

Damage to Advance Growth Resulting from Timber Harvesting During Final Cuttings

ARKADIUSZ STAŃCZYKIEWICZ*, GRZEGORZ SZEWCZYK AND DARIUSZ KULAK

University of Agriculture in Krakow, Faculty of Forestry, Department of Forest and Wood Utilization, Al. 29 Listopada 46, 31-425, Krakow, Poland;

tel.: +48126625090 / fax.: +48124124418 / e-mail: rlstancz@cyf-kr.edu.pl

Stańczykiewicz, A., Szewczyk, G. and Kulak, D. 2015. Damage to Advance Growth Resulting from Timber Harvesting During Final Cuttings. *Baltic Forestry* 21(1): 144–151.

Abstract

The research was conducted in the southern Poland, in mature spruce stand, where final cutting were carried out with the use of LARIX LAMAKO tower cable system combined with farm tractor and with the use of LKT 81 TURBO skidder. The tree-length system (TLS) timber harvesting technology was applied using chainsaw for felling, delimiting and cross-cutting and the above-mentioned machines for skidding to the landings. In the selected stand, four study plots were established, in which inventory of advance growth (saplings) was carried out before and after timber harvesting. In the case of technology using tower cable system, the level of damage to advance growth in individual manipulation sample plots was within the range of 21.9% – 25.4% (average 23.9%). In the case of skidder technology, damage reached the level of 55.6% – 65.9% (average 61.3%). The most commonly observed type of damage to the advance growth as a result of final cutting with the use of tower cable system technology was destroyed saplings. Most damage occurred in the lowest advance growth (up to 0.5m above the ground). As for skidder technology, the most commonly observed types of sapling damage were stem and side-branches breaks; most damage occurred in medium-sized advance growth (0.5 – 4.0 m). A few results presented in this paper may be used for long-term research consisting in continuous observation of the growth and development of damaged advance growth or quality and spatial distribution of saplings that were not affected by timber harvesting. Conducting such observations will be possible due to fixed circular research plots, permanently marked at the current stage of the investigations.

Key words: damage to saplings, spruce stand, tower cable system, skidder, final cutting

Introduction

The problem of damage to advance growth due to timber harvesting has been ever more frequently the subject of research in numerous countries, especially over the last decade. Studies carried out by many authors point to the fact that the proportion of damage to advance growth may vary substantially. As indicated by Petreš (2006), due to the use of LKT 81 tractor, 6.8% of young plants were damaged. Most damage was caused by hauling timber to skid trails. The extensive study of damage to advance growth in coniferous and deciduous stands, both on flat and steep terrain, was carried out by Stańczykiewicz (2006). The author pointed out the fact that timber harvesting by means of skidders during full vegetation period may result in damage level ranging from 7.5% to almost 32%. Velichkov (2007) showed that in mixed stands during winter time, the level of damage to saplings resulting from skidding by means of LKT skidder may oscillate at the level of 2-8%. On the other hand, study results presented by Naghdi et al. (2009) indicated that timber harvesting and

logging by means of skidders may result in 35% damage to natural regeneration. The most recent study on the damage level to spruce saplings was presented by Surakka et al. (2011). According to the authors, the level of damage as a result of machine harvesting by harvesters and forwarders oscillated between 17% and 61%. The comparison of the influence of various manual-machine timber harvesting technologies on the level of damage was carried out by Suchomel (1992). The author points out that the use of cable system, chiefly in the presence of snow cover, results in by far better effects as far as the influence on advance growth is concerned. The use of such technology makes it possible to limit damage to advance growth fourfold, as compared to technologies using LKT skidders (from ca 21% to ca 5% of damaged specimens). The benefits of using tower cableways with regards to the advanced regeneration have also been underlined by Modrz and Hubenž (2003), although the use of the above-mentioned devices may result in lowering the amount of the remaining regeneration by ca 25%. In turn, Eliasson et al. (2003) indicate the substantially higher probability of saplings

