ACTA Acta Sci. Pol.
Silv. Colendar. Rat. Ind. Lignar. 11(2) 2012, 37-51

DAMAGE TO TREES AND REGENERATION LAYER RESULTING FROM TIMBER HARVESTING WITH THE USE OF EQUIPMENT AGGREGATED WITH FARM TRACTORS IN THINNED PINE STANDS*

Arkadiusz Stańczykiewicz, Janusz M. Sowa, Dariusz Kulak, Krzysztof Leszczyński, Grzegorz Szewczyk
University of Agriculture in Krakow

Abstract. The research was conducted in pine stands where selective early and late thinning was carried out with the use of NIAB 5-15 and HYPRO 450 debranching and cutting processors along with a FRANSGÅRD V-6000 GS cable winch aggregated with farm tractors. In case of cut-to-length system, timber harvesting was executed by means of processors and in case of tree-length system – by means of a cable winch. The harvested timber was forwarded to the depots in the second stage with the use of self-loading trailers or skidded with the use of a cable winch. Tree damage in case of processor technology oscillated at the level of 3.1-11.3%, and in case of a cable winch: 3.0-10.9%. The level of damage to the regeneration layer amounted to 4.1-27.1% for the areas where processors had been used. For the areas where timber was harvested by means of a cable winch, the level of tree damage was 5.2 -14.0% of trees growing under the main stand's crown layer.

Key words: thinning processor, cable winch, farm tractor, early and late thinning, damage to trees and regeneration layer

INTRODUCTION, AIM AND SCOPE OF THE STUDY

Farm tractors constitute the largest group of machines used for timber skidding in the Polish forests [Kocel 2005, Zastocki 2001]. Although they are most commonly used for skidding, farm tractors, after having been aggregated with cable winches, can also be executed in forwarding [Glazar and Maciejewska 2009, Paschalis and Porter 1994], where they function as aggregates together with trailers equipped in hydraulic cranes [Hoffman et al. 2007]. Such devices can be used for cutting, felling, and debranching

*The research has been financed from the founds for science 2007-2010 as a research project N N309 4235 33.

Corresponding author – Adres do korespondencji: Dr inż. Arkadiusz Stańczykiewicz, Department of Forest and Wood Utilization of University of Agriculture in Krakow, 29 Listopada 46, 31-425 Kraków, Poland, e-mail: rlstancz@cyf-kr.edu.pl

trees, by working as small harvesters in younger age classes of stands [Athanassiadis 1997, Johansson 1997] or they can act as carriers for other machines used for tree harvesting, e.g. chippers or processors. The latter ones were commonly used in Scandinavia since mid eighties of the previous century [Hakansson 1989 a, b]. According to Lindroos et al. [2005], in the years 1985-2002 over 100 of such machines were sold in Sweden for the purpose of working in the forests. Only about 10 such machines are presently used for thinning purposes in Poland [Stańczykiewicz et al. 2011]. So far, the Polish subject matter literature regarding the use of processors in the Polish forests [Giefing 1994 a, b, Moskalik 2008, Sowa et al. 2007, Sowa and Szewczyk 2008, Walczyk 1997] mostly refers to exploitation and economic aspects of the issue only. Tree harvesting technology with the use of processors, on the other hand, is considered to be one of the least harmful technologies for the stands.

Therefore, the aim of this study was describing the character and scope of damage to the trees and regeneration layer in the stands of younger age classes, as a result of early and late thinning. The scope of research involved the comparison (from ecological perspective) of two manual-machine work technologies involving processors and commonly used cable winches.

The scope of analyses takes into account the quantitative and qualitative character of damage due to harvesting in chosen pine stands (*Pinus sylvestris* L.), growing on flat terrain. The research results presented in this paper constitute a supplementation and extension of the previously published study [Stańczykiewicz et al. 2011] regarding, among others, tree and regeneration layer damage as a result of wood harvesting of pine stands subjected to early thinning with the use of machines aggregated with farm tractors.

