RESIDUAL STAND DAMAGE CAUSED BY MECHANIZED HARVESTING SYSTEMS

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Abstract*: The development and deployment of harvesting systems aims to provide physically feasible, economically viable, and environmentally sound solutions. The paper aims to investigate one impact of environmental soundness - the effects of four harvesting systems on the frequency and the characteristics of residual tree damages. The following harvesting systems were surveyed: (i) a cut-to-length wheeled harvester-forwarder system, (ii) a cut-to-length tracked harvester-forwarder system (iii) a cut-to-length harvester-cable yarder system, and (iv) a whole-tree chainsaw-cable yarder-processor system working in Norway spruce stands. After finishing the harvesting operations, a field survey was done to collect data of all residual trees (species, DBH, height) and of tree wounds (size class, location and intensity of damage).*
The CTL wheeled harvester-forwarder system showed the lowest damage percentage, followed by the CTL tracked harvester-forwarder system, the CTL harvester-cable yarder system and the WT chainsaw-cable yarder processor system. Currently the description of the character of tree damages is confined to the two CTL harvester-forwarder systems, whereas no mentionable differences were found.

1. Introduction

Rationalization efforts have resulted in an increasing mechanization of timber harvesting systems. The development and deployment of harvesting systems aims to provide physically feasible, economically viable, and environmentally sound solutions. Environmental soundness consists of several impacts, such as damages to the residual stand, to the soil, or adverse effects on human health and safety.

While many studies were conducted to evaluate physically feasible machine solutions and to improve harvesting economics, the conservation of environment became even more and more essential in public discussion. Especially after thinning operations damage to the residual stand is of importance, because the subsequent affection with wood destroying fungi leads to dry rot and consequently to economical depreciation of the infected stems. For this reason, investigations were done to evaluate residual stand damage caused by different mechanized harvesting systems (e. g. Butora and Schwager, 1986; Han and Kellogg, 1997; Camp, 2002).

After comparing the results of different studies damage levels for every harvesting system should be determined. An evident problem is that in practical operations normally the damage levels from literature can not be reached, because of the presence of the time study crew the contractors worked more carefully. This lack could be avoided by taking the samples without the knowledge of the contractors after finishing the harvesting operations. Another fact is that in former studies the investigated areas and sampling plots were of rather small extent, wherefore the conclusions have conditional validity.

The paper aims to investigate the effects of four harvesting systems on the frequency and the characteristics of residual tree damages. For this reason an adapted sampling design was developed, and data of all residual trees and tree wounds in already harvested stands were collected. Specifically, the research should answer the following questions: (i) What is the total extent of damage in the residual stand that is caused by the different surveyed harvesting systems? (ii) How are the tree damages characterized relating to location on the tree, wound size and intensity? (iii) What is the influence of harvesting time on frequency and characteristics of residual tree damages? (iv) Where are our results situated in comparison to those documented by other studies?

2. Methods and material

2.1 Study sites

The harvested stands as part of this study are located in the plain areas of Upper and Lower Austria and in the mountainous terrain of Lower Austria and Styria and are characterized in Table 1. The areas of the 13 mixed stands, with an age from 50 to 100 years, reach from 1.55 to 4.25 ha. The corridor slopes range from 2 to 61 % and stand densities from 588 to 1357 stems per hectare before harvesting.

Table 1: Stand descriptions

Stand	Stand area [ha]	Tree diameter mean [cm]	Stand density [n/ha]	Corridor slope [%]	Age [y]	Tree species	Location
1	2.05	32.3	879	24 – 45	70	spruce, larch	Trofaiach
2	3.35	22.2	611	25 – 42	100	spruce, pine	Hohenberg
3	2.46	21.5	588	20 – 44	100	spruce, pine, hardwood	Hohenberg
4	2.37	29.9	743	36 – 54	90	spruce, larch, pine, beech	Hohenberg
5	2.15	21.8	683	2 – 8	50	spruce, hardwood	Schlaegl
6	1.55	22.5	881	5 – 11	50	spruce, beech	Schlaegl
7	4.25	24.1	838	36 – 50	100	spruce, larch, pine, beech	Hohenberg
8	2.09	22.1	1130	18 – 40	65	spruce, hardwood	Hohenberg
9	4.05	22.8	649	21 – 51	60	spruce, larch	Hohenberg
10	3.37	21.0	1357	56 – 61	45	spruce, larch, hardwood	Trofaiach
11	3.85	23.7	1101	2 – 4	65	spruce, pine	Litschau
12	4.05	23.4	1103	2 – 4	60	spruce, pine	Litschau
13	1.85	29.8	784	42 – 56	65	spruce, larch, birch	Leoben

2.2 Harvesting systems

The four compared thinning systems are commonly used in Austria. Within one harvesting system the same crew used the same equipment. All of the contractors had years of experience in thinning operations.