damage as a result of carrying out works in low temperatures (-15°C), as compared to operations performed on warmer days (0°C). An interesting approach to the issue of damage to regeneration is presented by Lotfalian et al. (2010). The authors attempted to estimate the cost of artificial restoration of regeneration damaged and destroyed due to manual-machine harvesting by means of skidders. Whereas, Dudek and Sosnowski (2011) made an attempt to evaluate selected technologies of timber skidding in mountain forests and established that the share of damages in natural regenerations oscillated within a range of 8-18% with the use of skidder LKT and 9-13% when tower cable system LARIX 3T was applied. According to data published by Sosnowski (2009), only 5 LARIX cableways (550, 3T and KOMBI models) had been used in Poland by the year of 2005. One of the cableways is currently used on the flat terrains of the north-western Poland and it serves for skidding alder timber in swampy and periodically inaccessible stands. The remaining tower cable systems are used for skidding timber in mountainous regions, specifically in these parts of stands which are inaccessible for other devices. The devices are not used in thinning stands at all. In turn, as indicated by Kocel (2005), over 600 multivendor tractor skidders were used in the Polish forests in 2003. The most popular models in this group were Slovakian LKT tractors with various engine versions and variable equipment.

Very limited number of studies describing the problem of degrading influence of cable system tech-

due to timber harvesting and skidding in spruce stand during final cuttings. The scope of the research embraced an inventory of regenerations and damages to saplings that emerged as a result of deploying two various manual-machine technologies of works differing in terms of the manner of skidding timber to landings. The first one was the technology using an LARIX LAMAKO tower cable system, the least frequently employed in Polish forests, and the other one was commonly applied technology with the use of a skidder of LKT 81 TURBO type.

Materials and Methods

Area of study

The research was located in the southern Poland, in Ujsoly Forest District situated within the Regional State Forest Directorate in Katowice (Figure 1).

Due to the specific character and variable terrain, timber harvesting in this Forest District is carried out by means of manual-machine technologies using chain saws for tree cutting and timber processing as well as horses and skidders (most often), and forwarders and cable systems (rarely) for skidding raw material. Final cuttings were carried out in a chosen spruce stand with admixture of beech of a total area of 25.1 ha located at an altitudes between 740 and 1,080 m above sea level ($49^{\circ}24'26''\text{N}$, $19^{\circ}02'33''\text{E}$). During operations, 475 m^3 of timber were harvested from the total area (about 20% of total reserve remained to harvesting). 125 m^3 were



Figure 1. Ujsoly Forest District within RDSF in Katowice and felling area

nologies on the forest environment during the last two decades (Suchomel 1992, Modrz and Hubenž 2003, Dudek and Sosnowski 2011) prompted the authors to make an attempt at analyzing the above-mentioned technologies in terms of damages they cause to natural tree regeneration.

The aim of this paper was to determine the level and character of damages to natural tree regeneration

skidded by means of tower cableways and the remaining part (350 m^3) by a LKT skidder. The overall characteristic of the stand with sample plots and average dimensions of harvested trees are presented in Table 1.

This research was conducted in four stand openings previously regenerated by means of shelterwood method. The aim is to make the widest use of natural regenerations (supplemented with artificial regenera-

Compartment	Area, ha	Stand composition	Age, years	Stand volume, m ³	Growing stock, m ³ ×ha ⁻¹	Stem d.b.h., cm	Mean height, M	Forest site type
200b	25.1	8 spruce* 2 beech**	125	475	19	46	34	Mixed mountain fresh broadleaved forest

* *Picea abies* L., ** *Fagus sylvatica* L.

Table 1. Characteristic of the stand with sample plots

tions as needed) in conditions of an overhead or side shelter of the stand over small areas, primarily, in the openings. It allows growing multi-species stands of various spatial structure and great diversification in terms of age and ensures maintaining an absolute spatial and organizational order based on a transport boundary and a net of skid trails. Through removing merely a part of trees at every cutting, forest canopy is thinned unevenly, with gaps and openings that are usually widened and enlarged (Zasady hodowli lasu 2012). Absent in the References – TN

The area of the openings was between 0.42 and 0.58 ha. Two stand openings were located on a steep slope (35-40% angle), therefore cableway combined with a ZETOR FORTERRA 115 farm tractor was used for skidding timber in this part of the stand. Skidding was based on a already existing skid trail, which had been created under skyline while using the system a few years before, during previous cutting sequence. The other two stand openings were located on a lower part of the stand, on a gentle slope (15-20%), which was more easily accessible for the skidder. Quadrangle-shaped manipulation sample plots of 25 × 60 m were