MATERIAL AND METHODS

Methodology of field research

Field research was carried out in the Rybnik Forest District located within the Regional Directorate of State Forests in Katowice and in the Dąbrowa Tarnowska Forest District situated within the Regional Directorate of State Forests in Kraków. Timber harvesting by means of HYPRO 450 continuous debranching processor was carried out in the stands of Rybnik Forest District while harvesting by means of NIAB 5-15 cyclical debranching processor as well as a FRANSGÅRD V-6000 GS cable winch was realized in the Dąbrowa Tarnowska Forest District. Both processors were equipped in radio-controlled cable winches of 20 and 25 kN draw-bar pull. Detailed technical data of the processors (Fig. 1, 2) aggregated with BELARUS (MTZ) farm tractors were presented in the previous article [Stańczykiewicz 2011 a]. The FRANSGÅRD V-6000 GS manually operated cable winch of 60 kN draw-bar pull and 80 m long cable (Fig. 3) was aggregated with a PRONAR farm tractor.

Harvesting was carried out by means of cut-to-length system technologies with the use of processors ($CTL_{PROCESSOR}$) and by means of tree-length-system with the use of a cable winch (TLS_{WINCH}) [Pulkki 2004].

The role of a logger within the plots where processors were involved in work was limited to cutting and felling trees. Debranching and cross-cutting were performed

Fig. 1. HYPRO 450 Processor (photo A. Stańczykiewicz)
Rys. 1. Procesor HYPRO 450 (fot. A. Stańczykiewicz)

Fig. 2. NIAB 5-15 Processor (photo A. Stańczykiewicz)
Rys. 2. Procesor NIAB 5-15 (fot. A. Stańczykiewicz)

by processors located on strip roads. The obtained basic material in the form of the middle-sized timber logs, was situated in irregular piles, directly by the routes from which it was then skid to depots by means of self-loading trailers. In case of technologies with cable winches, the logger's task, apart from felling and knocking down trees, was also debranching and cross-cutting the material. After cutting off the tree tops, the whole-length trees were skid to the skidding route by cable hauling, and transported to a depot

Fig. 3. FRANSGÅRD V-6000 GS cable winch (photo G. Szewczyk)
Rys. 3. Wciągarka FRANSGÅRD V-6000 GS (fot. G. Szewczyk)

by skidding after leaning tree-stumps against the winch plate. Manipulation plot areas were set up in such a way that the maximum logging distance of skidding in the first stage would not exceed 50 m.

No protective measures were used with regards to the level of damage trees and the regeneration level while hauling the material. However, one of the basic methods of limiting damage was maintaining the direction of knocking down trees possibly similar to the direction of the subsequent skidding to skidding routes by means of a cable.

Eighteen manipulation plots were set up in total in selected stands (six plots in the Rybnik Forest District and twelve in the Dąbrowa Tarnowska Forest District). Thinning was performed in high vegetation season. The overall characteristics of the stands with sample plots are presented in Table 1.

In order to determine the influence of the harvesting process on the existing regeneration level and on the remaining stand, research was done in two stages. As per methods presented in the previous studies [Sowa and Stańczykiewicz 2007, Stańczykiewicz 2010, 2011 a], in the first stage, in randomly selected fragments of stands, a network of squares with the side length of 12.5 m was established on manipulation plots of 0.5 ha (50 × 100 m, longer sides of the plots parallel to skidding routes). At the nodes of the network, 0.5-are circular plots with a radius of 3.99 m were located (altogether 32% of each manipulation plot area). Cataloguing trees and the regeneration layer had been performed before felling, with the use of a specifically drawn up computer programme installed on mobile PSION Workabout recorders.

The group of trees included all specimens with the breast-height diameter exceeding 7 cm. The regeneration layer included juveniles aged over 2 years, consisting of saplings of the main forest-creating and admixture species, whose breast-height diameter was below 7 cm. The species of bushes were disregarded. The field work resulted in permanent marking of 576 circular plots on which over 2,100 trees and almost 6,700 saplings in the regeneration layer were catalogued.