2.2.1 Cut-to-length wheeled harvester-forwarder system (CTL 1)

The first cut-to-length system consisted of a wheeled harvester and a forwarder. The harvester was a Timberjack 870B with a 9.2 m reaching Loglift Boom and a Timberjack 743 C harvesting head, which cuts trees up to 45 cm. The logs were extracted with a Steyr 8120 tractor with a Sami WD 12 trailer. No skid trails were designated, thereby the harvester drove all over the stand and completed felling, delimbing and bucking of the trees into log segments. The forwarder traveled on the trails that the harvester passed over and transported the assortments to the road.

2.2.2 Cut-to-length tracked harvester-forwarder system (CTL 2)

This cut-to-length system consisted of a tracked harvester and a forwarder. The harvester was a Valmet 911 Snake, with a 9.5 m reaching Cranab Boom and a Valmet 960 S-2 harvesting head, which cuts trees up to 65 cm. The forwarder was a Valmet 840. The working procedure was the same as described for CTL 1, but both, the harvester and the forwarder drove in dip line.

2.2.3 Cut-to-length harvester-cable yarder system (CTL 3)

The third cut-to-length system consisted of a tracked harvester and a cable yarder. The harvester was also a Valmet 911 Snake, described above. The cable yarder was a Tröstl TST 400 with a Koenigswieser carriage. Skyline corridors were determined and marked before felling by the contractor. The harvester worked on the designated corridors and between them on trails, where only felling and processing were done (“ghost trails”). He bunched and processed logs next to the skyline corridor and the cable yarder extracted the logs to the forest roadside.

2.2.4 Whole-tree chainsaw-cable yarder-processor system (WT)

The whole-tree system consisted of chainsaw tree felling, followed by whole-tree cable yarding. The cable yarder was a Mayr-Melnhof Wanderfalke with a Konrad Woody 50 processor. Skyline corridors were determined and marked before felling by the contractor. Two forest workers felled the trees and the whole trees were yarded to the landing in an integrated working system. Finally delimbing, bucking and piling of the logs was done by the processor.

2.3 Sampling design

The basic methodical formulation for quantification of residual stand damage is the experiment. For making accurate statements, such experiments should be systematically planned (Table 2).

For this study the following prerequisites had to be heeded:

- The contractors had no information about the following investigations.
- Same contractors within one harvesting system.
- Mainly spruce stands with admixtures.
- Minimum size of 1.5 to 2.0 ha per stand.
- No first thinnings.
- Variation in harvesting time.
- Variation in slope.

Table 2: Experimental design

Harvesting system	Summer	Winter
CTL wheeled harvester / forwarder	**2**	**2**
CTL tracked harvester / forwarder	**2**	**2**
CTL tracked harvester / cable yarder	**2**	**2**
WT chainsaw / cable yarder processor	**2**	**2**
Total	**8**	**8**

After finishing the harvesting operations, a field survey was done to collect data of all residual trees. Tree species, DBH and height were ascertained and the new stumps were counted to calculate the harvesting intensity. For stand description the stand area, stand age and the situation of final opening up were assessed. The number, length, width, azimuth and corridor slope of each harvester-/ skyline trail and the distance between them were determined.

The tree wounds were investigated according to the method of Meng (1978). On every tree of the residual stand the number of damages, separated into old and new wounds, was assessed. For every single damage the location on the stem, the wound size and the intensity were described. The division of wounds in damage categories (Table 3) permits an assessment of risk for infections by fungi. With an increase of damage category the probability of an infection also increases.

Table 3: Description of damage categories (DC 1 – 4)

	DC 1	DC 2	DC 3	DC 4
Location of damage	> 1 m	0,3 – 1 m	stump	root
Size of damage	< 10 cm^2	10 – 50 cm^2	51 – 200 cm^2	> 200 cm^2
Intensity of damage	Bark damaged	Bark squeezed	Wood visible, not damaged	Wood visible, damaged

According to Meng (1978) damages in the size-class 1 (< 10 cm^2) are irrelevant and as a rule there is no risk of an infection by wood-destroying fungi. With a wound area more than 10 cm^2 the stage of decay increases in relation to the size of injury.