set up within the above-mentioned openings. The plots were situated in stand openings; their longer side is along the boundary lines. They occupied about 25-35% of the openings' area. In the middle part, a 10-metre wide stretch was left along the skyline as well as along the skid trail, where the skidder was working. A network of squares with a side length 12.5 m was assigned within quadrangle manipulation sample plots. At the nodes, circular plots of 50 m² area were located (Figure 2), the centers of which were permanently marked with pickets driven into the ground. Moreover, geographical coordinates as well as azimuths values and distances between centers and axis of skid roads for circular plots, the nearest to these roads, were recorded. Owing to the data obtained in this manner, it will be possible to return to these circular plots in several years. Then, inventorying of an existing advance growth was carried out twice, before and after timber harvesting. This group included all specimens with breast height diameter less than 7 cm and over two years old.

Timber harvesting was carried out by means of a tree-length-system (TLS) (Pulkki 2004) at the end of



Figure 2. The simplified schemes of sample plots (arrows indicate logging direction under skyline or on a skid trail)

the vegetation process and without any snow cover. In the case of the tower cable system technology, timber was dragged to the skyline and then skidded to the landing. Further in the paper, this technology shall be referred to as LARIX. In the case of the skidder technology, timber was first hauled by cable to a skid trail, where the skidder was waiting, and then skidded. Due to the fact that part of long wood timber was located at an angle, which made it technically inaccessible for the skidder's winch, the machine operator had to approach each long wood separately or get the machine's rear part off the skidding route to the area of the openings. Further in the paper, this technology shall be referred to as LKT.

The classification of advance growth damage, which has been used at the Department of Forest and Wood Utilization for several years and which has been simplified for the purpose of this study, is presented in Table 2 (Stańczykiewicz 2006, Stańczykiewicz et al. 2012). The inventoried advance growth has been classified into three groups according to their height: up to 0.5 m (low saplings), from 0.5 to 4.0 m (medium-sized saplings) and over 4.0 m (high saplings). Additionally, it was assumed in the study that the entire advance growth was appropriate for cultivation.

As a result of field works on four manipulation sample plots (72 circular plots) almost 11,500 saplings were inventoried. Advance growth density in the stand openings, where harvesting was performed by means of LARIX technology was on average $17.6 \times 10^3 \text{ ha}^{-1}$, while in the openings, where harvesting was performed

by means of an LKT skidder, it amounted to $46.0 \times 10^3 \text{ ha}^{-1}$. The stand composition was predominantly spruce with admixture of fir and beech. Advance growth inventoried on individual circular plots was assigned to two zones. Zone A was located closer to the cableway and the skid trail (from 5 to 17.5 m off their axis), while zone B was located further (from 17.5 to 30 m). The total percentage of damage in individual damage classes was calculated on the basis of comparison to the number of pieces inventoried before intervention.

During examining the influence of the implemented technologies on advance growth, the authors made hypothesis of the accordance of empirical distributions with the normal distribution for the percentage share of damaged saplings in three classes of height and damage. The statistical verification of the above-mentioned hypothesis was made on the basis of the Shapiro-Wilk test. In order to specify the importance of differences between the damage level to advance growth in two distance zones from skid trails, the following hypothesis was made: the average values of the percentage of damage in advance growth within the mentioned zones are equal at a significance level $\alpha = 0.05$.

Due to the fact that the results of the Shapiro-Wilk test displayed accordance of empirical distributions with normal distribution, a Student's t-test was applied in order to specify the differences between the features of the investigated empirical distributions. Statistical data processing was carried out by using Statistica 9.1 StatSoft PL program.

Results

Almost 3,200 saplings were inventoried before cuttings within the stand openings, on which timber harvesting was carried out by means of LARIX LAMAKO tower cable system. The highest number of saplings belonged to the lowest group of advance growth (Table 3). It was also in this group that the highest percentage of damage occurred as compared to all saplings inventoried before cuttings.