Table 1. Characteristics of stands in specific sample plots
Tabela 1. Charakterystyka drzewostanów, w których zlokalizowano badania

Forest District (Forest Unit) Nadleśnictwo (Leśnictwo)	Compartment Oddział	Technology Technologia	Thinning category Kategoria trzebieży	Area, ha Powierzchnia, ha	Stand composition Skład gatunkowy	Age, years Wiek, lata	Index of stocking Zadrzewienie	Growing stock, $m^3 \cdot ha^{-1}$ Zasobność, $m^3 \cdot ha^{-1}$	Thinning intensity, % Intensywność trzebieży, %
Rybnik (Żory)	267d	HYPRO 450	ET TW	5.60	9 Scots pine 1 Common oak 9 So 1 Db	35	0.9	221	8.4
	250h		LT TP	6.13	Scots pine So	78	0.7	269	15.3
Dąbrowa Tarnowska (Waryś)	314d	NIAB 5-15	ET TW	5.19	Scots pine So	39	1.1	140	16.2
		FRANSGÅRD V-6000 GS							15.4
	304d	NIAB 5-15	LT TP	4.96	9 Scots pine 1 Silver birch 9 So 1 Brz	51	0.7	228	21.4
		FRANSGÅRD V-6000 GS							20.1

ET TW – early thinning, LT TP – late thinning.
ET TW – trzebież wczesna, LT TP – trzebież późna.

In the second stage, directly after thinning was completed, the size and quality of damage to trees and to the young generation were determined. Trees which remained after thinning, and which had been damaged, underwent two types of measurements: the height of injury located on stems and the linear injury dimensions (vertically-length, horizontally-width). The parameters of damage situated at the height over 2 m were estimated visually. Damage done to the regeneration layer was classified according to the damage classification which has been used in the Department for a few years and which is presented in Table 2 [Sowa and Stańczykiewicz 2005, 2007, Stańczykiewicz 2006, 2010, 2011 a, b]. Additionally, it was assumed that the whole regeneration layer has utility value from the perspective of forest cultivation.

Calculation methods

Based on the research results published by Butora and Schwager [1986], the area of damage due to timber harvesting was calculated using formulas for the field of an ellipsis or a rectangle, depending on the identified shape of the damage. Due to the varied numbers of saplings on the sample plots, the amount of damage and destruction in the regeneration layer was presented as percentage value. The percentage of losses

Table 2. Classification of regeneration damage
Tabela 2. Klasyfikacja uszkodzeń odnowienia

Damage class Klasa uszkodzenia	Characteristic of damage Charakterystyka uszkodzenia
I	destroyed or disappeared tree drzewko zniszczone
II	damaged tree not expected to survive drzewko uszkodzone w stopniu nierokującym przeżycia
III 1	leader broken above last whorl złamany pęd wierzchołkowy powyżej ostatniego okółka
III 2	stem broken below last whorl złamana strzałka poniżej ostatniego okółka
III a	broken side-branches (up to 20% of total amount) połamane gałęzie boczne (do 20% ilości ogólnej)
III b	broken side-branches (21-40% of total amount) połamane gałęzie boczne (od 21 do 40% ilości ogólnej)
III c	broken side-branches (above 40% of total amount) połamane gałęzie boczne (ponad 40% ilości ogólnej)
IV	tree out of the perpendicular drzewko odchylone od pionu
V	torn off bark zdarcie kory

in particular damage groups was calculated in relation to the number of trees inventoried before thinning.

In case of the analysis of the influence of the technologies applied on trees and the regeneration layer, hypotheses H_0 of the accordance of empirical distributions with the normal distribution were made for the following random variables:

1) the percentage of damaged trees
2) area of injuries on trees which remained in the stand after thinning
3) the height of location of injuries on tree stems
4) the percentage of damaged saplings in the regeneration layer.

Statistical verification of the above hypotheses H_0 was based on the Shapiro-Wilk's test.