In the case of external damage to bark a fungal infection could not be expected (Butora und Schwager, 1986). If the bark gets squeezed, the tree would only rarely be infected by fungi but an infection and the following decay mostly occur when the wood is visible. The probability, that wound rot fungi appear as a result of real wood injury (DC 4), raises by 40 to 50 percent compared with damage category 3.
The highest risk for decay is given for trees with injuries in the area of the felling cut and the root collar (Figure 1). Damages on superficial roots and above the root collar (> 0.3 m) get less often infected by wood-destroying fungi (Meng, 1978).

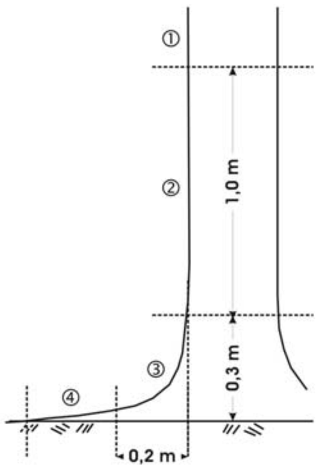

Figure 1: Division of stem in the four damage-locations according to Meng (1978)

3. First results and discussion

At that time the data of only 13 stands are collected and analyzed, two WT-operations and one CTL 3-operation are still missing, because the contractors had not as many employments as we expected they will have.

3.1 Damage percentage

A total of 18,182 live stems was sampled throughout the stands with 5,805 incidents of new damage, caused by the harvesting system, recorded. Table 4 shows that approximately 13 – 70 % of the standing stems were removed and that between 3 and 43 % of the residual trees have at least one new damage. The damage level of all sampling areas averages about 16 %.

Table 4: Damage percentages of harvesting systems

Stand	Harvesting system	Harvesting time	Tree diameter mean [cm]	Corridor slope [%]	Harvesting intensity [%]	Damage percentage [%]
5	CTL 1	winter	21.8	2 – 8	13.6	**3**
6	CTL 1	winter	22.5	5 – 11	14.2	**6**
11	CTL 1	summer	23.7	2 – 4	46.5	**12**
12	CTL 1	summer	23.4	2 – 4	41.8	**15**
2	CTL 2	winter	22.2	25 – 42	30.5	**20**
3	CTL 2	winter	21.5	20 – 44	42.0	**21**
8	CTL 2	summer	22.1	18 – 40	48.8	**17**
9	CTL 2	summer	22.8	21 – 51	45.2	**10**
4	CTL 3	winter	29.9	36 – 54	58.5	**20**
7	CTL 3	summer	24.1	36 – 50	61.3	**23**
13	CTL 3	summer	29.8	42 – 56	70.0	**42**
1	WT	winter	32.3	24 – 45	55.2	**43**
10	WT	summer	21.0	56 – 61	46.1	**15**
	Damage percentage mean [%]					**16**

The cut-to-length wheeled harvester-forwarder system (CTL 1) caused the lowest number of damages on retention trees. The two thinning operations in winter leaded to 3 and 6 % damaged trees, in summer 12 and 15 % of the residual trees sustained some form of damage. The very low damage level in stand 5 and 6 can be ascribed to the marginal slope on the one hand and to the removal of only 13.6 or rather 14.2 % of stems on the other hand. For comparison, McNeel and Ballard (1992) reported less than 5 % residual stand damage as a result of a harvester-forwarder thinning operation in a Douglas-fir plantation in a flat to rolling terrain (0 to 17 % terrain slope). In a literature review Bacher (1999) found an average value of 10 % wounded trees as an impact of harvester-forwarder system on the residual stand. In contrast to these findings, Bettinger and Kellogg (1993) told about 39.8 % damaged trees after a harvester-forwarder operation in a 47-year-old stand, consisting of Douglas-fir and western hemlock. Han and Kellogg (1997) found similarly high damage percentages after three stand treatments by harvester-forwarder system with between 31.9 and 41.3 % wounded trees.

