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Assessing loss of plywood due to spike damage from a harvester head

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Abstract: Harvesting of valuable hardwoods may inflict wood defects in lateral surface of logs done by feed rollers. The lateral round wood surface is the most valuable for plywood as it gives the biggest area of plywood sheet in a rotary cut. The objective of this research was to calculate a potential financial loss of plywood due to dents created by spikes of harvester head feed rollers spikes. For that, distribution and dimension of spike damage was measured on plywood logs after harvesting. The research was carried out in two matured alder stands in which a Valmet 911.4 harvester was used with a 360.2 head. Maximal spike dents as well as bark thickness were measured on the first four metres of plywood logs. Detailed measurements were carried out using an electronic calliper with an accuracy of 0.01 mm. There were differences between the maximal dents on the first metre and the other three sets of observations. Maximal values of dents were of 1.9–3.9 mm depth. Bark thickness ranged from 12.7 to 14.3 mm and was not statistically different at any of measurement points and it did not influence dents depth. The loss of plywood was calculated taking into consideration: taper, maximal values of dents and current prizes of plywood.

Keywords: plywood quality, wood defects, loss of wood, feed rollers

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Traffic pattern of a mixed-use forest road in Hungary

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Abstract: The traffic of a forest road in a touristically attractive area of Hungary was monitored by camera surveillance from 2012-2015. The aim of this research was to provide quantity and quality traffic data for the forestry company that owns this road to improve the management of the road. Around 70,000 photos of road users were processed by evaluators. The type of road user (e.g.: pedestrian, car), its direction and its activity (recreation, sport, forest operations) were assessed. The date and time data were stored automatically by the system. Basic descriptive statistics were calculated as well as more complex ones. Correlation analysis was performed to identify the main factors that determine the daily numbers of road users. Density functions were calculated for the main road user types that provided the probabilities of the occurrence of specific daily numbers of visitors. Based on these data a yearly and a daily road use model was developed for the three main road user categories: Pedestrians, cyclists and cars. It was found that visitor numbers were determined by the day of the week and the time of the year. Strong evidence was not found for the weather dependency of the visitor numbers. The number of pedestrians on weekdays were the highest during summer, though on weekends it was the highest in spring and autumn. The most frequent daily pedestrian number was around 50 for weekdays and around 300 for weekends. Cyclists tend to visit this road more frequently during summer. Their most frequent daily numbers were around 10 and around 110 for weekdays and weekends respectively. The car traffic seems to be more or less constant throughout the year – around 80 cars a day – with slightly higher numbers on weekdays. Based on this data the forestry company will have the opportunity to organize its wood transport and road maintenance activities so the disturbance of the recreational visitors will be minimal.

Keywords: traffic, statistical analysis, forest road, mixed-use, road management

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Private forestry contractors in Poland - current state and development opportunities

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Abstract: The forestry contractors sector in Poland exists for more than 20 years, passing, like other emerging sectors of the economy, subsequent phases of development - from the phase of dispersed (emerging) sector (1990 – 1996), through a phase of the "maturing" sector (1997 -2004), and ending with "the phase of the characteristics for global sector", which started since 2004, since Polish accession to the European Union (after 1 May 2004.) and continues to the present.
The basic external conditions of the functioning of the forestry contractors sector in Poland are following:
- Demographic and economic changes. On can observe the aging process which also applies to forestry contractors. In 1996 and 1999 dominated contractors 31-40 years old, in 2002 and 2006 - entrepreneurs 41-50 years old. It can be assumed that these were the same person. It also shows that this is "almost closed sector ".
- High labor costs. Employers look for savings, employing staff on civil contracts, so-called junk agreement.
- Loss of professional competence among forest workers.
- A significant negative factor is the lower wages compared to wages in the corporate sector. In 2012, the average salary in enterprise sector amounted to 3522 zł, while wages in the private forestry contractor sector only 2162 zł, almost 40% less than the average, and only 662 zł more than the minimum wage.
- Knowledge of forestry contractors on instruments and institutions supporting entrepreneurship is very low.
The number of private companies providing services to the forest districts in 2012-2014 shows a clear downward trend, decreased by 25.37% (744 companies), to 2190.
The Polish forest sector, in the short and long term, should:
- Takes a multidirectional efforts to change the image and increase the attractiveness of work in the forestry contractor sector.
- Implements comprehensive solutions for continuous improvement of qualifications of forestry contractors, including changes in professional forest education.
- Seeks the support of forestry contractors sector mainly in programs supporting the development of rural areas and small and medium-sized enterprises.

Keywords: private forestry

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Lean Communication Standard to raise efficiency of wood procurement in the WSC