In order to determine the significance of differences between the level of damage to the trees and the regeneration level, and their damage injury area as well as injury height, the following hypothesis was made: H_0 – the average values of the percentage of damage in the tree level and the regeneration level as well as the injury area and its location height on stems are equal $\alpha = 0.05$ at a significance level. It was assumed that in the case of accordance of empirical distributions with the normal distribution, the H_0 would be verified using the t-Student test. In the case of the lack of such accordance, the U-Mann-Whitney test would be applied.

RESULTS

The accordance analysis of empirical distributions of the damage level in both investigated stand layers by means of Shapiro-Wilk's test showed that the analysed variables (the percentage of tree and regeneration level damage) did not display normal distribution features (calculated significance level $p < 0.05$). Therefore, testing the significance of differences was based on non-parametric analysis by means of Kruskal-Wallis test and multiple comparison test as well as U-Mann-Whitney's test.

Tree damage

On the basis of the research results, it was noted that on the manipulation plots where harvesting was carried out using NIAB and HYPRO processors, damage was done to the total amount of 6.2% (1.2-5.4%) of the trees which remained on stem after thinning. On the other hand, thinning on the plots where the cable winch technology was applied resulted in damage to 6.3% (3.0-10.9%) of trees. Table 3 presents the percentage of damaged trees in relation to the kind of thinning and type of technology.

A conclusion has been drawn on the basis of analysing the results, that no significant difference between the levels of tree damage in case of all the three technologies can be noted. Testing results have been presented in Table 4.

Table 3. Percentage of damaged trees, %
Tabela 3. Odsetek uszkodzonych drzew, %

Technology Technologia	Thinning category – Kategoria trzebieży		
	early thinning trzebieże wczesne	late thinning trzebieże późne	all stands wszystkie drzewostany
CTL_{NIAB}	4.5	6.1	5.1
CTL_{HYPRO}	6.6	8.0	7.1
$CTL_{PROCESSOR}$	5.7	7.1	6.2
TLS_{WINCH}	5.9	6.9	6.3

Table 4. Results of testing the significance of differences between average values of the share of damaged trees
Tabela 4. Wyniki testowania istotności różnic wartości środkowych udziału uszkodzonych drzew

Results of Kruskal-Wallis's test Wyniki testu Kruskala-Wallisa		Results of multiple comparisons Wyniki porównań wielokrotnych			
statistics H statystyka H	value p wartość p	value 'p'	WINCH	NIAB	HYPRO
2.156	0.340	WINCH		+	+
		NIAB	1.000		+
		HYPRO	1.000	0.427	

Taking into account all manipulation plots and the results of U Mann-Whitney's test (Z_{emp} = –0.315, p = 0.752), and considering NIAB and HYPRO processors to represent one group of machines, (PROCESSOR technology), it should be noted that the median values of the damage level within the levels do not differ significantly (Fig. 4).

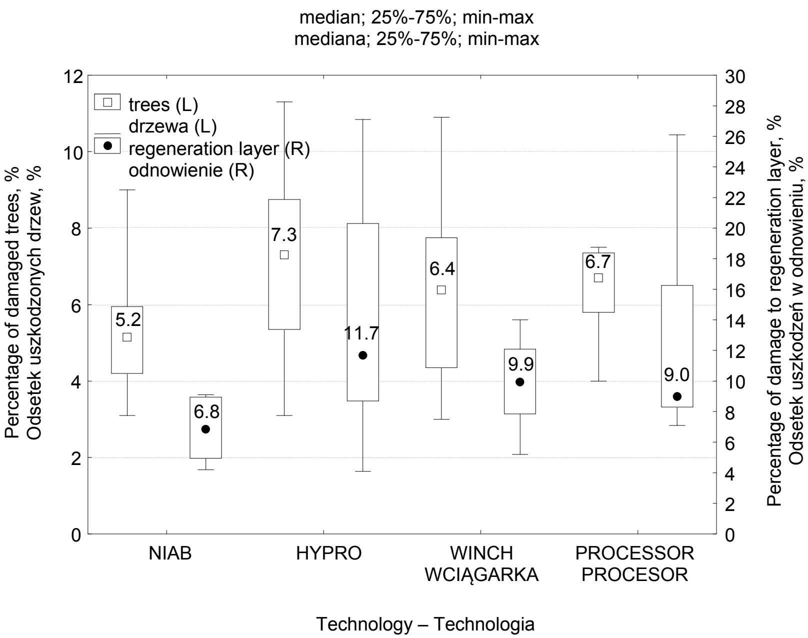

Fig. 4. Significance of differences between median values of tree and regeneration damage levels in pine stands