Table 2. Classification of advance growth damage

Damage class	Characteristic of damage
Destroyed	destroyed or disappeared sapling damaged sapling not expected to survive
Broken	leader broken above last whorl stem broken below last whorl broken side-branches
Out of Plumb	sapling out of plumb and/or torn off bark

Technology	Height of advance growth (height class)		Inventoried [pcs.]	Damage Class			Total	
	[m]	[pcs.]		Destroyed	Broken	Out of Plumb	[pcs.]	[%]
LARIX LAMAKO	< 0.5	Low	2,158	249	78	105	432	13.6
	0.5 – 4.0	Medium	976	159	49	104	312	9.9
	> 4.0	High	37	6	5	2	13	0.4
	Total	[pcs.]	3,171	414	132	211	757	23.9
LKT 81 TURBO	< 0.5	Low	3,498	712	677	613	2,002	24.1
	0.5 – 4.0	Medium	4,665	934	1159	980	3,073	37.1
	> 4.0	High	126	4	3	1	8	0.1
	Total	[pcs.]	8,289	1,650	1,839	1,594	5,083	61.3

Table 3. Damage to advance growth in stand openings after final cuttings in both technologies

Almost 8,300 saplings were inventoried before cuttings within stand openings, where harvesting was carried out by means of the LKT 81 TURBO skidder. The highest number of saplings belonged to medium group of advance growth (Table 3). It was also in this group that the highest percentage of damage occurred as compared to all saplings inventoried before cuttings.

Figures 3 and 4 indicate that in case of LARIX technology, destroyed saplings constituted the largest part of all damaged saplings in each height class. In case of LKT technology, broken saplings were the dominating type of damage only in the case of medium saplings (Table 3).

The analysis of differences between damage classes showed that in the case of LARIX technology the level of destroyed saplings was significantly higher than the level of other damage classes (t -Student_{LARIX} (3.65 ÷ 6.72); $p_{LARIX} < 0.05$) in each height class (Figure 3). In the case of LKT technology the differences shown in Figure 4 turned out to be insignificant.

Figures 5 and 6 indicate that both in LARIX and in LKT technologies damage level to advance growth

was higher in zone A (located closer to skid trail). For LARIX technology, about 55% more damage occurred in zone A than in zone B (located further from the skid trail). For LKT technology, on the other hand, damage was 20% higher in zone A (closer to skid trail) than in zone B. Moreover, as a result of implementing the above-mentioned technology, over twice as much damage occurred in zone A (67%) and almost three times more in zone B (56.6%).

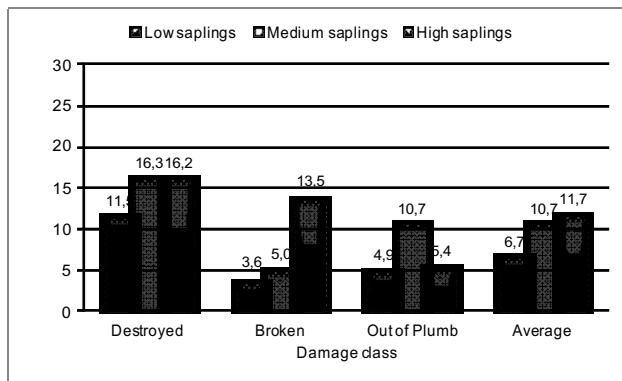


Figure 3. Class of advance growth damage due to harvesting by means of LARIX LAMAKO

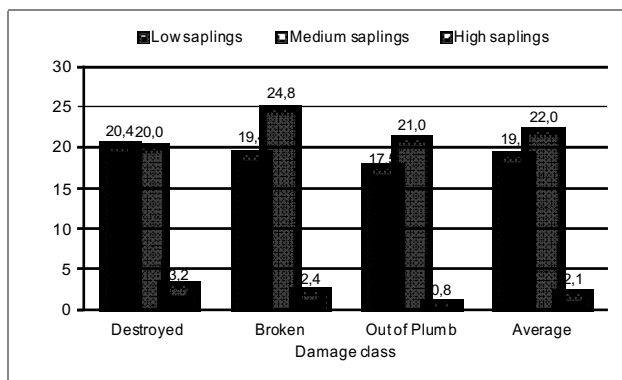


Figure 4. Class of advance growth damage due to harvesting by means of LKT 81 TURBO

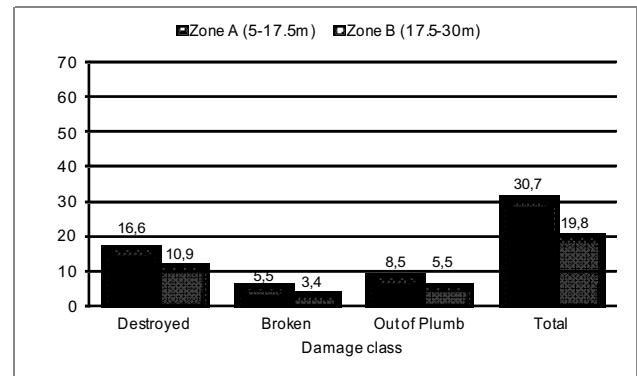


Figure 5. Damage to advance growth depending on the distance from skid trail (LARIX LAMAKO)