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Abstract: The ELDAT Standard has been established in 2002 and is supposed to unify electronic communication between wood suppliers, logistics and woodworking industry in Germany during the process of timber harvesting, trading and shipment. In today's forest business processes efficient electronic instruments of wood measuring – like photo optical timber measuration – and harvesters with size and weight measuring sawing units become ever more important. Hereby collected data of each log can be uploaded to trading programs of the forest owner and could then be transferred to woodworking partners in a standardized form. This is possible due to electronic interfaces between the data collecting devices and ELDAT. Additionally each log pile can be linked in ELDAT via an electronic interface to geographic coordinates so transport companies approach the piles easily by GPS. In December 2015 a new project for an efficient electronic data interchange in the forest and wood sector in Germany has been launched to adjust the ELDAT Standard. The so called ELDATsmart project has duration until the end of 2017 and is funded by the German Federal Ministry of Food and Agriculture. ELDATsmart aims to integrate modern business processes in timber procurement to the ELDAT Standard. In contrast to former German timber trading processes with single logs or whole order volumes, more efficient trading units have evolved in timber procurement. Therefore log piles will be added to the Standard as accounting units and brought into focus for timber trading processes in the ELDAT Standard. Due to numerous complains about unmatched communications, the Standard will also be defined tighter and added with a user manual. A tighter Standard will lead to more automated and thus efficient processes with a minimum of extra consultation between trading partners. In the end there will be a completely digital and mainly automatical timber manipulation from harvest to the plant. Therefore ELDATsmart is part of the fourth industrial revolution concept in the forest and wood sector. Furthermore there will be applications for significantly involved logistic partners and a low-threshold entry especially for small and medium sized forest owners. ELDATsmart will be assessed continually by a special User Group during the development process to guarantee an easy handling in day-to-day business and to increase acceptance in the forest and wood sector. A consultative committee will accompany the project for fast agreements and minor decisions.

Keywords: Logistics, ELDAT, 4th industrial revolution, electronic interfaces, WSC

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Evaluation of advanced solutions for wood transportation by road – a simulation approach

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Abstract: Backhauling and high-capacity-truck transportation (HCT) are special systems in roundwood transportation, being the most competitive in long distances. In Finland, HCT, i.e. a truck with over 76 t gross weight, is a novel solution that is currently being demonstrated in real-life conditions with three roundwood trucks and eight other trucks. In most cases, HCTs are not able to access roadside storages, but they are expected to bring cost efficiency in highway transportation between mill-yards and intermediate wood terminals. The issue of special transport fleet and advanced transport solutions in Finland is topical for at least three reasons 1) increasing the sustainability of the supply chain through lower transport-fuel consumption, 2) prevention of road erosion and 3) re-balancing the gap between surplus and deficit areas of feedstock supply as new pulp mills are built or planned. HCTs could also be useful for shuttle transportation of wood fuels from feed-in terminals in cases where large power plants are located in densely populated areas. Evaluation of the best solutions is, however, challenging due to the complexity of the transportation systems. Simulation modelling approach is a convenient way to analyze the overall impacts of the implementation of new methods in the system. The purpose of this paper is to present 1) real-life examples where HCTs are currently demonstrated in Finland and 2) dynamic modelling methods for investigating opportunities for cost-savings in roundwood and bioenergy supply logistics with the systems in focus. Geographical datasets about feedstock sources and transportation are a significant part of the study material. Simulation outputs are presented from different study cases where, e.g., conventional transport methods could be partly replaced by HCT, or backhauling could be integrated with a new subsystem based on intermediate terminals. In the simulation model, the performance of the transportation system is also visualized on a map, which enables better validation and verification of the model.

Keywords: roundwood transportation, high-capacity trucks (HCT), supply chain, simulation modelling

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Damage to residual stands caused by harvesting operations in steep terrain

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Abstract: To support timber production for meeting the industry demand for raw materials, efficient timber harvesting is a key element of concepts for mountain forest management. To carry out harvesting operations in mountainous areas is not only complex because of considering various ecosystem services but also to account for the difficult terrain characteristics. Damage to residual stand has been chosen as indicator for the stability and vitality of a stand which is one of the main objectives for forests which are producing drinking water. The objective of this study was to identify parameters, which are influencing the number and size of damages on remaining trees and to develop models for predicting the number of damages on plot and on tree level. Covariance analyses were used for developing the plot level model, binary logistic regression models were used in order to explore variables affecting the probability of a single tree being damaged during a harvesting operation. A total of 2,080 live trees were examined whereof 485 trees had at least a single damage ($\geq$1 cm²) caused by extraction or felling operations. Plot level analysis showed that slope, harvesting intensity, extraction direction, harvesting and payment method have a significant impact on damage level. The higher the harvesting intensity or the slope, the higher the damage to residual trees. The level of damage is also widely positively correlated with the average DBH and thus with the age of the stand. Tree level analysis showed that the probability of a single tree being damaged is influenced by slope, harvesting intensity, stand density, extraction direction, harvesting and payment method and season. The probability of damage is negatively correlated with the lateral yarding distance.

Keywords: damage, residual stand, timber harvesting, cable yarder

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Harvester measuring systems and IT as basis for optimal bucking and creation of value in German forestry

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Abstract: On-board computers of harvesting machines have been available since the early 1990's. Aside from providing detailed monitoring of engine, hydraulic and electrical systems, on-board computers of modern cut-to-length harvesters can also optimize bucking (task of cutting stems into different log lengths) by relying on value and demand matrices. Despite existing benefits of these on-board bucking optimization systems in increasing product recovery, as mainly tested in Nordic countries, they remain largely under-utilized and generally poorly understood in German mechanized forest operations. Reasons for this are certain specific conditions (e.g. lack of operator training, type of assortments, selective cuts, mixed stands with various tree species, rather low removal rate per entry) often encountered in German forests. To gain further insight, the study aims to compare and quantify the differences in value recovery and machine productivity between two bucking methods (automatic and quality bucking). A mature forest stand with a high proportion of Scots pine (*Pinus sylvestris* L.) will be divided into 30 m x 100 m plots where both treatments (automatic or quality bucking) will be randomly distributed and replicated 18 times. Pre-harvest inventory (species, dbh, height, and tree form) will be performed on each tree targeted for removal via a commercial thinning operation. Harvesting will occur with an excavator based Atlas T23 Königstiger single-grip harvester equipped with a Ponsse H6 harvesting head mounted on a 15 m boom. The same experienced operator will be asked to harvest both treatments. The on-board bucking optimization solutions provided by the Opti4G software will be applied in the automatic bucking treatment whereas the operator will decide the assortments to be derived from each tree in the quality bucking treatment. During harvesting operations, continuous footage will be recorded with a video camera mounted in the operator cabin and aimed at the harvesting head. The recorded video will be analyzed at posteriori with a video time and motion software to allow the reconstruction of individual tree cycle elements and associated products obtained from the on-board computer database. When up-to-date value and demand matrices are used during automatic bucking optimization, we anticipate higher revenues of harvesting operations and potentially higher machine productivity via a tailored and demand oriented product assortment.