Damage levels of the four stands thinned with the cut-to-length tracked harvester-forwarder system (CTL 2) are considerably higher than those of the CTL 1-treated stands. The main reason for this result may be the higher slope. Up to now a correlation between terrain slope and damage level is not scientifically proven but a trend is reported from several authors (e. g. Stampfer et al., 2001). The same authors reported damage percentages between 1.5 and 7.7 % for several tracked harvesters, but these values apply only for felling, the damage caused by skidding is not included.

With the cut-to-length harvester-cable yarder system (CTL 3) three stands were commercially thinned, one winter-operation is still missing. The damage percentage (42 %) in stand 13 is noticeable high, potentially caused by the very high removal of standing stems (70 %). The other two damage levels, 20 % and 23 %, are situated a little above the value (14 %) Steinmüller and Stampfer (2000) reported in their study about cable yarding after harvester. Frutig and Trümpi (1990) found damage percentages between 5 and 25 % for skyline logging after chainsaw tree felling, limbing and bucking. Similar damage levels were the result from analyses of Han and Kellogg (1997), where cable yarding of assortments, made by chainsaw, caused 13.5 to 20.2 % residual stand damage.

Until now only two thinning operations were done with the whole-tree chainsaw-cable yarder-processor system (WT). The big difference between the two damage levels, 43 % in winter and 15 % in summer, is mainly a result of angular skyline trails (not in dip line) and no topping in stand 1. For comparison, Toplitsch (1987) analyzed the effects of whole-tree system on residual stand damage and found a damage level of 24.7 %, Limbeck-Lilienau (2002) told about damage percentages between 22 and 39 % after whole-tree cable yarding. Frutig and Trümpi (1990) reported a damage percentage of 40 % caused by cable yarding of long logs at a ground slope of 55 %.

3.1 Characterization of tree damages

Regarding the fact that all four planned sampling areas per harvesting system were investigated only for the two CTL harvester-forwarder systems, the description of the character of tree damages is confined to these two working systems.

Figure 2 and 3 show the distribution of residual stand damages in the four damage categories caused by the two CTL harvester-forwarder systems, separated in location, size and intensity of the wounds and differentiated for summer and winter.

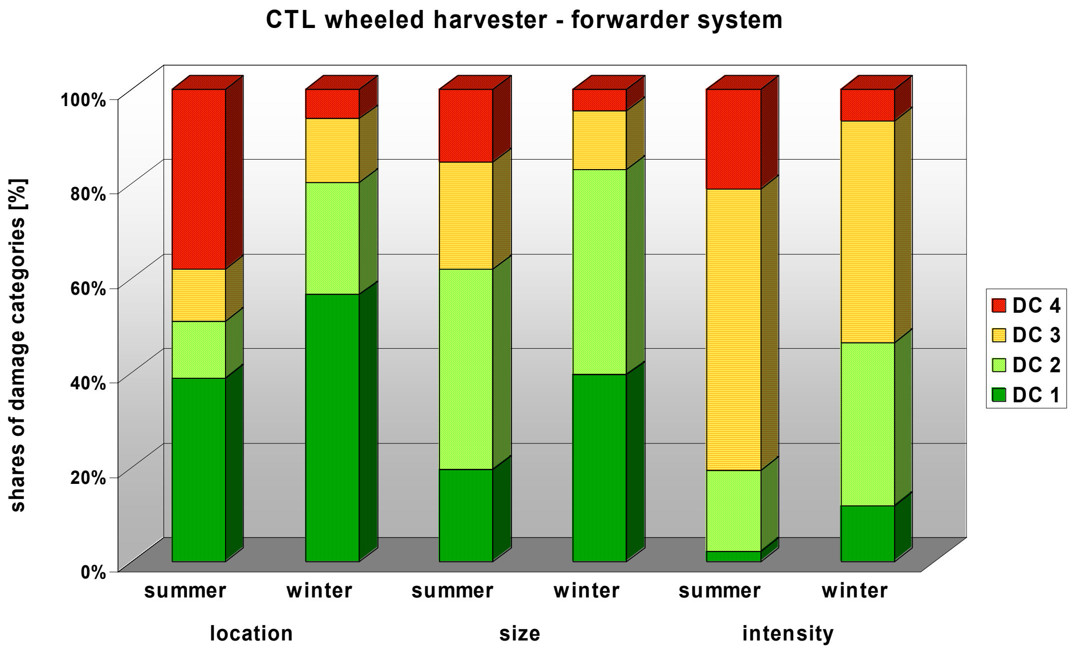

Figure 2: Shares of damage categories for the CTL wheeled harvester-forwarder system