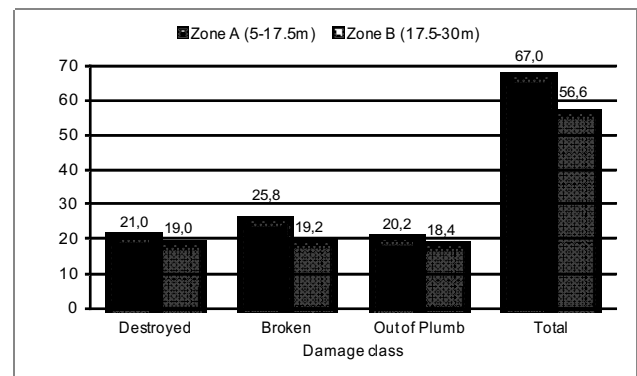


Figure 6. Damage to advance growth depending on distance from skid trail (LKT 81 TURBO)

The analysis of the importance of differences, however, proved that in the case of LARIX and LKT technologies both the differences in the total level of damages as well as in individual classes of damages were statistically insignificant [t -Student_{LARIX} (-0.55 ÷ 1.62); p_{LARIX} (0.12 ÷ 0.59) / t -Student_{LKT} (-0.45 ÷ 0.40); p_{LKT} (0.66 ÷ 0.69)].

Discussion and Conclusions

Due to the use of the tower cable system harvesting technology for final cutting, about 24% of saplings

located within stand openings were damaged. Timber harvesting by means of skidder technology resulted in damage at the level of over 61%. Research results presented in this study indicate that the level of damage to advance growth resulting from LARIX technology was relatively high. On the other hand, it should be underlined that the condition of advance growth after final cutting leaves much to be desired and the level of damage should be considered as extremely high. At this point it should be underlined that joint levels of damages caused by application of two various technologies, given into evaluation in this research, are not comparable. Different landform conditions (e.g. slope angles), different density of regeneration as well as different volume of harvested timber within capacities of both technologies might have affected the final result of the investigations. Therefore, at the moment the results obtained during this research should be considered merely as basic information. We are not able to predict what the consequences of recorded damages will be in the future. We do not know the influence of damages in advance growth on the course of selection and forthcoming spatial distribution of trees, rate of withering or regeneration of damaged saplings, finally, technical quality of mature trees. Due to this long-term research should be conducted consisting in, i.e., continuous observation of the growth and development of damaged advanced growth or quality and spatial distribution of saplings that did not suffer from injuries caused by timber harvesting. Conducting such observations will be possible due to fixed circular research plots, permanently marked at the current stage of the investigations. Information obtained in this manner combined with other data concerning volume of harvested timber would allow optimization of, e.g., intensity of cuttings (Surakka et al. 2011).

Following the recently developed principles of certification in forest utilization (Paschalis-Jakubowicz 2009), the recommended permissible level of tree damage in mountainous regions is 15%. As for the advance growth, it is merely required to minimize damage. That is why, most probably, timber harvesting entities do not always take into account the existing natural advance growth. On the other hand, however, on the basis of previously published information, it is clear that the damage level in spruce stands as a result of manual-machine technologies of timber harvesting may reach from 26 to 50%. In the case of machine technologies, damage was observed on as many as 75% of saplings in the advance growth (Granhus and Fjeld 2001). Other studies carried out in spruce stands proved that damage to advance growth resulting from harvesting by single grip harvesters may oscillate at the level from 36 to 53% (Sikström and

Glöde 2000, Glöde and Sikström 2001). A higher range of damage to advance growth was noted by Surakka et al. (2011), who argued that from 18 to even 61% of natural seedlings and undergrowth may result from machine technologies. According to Suchomel (1992 after Mikuška) even 78% of advance growth may be at risk of damage resulting from LKT skidders. It was the same author, who also proved in his research that the highest percentage (ca. 43%) of damage among all damage classes as a result of using KSK-16 cable system for skidding, were destroyed saplings. This particular study came up with analogical results, i.e. almost 55% (414 pcs. among 757 total) of damaged saplings were destroyed specimens (Table 2). The situation looks rather different in the case of LKT skidder technology. Here the share of individual damage classes oscillates at a more or less similar level, from 31.3% (1,594 pcs.) to 36.2% (1,839 pcs. among 5,083 in totals) with slight domination of break-type damage. Also, Glöde and Sikström (2001) noted similar domination of the same damage class in their research (from 48 to 65%). However, these two authors analyzed damage to advance growth of two alternatives of harvesting by means of harvesters in spruce stands.