Keywords: on-board computers, harvesting, value recovery, cut-to-length

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Accident analysis in forest operations in an alpine context

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Abstract: Forest operations are recognized as one of the most dangerous works in all the productive sectors. In a sustainable perspective, where wood perfectly responds to environmental needs, social sustainability and the related health and safety of forest workers cannot be disregarded. The aim of this study was the analysis of the accidents records in public companies in the Province of Trento, in Northern Italy, regarding forest operations in the period 1995–2013. Several information were available thanks to the up-to-date accident books compiled by each company. With an average Frequency index in the examined period of 88 injuries per million hours worked, forest operations were confirmed as one of the most dangerous works along all productive sectors. Monday had a significant higher frequency of accidents comparing to the other weekdays. The age of the workers seemed influencing the recovery period after injuries, which exponentially increase at rising age. Felling and processing definitely resulted as the most dangerous activity in forest operations covering the 31% of total accidents happened. 'He puts a foot wrong…', 'He was hit by…' and 'He was hit with…' are the most common phrases used in describing the studied accidents; these were the action cause of the accident and contribute explaining why body extremities, first of all the hands, were the body parts most injured. Finally, a new concept in accident analysis was proposed introducing the analysis of 'recidivism', which analysed the eventual recurrence of accidents to the same worker in a given period. Results have underlined that some workers had more than one injury during the analysed period, up to seven accidents for one of them.

Keywords: health and safety, injury, ergonomics, recidivism, Monday, severity

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Environmental assessment of two different logging methods in coppice

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Abstract: Wood is a renewable resource and it actively contributes to enhance energy production under a sustainable perspective. There are different ways for managing forests dedicated to wood production and the sustainable approach is fundamental in order to preserve the resource. In this context, Life Cycle Assessment (LCA) is an useful tool for estimating the environmental impacts related to renewable resources. Traditional coppice is a common approach for forest management in several areas, including southern Europe and, specifically, in Italy, Spain and the Balkans. Different types of forest operations are considered for wood extraction from coppices, where the main product is firewood used in domestic heating. The aim of this work was to compare the two main common systems for firewood production (Short Wood System and Whole Tree Harvesting), in a representative environment in central Italy, by means of LCA. Seven different impact categories were evaluated in a cradle-to-gate perspective taking into account all the operations carried out from the trees felling to the firewood storage at factory. Results showed that the extraction phase was the most important in terms of environmental burdens in firewood production and the use of heavy and high-power machines negatively influenced the emissions compared with manual operations. Finally, considering the general low-inputs involved in wood production in coppice, the transport of workers by car to the work site resulted on consistent contributions into environmental burdens. An additional analysis on soil emissions attributable to the extraction phase were made regarding Climate Change impact category, using bibliographic information. Results showed an increment of 3% and 10% of CO_2eq for Whole Tree Harvesting and Short Wood System respectively.

Keywords: Life Cycle Assessment, environmental impact, no-industrial forestry, renewable energy, southern Europe; soil emissions

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Sustainability of wood products: environmental performance of wood pellets' production by means of Life Cycle Assessment

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Abstract: Nowadays, there is a growing concern and interest in using biomass-based energy sources as alternative to fossil-based ones. In this sense, forests play a key role as source of a renewable material and/or fuel: wood. The aim of this study was to evaluate the environmental impacts related to high-quality pellets production for domestic heating considering the Tuscany region as a representative case study of Italian and European pellets manufacturing, since it is one of the most interesting areas in Italian forest sector, following the Life Cycle Assessment (LCA) methodology and considering a cradle-to-gate perspective. Thus, all the activities involved from wood extraction in no-industrial forests to packed pellets production, ready for delivering to final users were taken into account. No-industrial forestry is widespread in Italy. In mountainous areas, a close-to-nature management regime is applied, i.e. continuous cover forestry management system, aiming at natural regeneration of forest stands. The environmental analysis was performed in terms of seven impact categories: Climate Change, Ozone Depletion, Terrestrial Acidification, Freshwater Eutrophication, Marine Eutrophication, Photochemical Oxidant Formation and Fossil Depletion. Results showed how the most important environmental burdens are related to the use of electricity during pellets production, being responsible for more than 90% of the total in most of the impact categories. Operations carried out in the forest cause a reduced part of the impacts in relation to the entire cycle (from 1% to less than 10% depending on the category).In order to enhance the environmental profile of the factory, four different scenarios for producing and supplying electricity and heat were proposed and investigated. The substitution of the boiler by a cogeneration unit could improve the environmental burdens in all the impacts categories (except in Marine Eutrophication), obtaining the best results when all the electricity requirements are satisfied by this alternative system. The results reported in this study could be considered representative and interesting not only for Italian pellet factories but also for similar factories located in Central Europe because of the key-role played by Italy in the production capacity of that area.