Analyses of damage to the remaining trees caused by the CTL wheeled harvester-forwarder system (CTL 1) demonstrate that the thinning operations in summer leaded to more severe tree wounds. Regarding the location on the stem, in winter only 20 % of the damages were located in the area of the felling cut and the root collar and on superficial roots (DC 3 and 4), compared to nearly 50 % in summer. This result can be traced back to the fact, that during the operations in winter a snow cover was given. Looking at the wound sizes, one can see, that wounds bigger than 200 cm^2 (DC 4) appeared three times more in summer than in winter and about 80 % of the damages inflicted in winter belong to damage categories 1 and 2. A similarly situation is given with the intensity of the damages. In winter only 7 % of the wounds belonged to damage category 4, in contrast to summer, where in more than a fifth part of the cases the wood was destroyed.

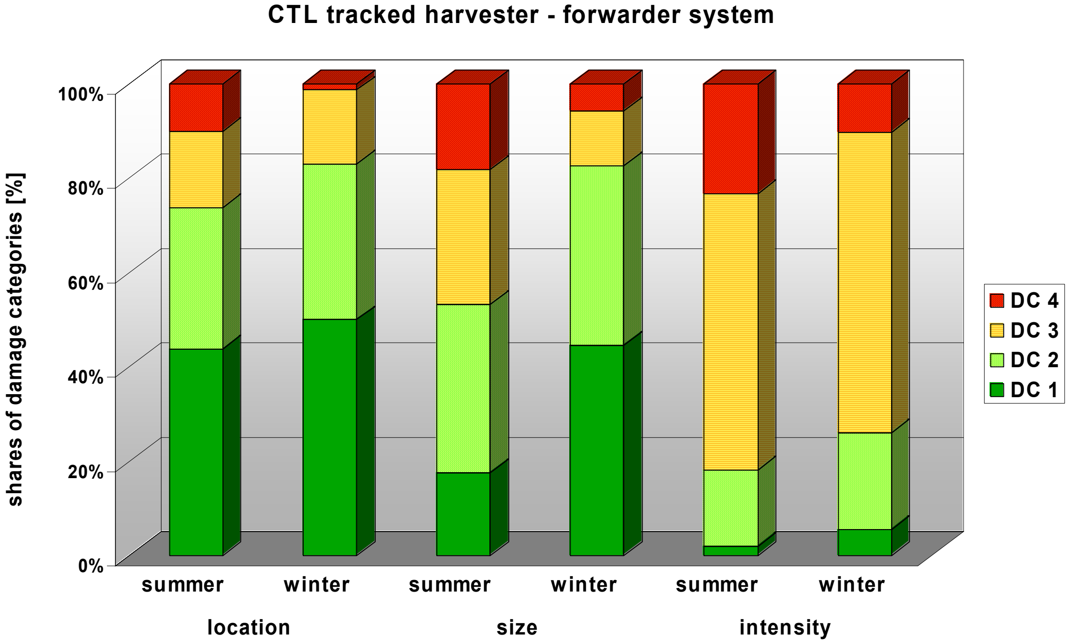

Figure 3: Shares of damage categories for the CTL tracked harvester-forwarder system

The evaluation of damages on residual stems caused by the CTL tracked harvester-forwarder system (CTL 2) shows approximately the same results as the analyses of the impacts of the CTL 1-system. Fundamental, in summer more serious damages were caused by the CTL 2-system than in winter. Concerning the location, in summer 10 % of the wounds were in damage category 4, whereas in winter only 1 % of the damages were located on the roots. Analyses of the wound size showed, that in summer 47 % off all damages were bigger than 50 cm^2, compared to only 18 % in winter. With regard to damage intensity, in 10 % of the cases the wood was destroyed after winter operations (23 % in summer), but in damage category 3 (wood visible, not destroyed) more wounds were found in winter than in summer (64 % compared to 59 %).

Comparing these two investigated harvesting systems with each other, the similarity in the configuration of damages is obvious. Nearly no differences were found regarding wound size and intensity. Looking at the location on the tree, more damages caused by the CTL 1-system were located on the roots (38 % in summer, 6 % in winter) than after harvesting operations with the CTL 2-system (10 % in summer, 1 % in winter).