Perhaps the extremely high level of damage to advance growth due to LKT technology observed in this study was a result of poor accessibility of the stand. As indicated by Stańczykiewicz (2006), in the event of absence of appropriately designed network of routes, it is a common practice to approach each individual felled tree separately. Such procedure prevents merging the skidding routes into one joint canal and does not allow for reducing the area, which is potentially subject to damage. Consequently, the probability of damage to advance growth increases. Moreover, it is extremely important that chainsaw operators cut trees in possibly the same direction as their further skidding. Felled trees lying scattered in various directions will add up to considerable damage in the first stage of moving timber that is during their allocation at the extension of the hauling line. Even more so, that the tree-length-system commonly used in such conditions prevents cutting to shorter length, e.g. below 6 m. In the case of hauling timber to the skidding route at an angle of 30°, when the tree length is 6 to 14 m, the area of the stand potentially subjected to damage is between 10–52 m². That may also be of quite importance, is the fact that LKT tractors equipped with cable winches lack remote radio control. As indicated in the research of damage to advance growth carried out in coniferous thinning stands (Stańczykiewicz 2011, Stańczykiewicz et al. 2012), by means of processors combined with farm tractors, the level of damage to advance growth oscillated within the range

of 3.3% to 15.3%. During research, the authors could frequently observe the processor operator's appropriately quick reactions. The operator, who was remotely steering the cable winch, followed skidded timber and, if necessary, corrected the skidding route direction. He did that first and foremost in order to facilitate the work process but also to reduce possible damage to precious advance growth. Observations made during field works lead to a conclusion that lower damage level resulting from LARIX technology in this particular study could stem from the fact that while hauling timber to the skyline (stretched a few meters above the ground), the skidded material was first lifted from the ground to a skidding position so that one end of the long wood was lifted much higher above the ground, and thus, it was moving above some saplings. This would not be the case if trees were hauled by a skidder. Additionally, as emphasized by Modrz and Hubenż (2003), the usage of cable systems is considerably more beneficial to advance growth, as damage is mainly caused by harvested timber, and – to an insignificant extent – by the involved equipment or its subunits.

Research results presented in this study proved that the level of damage to advance growth resulting from LARIX cable system (technology rarely used in Poland) was over twice lower than the level of damage due to skidder technology. It should be underlined that such high level of damage involved in this research could be accidental and it should by no means be generalized or identified with the analyzed LKT technology commonly used in many regions of Poland. Over 60% of damage to natural advance growth should, however, encourage field workers of the State Forests administration to observe closer how commissioned tasks are carried out, which primarily concerns the stands growing under difficult habitat conditions, where regenerations were obtained at high costs, or they are exposed to an excessive devastation caused by deer. If glaringly high levels of damage occur (not only in advance growth but in general), steps should be undertaken to train workers, especially chainsaw operators, on the necessity of habitual cutting and felling trees in line with the skidding direction, especially, when using devices equipped with cable winches. Moreover, it should be stressed that it is necessary to conduct further, regular and long-term observations of development of both, the advanced growth that suffered at timber harvesting, as well as those remained untouched. This is the only course of action that may answer the question whether the damages caused presently will influence the quality of stands in the future.