Keywords: environmental impact, Life Cycle Assessment, no-industrial forestry, renewable energy, domestic heating

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A new device for reducing crew size and operator workload during log winching operations

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Abstract: Winching has a low productivity and it is a labor-intensive task with heavy strain on the circulatory and respiratory systems. It is considered as heavy physical and unattractive work. An Italian manufacturer developed an auxiliary winch for automatically returning the winch cable to the load site, avoiding to the loggers to walk to the winch and pulled the cable back to the loading site. The goal of the study was to test if the new device allowed a significant improvement of winching productivity with a reduction of winching cost and mitigation of operator workload. A comparative test was conducted on the hills north of Florence, in Central Italy, in a 30-year-old Turkey oak (*Quercus cerris* L.) coppice, which was being clearcut at the end of its ordinary rotation. The experiment tested 6 male operators covering a whole range of age and fitness characteristics. Each operator worked for half-day with the auxiliary winch and half-day without and work bouts were randomly distributed with a minimum of two hours rest between bouts in order to avoid carry-over effects. Each work bout was conducted on a parallel winching corridor. Performance was determined by stop-watching all winching cycles, with and without the innovative device. Each cycle was associated with the exact winching distance and load size. Physiological workload was determined by measuring the operators' heart rate for the work session. Regression analysis showed that winching cycle time was significantly affected by winching distance, device and operators. Tree size had no effect on winching time. Use of the auxiliary winch allowed a mean cost reduction between 20% and 35%, depending on team selection. The cost reduction obtained with the auxiliary winch increases with distance. Physiological workload was reduced between 7% and 30%. The auxiliary winch proved to be effective in the operating conditions of the study area. It allowed a reduction in manpower to achieve the same task and gave the winching assistant more time to prepare the loads. The new device seemed very effective also in reducing operator workload, which could not be achieved with other solutions, such as the replacement of steel cable with synthetic rope or the introduction of a powered slack-puller.

Keywords: ergonomics, productivity, winch, coppice, heart rate

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Lowering forwarding costs: calculating decrease in forwarder distance due to lower number of assortments and stand area partition

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Abstract: Forwarding can be an efficient method of extracting timber when a limited variety of assortments are prepared by harvester. For high efficiency, a maximum of two different assortments are usually loaded onto a forwarder, one in front and one at the rear of the loading space. However, customers often demand different cut-to-length assortments for particular products. This means that many different log lengths are cut by harvester, and as a consequence, forwarding becomes less efficient. The objective of this research was to find out how much forwarder driving distance decreased in two cases: 1) when two different assortments were extracted (FD2) instead of four (FD4), but to one landing area (1LA) in each case, and 2) when the stand area was divided into two zones from which timber was extracted (as two and four assortments) to two separate landing areas (2LAs).A theoretical thinning stand was established in order to provide mathematical calculations. For one landing area (1LA) two forwarding distances (FD) were calculated and compared: 1LA-FD4 when four assortments: a1, a2, a3 and a4 were extracted, each amounting to 25% of the total harvested timber (THT), and 1LA-FD2, when two assortments: A1 and A2 were extracted, each amounting to 50% of the THT. In both cases, when 1LA-FD4 and 1LA-FD2 were calculated, the THT was of the same volume in the same theoretical stand. In addition, the distance was calculated for the same theoretical stand divided into two zones of equal size with two separate landing areas (2LAs) and with the same assortment pattern: 2LAs-FD4 and 2LAs-FD2. In the case of 2LAs, the timber from each half of the stand area was delivered to the appropriate LA.It was found that when 1LA was designed, FD2 was NN% shorter than to FD4, and the application of 2LAs shortened FD2 and FD4 by NN and NN%, respectively. Since the shorter forwarding distance leads to lower costs (mainly due to lower diesel consumption and lower labour costs), the number of assortments should be considered when calculating forwarding costs. Lower costs can be achieved when more landing areas are designed for extraction. NN – values will be presented at the conference presentation.

Keywords: forwarding optimisation, cut-to-length technology, strip roads, landing areas

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Recovery of soil physical properties from compaction caused by ground based skidding in Hyrcanian forest, Iran

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Abstract: Short-term natural recovery of soil physical properties on skid trails was investigated immediately response to skidding, one and three years after skidding. At each time, mean values for bulk density (BD) and total porosity (TP) were assessed for three levels of traffic (two, seven, and 13 passes). Immediately after skidding, bulk density in the compacted plots increased between 25–86%, and total porosity decreased between 14–37% compared to undisturbed levels. Over the one-year period, mean values for light, moderate and heavy traffic intensity were 40, 77 and 103% (BD) greater and 23, 33 and 45% (TP) lower compared to undisturbed area; over the three-year period, values were 32, 70 and 99% (BD) greater and 17, 26 and 43% (TP) respectively. Surface soil compaction did not show any recovery over the one-year and three-year periods, illustrating the persistent effects of compaction on the surface soil structure. Soil samples collected immediately after skidding indicated slight response to trafficking but soil samples collected within one year after skidding indicated a greater response. This increase may be a reflection of site variability, but other factors, such as organic matter loss after the canopy was removed or raindrop impact on the exposed soil, may contribute to this increase. Also this was presumably due to differences in soil moisture content at the time of sampling.