Rys. 4. Wykres istotności różnic wartości środkowych poziomów uszkodzeń drzew i odnowienia w drzewostanach sosnowych

The results of the analyses concerning the comparison of the injury areas in case of all stands allow for a conclusion that, in the trees damaged in the TLS_{WINCH} technology, the size of injuries was larger in comparison with the injuries created as a result of $CTL_{PROCESSOR}$ technology (Fig. 5). The differences (Table 5), however, are statistically insignificant at the probability level p = 0.207 (Z_{emp} = –1.261). An analogical situation was observed both in case of stands subjected to early and to late thinning.

The analysis of the height of injuries allowed for a conclusion that, on the plots where the cable winch technology had been used, injuries on the tree stems were located lower than on the pots where processors had been used (Fig. 5). Nevertheless, the U-test results (Table 5) indicate that there is lack of significant difference between the height of injuries on the stems of the injured trees in all stands ($1.039 < Z_{emp} > 1.942$; $0.052 < p > 0.299$).

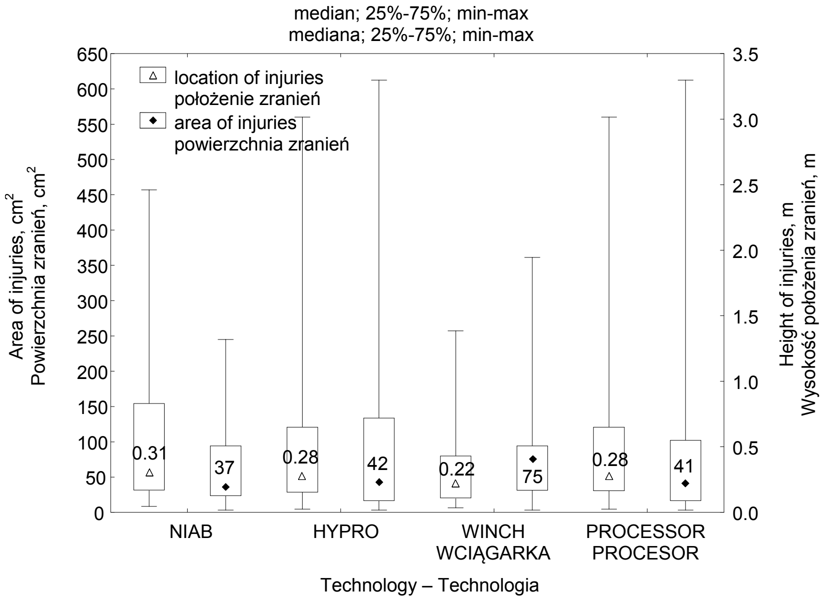

Fig. 5. Significance of differences between median values of the area and height of location of injuries

Rys. 5. Wykres istotności różnic wartości środkowych powierzchni oraz wysokości położenia zranień

Table 5. Results of Mann-Whitney U test of significance of difference between tested variables injuries on trees in technologies with processors (A) and with cable winch (B)

Tabela 5. Wyniki testu U Manna-Whitneya istotności różnic między analizowanymi zmiennymi zranień na drzewach w technologiach z procesorami (A) i wciągarką (B)

Technology of timber harvesting Technologia pozyskiwania drewna	Variable Zmienna		Median Mediana	Z_{emp}	p	H_0
All stands Wszystkie drzewostany	area powierzchnia	cm^2	41^A / 75^B	–1.261	0.207	+
	height wysokość	m	0.28^A / 0.22^B	1.942	0.052	+
Early thinning Trzebieże wczesne	area powierzchnia	cm^2	41 / 75	–0.874	0.382	+
	height wysokość	m	0.28 / 0.28	1.039	0.299	+
Late thinning Trzebieże późne	area powierzchnia	cm^2	40 / 69	–0.919	0.358	+
	height wysokość	m	0.33 / 0.20	1.663	0.096	+

Symbols: Z_{emp} – normal distribution statistics, p – statistic probability, H_0 – zero hypothesis (+ accept, – reject).