4. Summary

The paper aims to investigate the effects of four harvesting systems on frequency and characteristics of residual tree damages. The total dimension of damage (regarding the residual stand) is of interest as well as location on trees, wound sizes and intensity of damages. Furthermore the influence of harvesting time should be quantified.

The cut-to-length wheeled harvester-forwarder system (CTL 1) caused the lowest number of damages to remaining trees. The two thinning operations in winter leaded to 3 and 6 % damaged trees, in summer 12 and 15 % of the residual trees sustained some form of damage. The steep terrain may be the reason for the considerably higher damage level of the four stands thinned with the cut-to-length tracked harvester-forwarder system (CTL 2). There is a great variation of damage percentages (20 – 42 %) caused by the cut-to-length harvester-cable yarder system (CTL 3), most probably due to different harvesting intensities (58.5 – 70 %). Only two thinning operations were done with the whole-tree chainsaw-cable yarder-processor system (WT), which resulted in damage levels of 43 and 15 %, respectively. Up to now the description of the character of tree damages is confined to the two CTL harvester-forwarder systems, whereas no mentionable differences were found.

The damage percentages of the present study are mostly in accordance with results from literature.

The analysis of the remaining three harvesting operations is absolutely necessary in order to confirm these first results. An evaluation of ecological and economical impacts from residual stand damage was not part of this study, but should be concerned in following research projects.

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6. References

Bacher, M. (1999) Literaturstudie Bestandesschäden, Versuchsbericht der Forstlichen Versuchs- und Forschungsanstalt Baden-Württemberg, Abteilung Arbeitswirtschaft und Forstbenutzung, Nr. 6, 13 p.

Bettinger, P. and Kellogg, L. D. (1993) Residual stand damage from cut-to-length thinning of second-growth timber in the Cascade Range of western Oregon, Forest Products Journal, 43, 11/12: 59 – 64.

Butora, A. and Schwager, G. (1986) Holzernteschäden in Durchforstungsbeständen, Bericht der Eidgenössischen Anstalt für das forstliche Versuchswesen, Nr. 288, Schweiz. 47 p.

Camp, A. (2002) Damage to residual trees by four mechanized harvest systems operating in small-diameter, mixed-conifer forests an steep slopes in northeastern Washington: A case study, Western Journal of Applied Forestry, 17, 1: 14 – 22.

Frutig, F. and Trümpi, D. (1990) Holzbringung mit Mobilseilkran . Ergebnisse der Versuchseinsätze mit dem Koller K-600, Bericht der Eidgenössischen Anstalt für das forstliche Versuchswesen, Nr. 316, Schweiz. 44 p.

Han, H.-S. and Kellogg, L. D. (1997) Comparison of damage characteristics to young Douglas-fir stands from commercial thinning using four timber harvesting systems, Proceedings of the Council on Forest Engineering, Rapid City, South Dakota, USA, July 28 – 30, 1997.10 p.

Limbeck-Lilienau, B. (2002) Hochmechanisierte Holzernte mit schräger Seiltrasse. Diploma Thesis, Institut für Alpine Naturgefahren und Forstliches Ingenieurwesen, Universität für Bodenkultur, Wien. 56p.

McNeel, J. F. und Ballard, T. M. (1992) Analysis of site stand impacts from thinning with a harvester-forwarder system, Journal of Forest Engineering, 4, 1: 23 – 29.

Meng, W. (1978) Baumverletzungen durch Transportvorgänge bei der Holzernte – Ausmaß und Verteilung, Folgeschäden am Holz und Versuch ihrer Bewertung. Schriftenreihe der LFV Baden-Württemberg, Band 53. 159 p.

Stampfer, K.; Steinmüller, T.; Svaton, R. (2001) Grenzen der Steigfähigkeit, Österreichische Forstzeitung (Arbeit im Wald), 112, 3: 1 – 3.

Steinmüller, T. and Stampfer, K. (2000) Seilrückung nach Harvester - Produktivität und Bestandes-schäden, Österreichische Forstzeitung (Arbeit im Wald), 111, 5: 6 – 7.

Toplitsch, M. (1987) Untersuchungen über Rückeschäden bei der Seilarbeit. Diploma Thesis, Institut für Forsttechnik, Universität für Bodenkultur, Wien. 128 p.