Keywords: dry bulk density,porosity, soil disturbance, traffic frequency

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Limits of trafficability on forest soils. Influencing parameters on rutting

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Abstract: In most discussions about soil protection in context with forest operations, the wheel loads exerted by the harvesting and forwarding machines are indicated as the main reason for negative modification in soil characteristics and rutting process. The loads cause soil compaction with increased bulk density and strong reduced pore volume. Advanced investigations have shown that the factors of wheel slip, soil water content and soil parameters have also a major effect on rutting. All describing factors for rutting in combination with different machine configurations were acquired in the project „Influence of wheel load and wheel slip on rutting in forest operations" and ordered in term of significance. The results show that the soil water content is the most important variable for rutting, while the numbers of machine passes determine the depth of ruts. On the basis of these results major issues are established: How long is it possible to maintain the technical trafficability? Is it possible to find a mathematical model to describe these limits? The properties and formation of ruts can be described as a mathematical function, where the points of soil compaction and viscose flow characterize this function. In particular, a sigmoid function characterizes the formation of ruts. Aim of the curve-fitting is to reduce all impact factors (machine and soil parameter) to very few factors included in the mathematical function. The function is defined by two slope parameters, inflection point and the relation of maximal number of passes to the number of passes at the inflection point. Finally, a regression analysis describes the strength of the parameter connectivity quantitatively and predicts the rut depth in a supposed number of passes.

Keywords: wheel slip, rutting, forwarding operations, machine operating trail, trafficability

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Planning of primary forest road network on strategic and tactical level – from idea to implementation in operational forestry

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Abstract: Forest traffic infrastructure, in commercial forests and for ground based timber extraction purposes, consists of primary forest traffic infrastructure (all forest roads, public and non-categorized roads that can be used for forest operations) and secondary forest traffic infrastructure (skid roads and skid trails). The establishment and later also the management of the optimal primary forest road network is always carried out through four work stages: 1. planning, 2. designing, 3. construction with supervision and 4. maintenance. Sometimes and when necessary, during their life span other two work stages may appear: 1. reconstruction, 2. removal and restoring. Planning of primary forest roads, depending on the level, is in accordance with the time period for which the plans are made, considering the size of the area in question and based on complexity of the whole planning procedure, can be: 1. strategic, 2. tactical and 3. operational. Strategic planning (planning on the relief area level) and tactical planning (planning on the management unit level) of primary forest traffic infrastructure are related to the planning of the entire network of primary forest traffic infrastructure, while the operational planning is related to the planning of individual forest roads. This paper gives a critical analysis of the current situation regarding the stage of planning primary forest traffic infrastructure in the Republic of Croatia. The emphasis is placed on strategic and especially on tactical planning. The results have been presented of previous research on planning primary forest traffic infrastructure with the attention on the results of research carried out in the last fifteen years. The basic problems present today have been identified and the guidelines for solving/lessening them have been recommended. The Study of Efficiency of Forest Roads – Primary Forest Traffic Infrastructure has been analyzed in detail in all work phases, indicating good and less good solutions.
The Study is the document that must be prepared and enclosed when forest owners apply for nonrefundable EU funds in the framework of the Program of Rural Development of the Republic of Croatia in the period 2014–2020, based on which the quality and quantity of the network of primary forest traffic infrastructure in the management unit is assessed. Case study for the specific management unit has also been made. The Study of Efficiency of Forest Roads – Primary Forest Traffic Infrastructure presents a good transitional solution towards the introduction of the Study of Primary Forest Opening as a legally binding document in operational forestry of the Republic of Croatia. The basic components of the Study of Primary Forest Opening are described as well as work phases/subphases through which the above components are formed. Benefits that can be achieved by applying the Study of Primary Forest Opening have also been outlined.

Keywords: primary forest traffic infrastructure, strategic planning, tactical planning, Study of Primary Forest Opening

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Measuring wheel ruts with close range photogrammetry

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Abstract: We demonstrate the efficacy of using close range photogrammetry from a consumer grade camera as a tool in capturing high resolution data for detailed analysis or monitoring of the wheel ruts. The technique could lead to considerable resource savings as compared with the conventional manual registration, while providing a greatly enhanced source of information. The method outputs a 3-dimensional coloured point cloud that can be analysed for both physical and biological change, and can be stored in a repository for later operations management or monitoring. This study also presents the method to derive and quantify properties such as rut depths and soil depositions volumes. In evaluating the potential for widespread adoption of the method amongst forest or environmental managers, the study also presents the workflow and provides a comparison of the ease of use and quality of the results obtained from 3 different image processing software packages. Results from a case study showed no significant difference on point cloud quality in terms of model distortion. Comparison of photogrammetric profiles against profiles measured manually resulted in RMSE of alignment error between manual registration and reconstructed surface that spans between 2.07 and 3.84 cm for 5 selected road profiles. Maximal wheel rut depth for three different models were 1.15m, 0.99m, 1.01m and estimated rut volume were 9.84m^3, 9.10m^3, 9.09m^3 respectively for 22.5m long sections.