References

- Dudek, T. and Sosnowski, J.** 2011. Ocena środowiskooszczędności wybranych technologii zrywki drewna w lasach górskich [Evaluation of the environmental impact of the selected timber extraction technologies used in mountain forests]. *Sylwan* 155(6): 413-420.
- Eliasson, L., Lageson, H. and Valinger, E.** 2003. Influence of sapling height and temperature on damage to advance regeneration. *Forest Ecology and Management* 175: 217-222.
- Glöde, D. and Sikström, U.** 2001. Two Felling Methods in Final Cutting of Shelterwood, Single-Grip Harvester Productivity and Damage to the Regeneration. *Silva Fennica* 35(1): 71-83.
- Granhus, A. and Fjeld, D.** 2001. Spatial distribution of injuries to Norway spruce advance growth after selection harvesting. *Canadian Journal of Forest Research* 31: 1903-1913.
- Kocel, J.** 2005. Prywatny sektor usług leśnych w latach 1999 – 2003 [The private sector of forest services in 1999–2003]. *Leśne Prace Badawcze [Forest Research Papers]* 66(2): 17-34.
- Lotfalian, M., Emadian, S.F., Kooch, Y. and Khoo, A.P.** 2010. A method for economic assessment of logging damage on forest stand and regeneration. *Scandinavian Journal of Forest Research* 25: 78-88.
- Modrz, M. and Hubenż, D.** 2003. Impact of skidder and high-lead system logging on forest soils and advanced regeneration. *Journal of Forest Science* 49(6): 273-280.
- Naghdi, R., Lotfalian, M., Bagheri, I. and Jalali, A.M.** 2009. Damages of Skidder and Animal Logging to Forest Soils and Natural Regeneration. *Croatian Journal of Forest Engineering* 30(2): 141-149.
- Paschalis-Jakubowicz, P.** 2009. Certyfikacja gospodarki leśnej w użytkowaniu lasu w Polsce [The certification of forest management in the range of forest utilization in Poland]. In: P. Paschalis-Jakubowicz (Editor), *Sprawozdanie końcowe z wykonania tematu badawczego [Report of a research project]* (unpubl). 52 pp. (in Polish).
- Petreš, S.** 2006. Oštečivanje ponika i pomlatka pri privitlavanju i privlačenju oblovine traktorom LKT 81 T iz dovršne sječine hrasta lužnjaka [Damage to young plants during timber extraction by cable skidder LKT 81 T from the final cut of penduculate oak]. *Šumarski list* 3-4(CXXX): 87-100.
- Pulkki, R. E.** 2004. Glossary of forest harvesting terminology. <<http://flash.lakeheadu.ca>> (Accessed 15 April 2007).
- Sikström, U. and Glöde, D.** 2000. Damage to *Picea abies*: Regeneration After Final Cutting of Shelterwood with Single- and Double-grip Harvester Systems. *Scandinavian Journal of Forest Research* 15: 274-283.
- Sosnowski, J.** 2009. Techniczne, ekonomiczne i terenowe uwarunkowania użycia kolejek linowych do zrywki drewna na przykładzie kolejki Larix 3T [Technical, economical and terrain conditions of cableways utilization for timber extraction on the example of Larix 3T cableway]. *Sylwan* 153(6): 393-405.
- Stańczykiewicz, A.** 2006. Poziom uszkodzeń odnowienia w wyniku stosowania ręczno-maszynowych technologii pozyskiwania drewna [The level of regeneration damage caused by manual and mechanical technologies of timber harvesting]. *Acta Agraria et Silvestria ser. Silvestris* 44: 91-116.
- Stańczykiewicz, A.** 2011. Damage to trees and regeneration layer resulting from timber harvesting with the use equipment aggregated with farm tractors in thinned fir stands.

In: J. Starzyk (Editor), Technology and ergonomics in the service of modern forestry. Krakow, p. 253-268.

- Stańczykiewicz, A., Sowa, J.M., Kulak, D., Leszczyński, K. and Szewczyk, G.** 2012. Damage to trees and regeneration layer resulting from timber harvesting with the use of equipment aggregated with farm tractors in thinned pine stands. *Acta Sci. Pol., Silv. Colendar. Rat. Ind. Lignar.* 11(2): 37-51.
- Suchomel, J.** 1992. Poškodzovanie porastu, podrastu a pôdy vo vybraných t'ážbových a dopravných technológiách [The damage of stand, underwood and soil by chosen log-

ging and transport technologies]. *Acta Facultatis Forestalis* 34: 331-341.

- Surakka, H., Sirén, M., Heikkinen, J. and Valkonen, S.** 2011. Damage to saplings in mechanized selection cutting in uneven-aged Norway spruce stands. *Scandinavian Journal of Forest Research* 26: 232-244.
- Velichkov, I.** 2007. Reproduction damages after different timber-harvesting techniques in shelterwood method in Osogovo Mountain, southwest Bulgaria. *Silva Balcanica* 8(1): 25-31.

Received 10 April 2014
Accepted 21 October 2014