Keywords: forest operations, wheelrut, photogrammetry

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Impact of harvester engine rotation speed on effectiveness of birch log processing

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Abstract: Harvester operations with a lower engine rotation speed per minute (RPM) make it possible to reduce fuel consumption while maintaining efficiency. However, in broadleaved stands, higher engine power may be necessary for the efficient delimbing of thick branches. The objective of the research was to compare the effectiveness of a John Deere 1270E harvester in a birch stand with the engine working at two different rotation speeds: 1800 and 1600 RPM. The effects were analysed with respect to productivity and log quality assessment, including tree trunk utilisation. The operational productivity was 37.27 and 32.88 m^3/h, respectively for work at 1800 and 1600 RPM. Delimbing and cross-cutting consumed 12% less time at a higher speed. Higher RPM allowed better trunk utilisation – log processing and delimbing was possible from the highest part of the tree with a minimum diameter of 7 cm. In addition, the assortments obtained using 1800 RPM were delimbed more precisely. The percentage of short stubs (up to 10 mm) was 72 and 43%, at 1800 and 1600 RPM respectively. However, a lower engine rotation speed made it possible to reduce timber damage. The results showed that a higher harvester engine rotation speed is more suitable for birch log processing in terms of productivity, merchantable timber utilisation and delimbing quality.

Keywords: timber harvesting, broadleaved species, birch, trunk utilisation, logs quality

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Validation of prediction models for estimating moisture content of logging residues

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Abstract: Increased use of forest biomass for energy and rising transportation costs are forcing biomass suppliers towards better moisture content management in the supply chain. Natural drying is used to decrease moisture content of energy wood. Drying models for estimating the optimal storage time based on average moisture changes in fuel wood stacks stored outdoors has been developed for different stem wood and logging residues. Models are easy option to get an estimate of the moisture content of energy wood pile if compared with sampling and measuring the moisture of samples. In this study stand and roadside storage models for logging residues were validated against data from forest companies. 120 reference piles for stand model, 13 piles for road side model and 9 piles for combined model were studied. Results of the validation are promising. The difference between measured and modelled moisture was in average only 0.9%. Presented models can be implemented in Finland everywhere, because Finnish Meteorological Institute has weather history service, which offers weather history data to every location in Finland. For international use, parameters need to be estimated case by case, but the approach itself should be possible to be implemented also elsewhere.

Keywords: logging residues, quality, storing, drying models, natural drying, model validation

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Mobilisation by better information of private Forest Owners in Germany

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Abstract: The initiation of forest owners to manage small, fragmented forest areas as well as support their advisers and professional consultants in technical aspects of timber harvesting is an outstanding topic of KWF information duties. Within the EU-SIMWOOD-Project the KWF is to provide expertise in harvesting procedures and techniques in small forests. Characteristic for many woodland owners is a lack of basic information in adequate equipment, tools, skills and operational safety. Therefore the KWF established the Regional Learning Lab (RLL) Lower Saxony and conducted the 3. KWF Focus Days in October 2015. The event had a tripartite structure “professional forums”, “field demonstrations” and “thematic exhibitions”. The contribution will analyze success factors of mobilizsation of private forest owners in this model region by visitor survey, targeted interview and additional benchmark indicators.

Keywords: Small-scale forestry, managing small forests, RLL Lower Saxony

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The construction of forest roads on the low bearing capacity using timber rafts and brushwood mattresses

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Abstract: The area of habitat of moist and boggy sites and alder forests in state forests in Poland is a total of 1477.76 thousand ha, which represents 16.1% area of all forests. These are areas of low bearing capacity. Forest Districts PGL LP in 2007 showed almost 264 thousand ha of inaccessible forest areas and 749 thousand ha hard to reach, which is associated with a lack of road infrastructure and difficult terrain conditions. In the literature, examples are given for roads on the ground reinforced with timber rafts from 4,000 BC in Ireland, as well as from the twentieth century in Finland, Norway, and Scotland. The aim of the study was to analyze the technical parameters of forest roads made on the ground reinforced with timber rafts (poles) and brushwood mattresses. As part of the research work the application of rollers and mats to strengthen the ground on existing forest roads and their parameters were analyzed. The new trial sections with reinforced road substrate with timber rafts and brushwood mattresses were designed and performed. For the analysis of technical parameters important for road users and their managers were selected and these have included: bearing capacity of pavement and road substrate, pavement deformation index, pavement evenness in the transverse direction, the width of the roadway and shoulder, the characteristics of the surface structure. The ability of testing surface to receive loads from the wheels of vehicles was determined based on the deflection pavement and the primary (MEI) and secondary (MEII) deformation module with calculated deformation indicator (I0). Designation of deformation module ME of the pavement and the road substrate was made using VSS plate with a diameter of 300 mm. Evenness of pavement and its transverse deformations were determined by geodetic measurements.It was assumed 7 tested sections on existing roads reinforced with rollers from different types of wood (pine, spruce, oak) and with different time of exploitation from 3 to 40 years and section on the road from 2014 reinforced with brushwood mattresses. For this study 500 m of the road with standard sections in different variants of reinforced ground with rollers (oak, pine) and brushwood mattresses. On all roads reference section without reinforced road ground was established.Graphs of pavement deflection for the mean values measured on each section, and the deformation (rutting) in cross section will be presented. It was received a large range of results (27-173 MPa) secondary pavement deformation module MEII, which are depended mainly on the diameter of the rollers used and way of their arrangement. For pavement of crushed aggregates (gravel) on the ground reinforced with brushwood mattresses MEII was in the range 94-187 MPa. On the part of sections of roads the placement of too short rollers and too shallow their placement in the corpus of the road were found.

Keywords: roads, road infrastructure, brushwood mattresses, timber raft, wood depreciation

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Mapping and comparison of harvesting production management in Norwegian forest owners associations

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Abstract: Competitive wood supply starts with stable deliveries at low costs. While seasonal supply variations can be partially dampened by stock and transport management, these inherently assume some degree of service provider overcapacity, with corresponding extra costs. Harvesting production management practices which secure even wood flows and capacity utilization as well as high delivery precision are, therefore, an important platform.

This paper presents the first part of a project aiming to find potential improvements in harvesting production management for Norwegian forest owners associations. Current production management routines were captured using business process mapping methodology. Data collection used the virtual walk-through approach. The walk-through started with central functions setting the framework of supply goals and mill agreements, progressing to the regional level where supply is coordinated between districts before exploring the local variants of how managers schedule operations in their districts.

Result show that assumptions for production management vary between contexts. Production managers often have an additional wood purchase function, and the local harvesting contractors also play a key role in procuring volumes from non-industrial private forest owners. Production management in this context includes numerous levels and activities. The most common sub-processes include: A) Overall planning within the forest owner association, B) Operational scheduling of harvesting and C) Production follow-up. Multiple re-planning loops are found within sub-processes B) and C) to adjust scheduling due to variations in weather/bearing capacity and secure the optimal machine choice from the available harvesting companies.

Scheduling activities in sub-process B) typically starts with a preliminary bank of long-term contracts with key forest owners, continuously supplemented by new contracts with neighboring owners. Management practices vary between winter and summer where managers constantly strive to re-schedule operations from the forest owner's initial preference (normally winter) to periods more suitable for mill delivery plans. After this initial scheduling, traditional practice aims to facilitate maximal contractor production through routing which concentrates harvesting and minimizes relocation costs. In this case, achieving balance in wood supply often becomes the responsibility of the regional manager where temporary contractor capacity is utilized to achieve overall balance.

Two main variants were found, depending on the degree of centralization in the organization. These are compared to three main variants mapped in a neighboring Swedish forest owners association.

Keywords: production management, transport management, wood supply

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Characterizing north-Italian logging contractors: success factors, obstacles and perspectives

Raffaele Spinelli*, Michel Soucy, Eric Jessup, Natascia Magagnotti

Abstract: After conducting a comprehensive census of the over 1200 north-Italian logging contractors, the Authors extracted randomly 320 contractors and interviewed them, in order to determine their perceived success factors and obstacles, and their future business perspectives. The resulting view was that of a continuity and resilience. Over 80% of the 320 respondents stated that they came from a family of loggers, and over 70% predicted that their sons would continue into the business. Over half stated they were accruing profits and they thought to continue in business for many years to come. However, more than 50% stated they had difficulty replacing old equipment, due to limited cash flow. Furthermore, the study disclosed significant differences in perceived performance and perspectives among contractors working in different regions of Italy, and among those using different technology types and levels. The study also probed differences between companies targeting different resources (public forests or NIPF) and moving different work volumes. The study provides an insight into the entrepreneurial reality of northern Italian logging companies, as one example of the larger population of mountain loggers spread across the Alps an through much of Central and Southern Europe.

Keywords: Loggers, Mountains, Social

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The efficiency of timber harvesting using the HYPRO 450 processor combined with a farm tractor

Arkadiusz Stańczykiewicz*, Krzysztof Leszczyński, Janusz M. Sowa, Dariusz Kulak, Grzegorz Szewczyk

Abstract: Timber harvesting with the use of a processor combined with a farm tractor was performed is pine stands growing on flat terrain, subjected to early and late thinning treatments, as well as fir and spruce stands on sloping lands, where early thinning was done. The studies were located in southern Poland, within the area of the Forest Districts of Rybnik and Wisła (Regional Directorate of the State Forests in Katowice), and the Forest District of Myślenice (RDSF in Krakow).
The logging operations took place in 12 rectangular manipulation zones with dimensions of 50x100m, and their longer sides touching the skidding trails, where the processor was placed. Cutting and felling of trees in all the stands under scrutiny was performed by the same chainsaw operator. Operations of delimbing and cross-cutting of harvested trees, which had been previously hauled with the use of a cable winch over a maximum distance of 50 m, were performed by two operators (one in pine stands, the other one in fir and spruce stands). The stems were processed into rollers with a length of 1.25 m and 3.0 m (destined for transport pallets and construction props), and logs with a length of 6.5-17.5 m (destined for coal mines - only from late thinning in pine stands).
The efficiency and time consumption of operations performed by a chainsaw operator and a processor's operator were computed within a productive work time, including main work times (e.g. timber processing) and complementary work times (e.g. relocation and travels along the operational tracks within the worksite).
The average productive efficiency of the processor in pine stands accounted for 2.88 m^3/h (2.46-3.17) for early thinning and 7.80 m^3/h (4.85-9.99) for late thinning. Whereas, in fir and spruce stands, subjected to early thinning treatments, the average processor efficiency amounted to 1.53 m^3/h (1.22-1.73) and 1.58 m^3/h (1.35-1.87), respectively. With regard to time consumption of operations performed by the processor in pine stands, it enclosed within a range of 18.9-24.4 min/m^3 (21.1 min/m^3 on average) for early thinning and 6.0-12.4 min/m^3 (8.5 min/m^3 on average) for late thinning. In fir and spruce stands the average time consumption of logging works accounted for 39.2 min/m^3 (33.4-46.3 min/m^3) and 38.0 min/m^3 (31.9-42.5 min/m^3), respectively.
In pine stands the productive efficiency of a chainsaw operator performing early and late thinning treatments amounted to 8.05 m^3/h and 15.67 m^3/h. While in fir stands it was 3.51 m^3/h, and in spruce stands the efficiency accounted for 6.57 m^3/h. The time consumption of operations performed by a chainsaw operator in pine stands amounted to 7,6 min/m^3 for early thinning and 4,1 min/m^3 for late thinning. Whereas, in fir and spruce stands (early thinning) it reached the level of 17,7 min/m^3 and 9,8 min/m^3, respectively.

Keywords: work efficiency, time consumption, motor-manual technology, thinning treatments, coniferous stands

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The variability in work volition of harvester's operators

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Arkadiusz Stańczykiewicz, Dominika Gaj-Gielarowiec

Abstract: Recognition of the structure and distribution of rest breaks taken by workers during a workday is particularly important at worksites characterised by a high level of energy expenditure, which is typical of most of the timber harvesting technologies. Introducing harvesters into the forest practice in the recent years, for which other tediousness, such as monotonous and repetitive work was recorded, makes the above-mentioned issue even more actual. This paper aimed to determine the nature of variability in work performance within a working shift at the worksite of a harvester's operator, and to recognise the form, distribution and duration of rest breaks per particular periods of a workday. The studies were carried out in clear-cut and post-disaster pine stands. The authors assumed that the most significant determinant of work performance level at the worksite under scrutiny was the time of delimbing. For describing the variability of delimbing work times within particular periods of a workday, and the duration of rest breaks, fourth degree polynomials were used. A characteristic rhythm of work volition was revealed, which differed from the work curve developed by Graf. The structure of rest breaks recorded in these studies resulted from an increasing mental fatigue and escalating need for body regeneration. The research results indicated that the distribution of rest breaks within a working shift did not correspond entirely with the model system of work organisation.

Keywords: timber harvesting, harvester, workday structure, work curve, work volition

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Productivity models for harvesting processes – "HeProMo"

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Abstract: "HeProMo" is a JAVA-based software to estimate productivities and costs of harvesting operations. It contains models of the most important harvesting systems. Time and cost calculations for individual stands are possible. The software provides also the possibility of sensitivity analysis which is very useful. In Switzerland "HeProMo" is widely-used in practice and science. It is freeware. The productivity models, realized in 2003, are partially going to be out-dated and several models for new modern harvesting processes are missing yet. The aims of the project are to renew some of the existing models based on new data sets and to create new models for current harvesting processes, such as logging and chipping of energy wood, transport of chips and logging of full trees by cable-crane. Big data sets of German and some Swiss forest enterprises are used for modeling. Each model is well documented concerning (i) the use of the model and (ii) the statistics of modeling. The software will be available in different languages (German, French, Italian and English). We would like to present an overview of the productivity models, some insights into the modeling work and in a final step applications of the software.

Keywords: harvesting, productivity, models

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Accuracy of logs' volume determination due to measurement systems applied in harvesters

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Abstract: The volume of the timber harvested in Poland by using multi-operation machines has increased significantly over the last few years. All harvesters come equipped with computerized measurement systems. In many countries, information about the volume of harvested wood comes directly from the on-board computers and is used in trade; in Poland not yet. Foresters make additional measurements of logs and their volume is calculated in States Forest Information System. The main purpose of the research presented in this study was to assess the accuracy of measurement systems used in harvesters in application to logs' volume determination. The analysis include volume errors as a result of subtraction between volume calculated by harvester system and volume calculated by Huber sectional formula, assumed as real volume. The measurement data come from Scots pine stands – the main tree species in Polish forests - located in the Piska Forest (North of Poland) and the Sandomierska Forest (South of Poland). Empirical material includes diameters outside and inside bark measured in one meter long sections. The investigation was carried out for 3 and 5 meters long logs with few variants of the measurement. The main point that can be taken from this research is that only in certain cases selected variants of measurement methods can be considered as appropriate to use in Polish forests conditions. In addition, the work shows that the biggest number of inaccuracies in determining the volume results from the size and manner of bark reduction and also the selection of taper coefficient. The observed systematic errors indicate a need to validate measurement methods used by multi-operation machines.

Keywords: harvesters, log volume, volume measurement system, accuracy of volume determination

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Carbon footprint of a firewood supply chain in Northern Greece

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Abstract: Firewood comprises more than 70% of the total wood production in Greece. The study assessed the energy requirements and carbon footprint of a firewood supply chain in Northern Greece. The supply chain was analysed from the harvesting site to the retailer's premises, 165 km away, where 1 m logs were transported and processed to 33 cm billets, and then to the consumer's location where the firewood was consumed. The boundaries of the system have been defined and a Life Cycle Inventory (LCI) has been created. All activities, equipment and fuel consumption data have been included in the LCI, with the wood harvesting and log processing data been collected by means of time studies. Truck transportation from the roadside to the firewood retailer was responsible for 58.21 % of the total energy expenditure. The energy input-output ratio was 1:31.5 in the case of forest operations but it increased to 1:9 when all processes were included. The carbon footprint per functional unit has been estimated at 1.60 kg CO_2e per KWh of energy produced. According to our findings, the firewood supply chain in its present form constitutes a sustainable and environmentally friendly source of fuel, which can be further improved in terms of energy efficiency and GHG emissions.

Keywords: biomass supply chain, carbon footprint, energy balance, Life Cycle Inventory

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