Oznaczenia: Z_{emp} – statystyka rozkładu normalnego, p – prawdopodobieństwo, H_0 – hipoteza zerowa (+ przyjąć, – odrzucić).

Regeneration layer damage

Regarding damage to the regeneration layer presented in Table 6, it can be noticed that the percentage of damaged and injured saplings in all stands was higher on manipulation plots where harvesting with the use of processors had been applied although the situation was quite different when it comes to particular thinning categories. In early thinning more damage was done with cable winch technology and in late thinnings – with processor technology. Undoubtedly this was the result of the high level of damage by HYPRO processor (Table 6). Taking into account the percentage of damage in particular damage classes, the highest percentage was observed in class I of destroyed and missing trees (from 4.8 to 5.2% in case of TLS_{WINCH} and from 4.3 to 8.9% in case of $CTL_{PROCESSOR}$) and in class IV of trees out of plumb (from 2.7 to 4.0% in case of TLS_{WINCH} and from 2.2 to 2.5% in case of $CTL_{PROCESSOR}$). Worth attention is also the percentage of trees with torn off bark which ranked third among all classes of damage.

Table 6. Percentage of damage in regeneration layer, %
Tabela 6. Odsetek uszkodzeń w warstwie odnowienia, %

Technology of timber harvesting Technologia pozyskania drewna		Damage class Klasa uszkodzeń									Total Łącznie
		I	II	III 1	III 2	III a	III b	III c	IV	V	
Early thinning Trzebieże wczesne	CTL_{NIAB}	4.4	–	0.2	0.1	0.1	0.2	–	2.6	1.5	9.1
	CTL_{HYPRO}	4.1	0.4	0.5	0.1	0.6	–	–	1.5	0.8	8.0
	$CTL_{PROCESSOR}$	4.3	0.2	0.3	0.1	0.3	0.1	–	2.2	1.2	8.7
	TLS_{WINCH}	5.2	0.1	0.5	–	–	–	–	2.7	1.2	9.7
Late thinning Trzebieże późne	CTL_{NIAB}	2.1	–	–	0.5	–	–	–	2.1	–	4.8
	CTL_{HYPRO}	10.3	0.3	0.1	0.8	0.4	–	–	2.6	2.9	17.5
	$CTL_{PROCESSOR}$	8.9	0.3	0.1	0.7	0.4	–	–	2.5	2.4	15.3
	TLS_{WINCH}	4.8	–	0.8	–	0.8	–	–	4.0	–	10.3
All stands Wszystkie drzewostany	CTL_{NIAB}	4.2	–	0.2	0.1	0.1	0.2	–	2.6	1.4	8.8
	CTL_{HYPRO}	6.3	0.4	0.4	0.4	0.5	–	–	1.9	1.5	11.4
	$CTL_{PROCESSOR}$	5.2	0.2	0.3	0.2	0.3	0.1	–	2.2	1.5	10.0
	TLS_{WINCH}	5.2	0.1	0.5	–	0.1	–	–	2.8	1.1	9.8

The analysis of the importance of differences between the regeneration layer damage percentages as a result of using three manual-machine work technologies, it can be stated that the estimated differences turned out to be insignificant from the statistical point of view. The results of the analyses have been presented in Table 7.

The results of the analyses concerning the significance of differences while NIAB and HYPRO processors were considered one group of machines (PROCESSOR technology), do not allow for rejecting the hypothesis on the median values of damage in the analyzed layer (Z_{emp} = –0.368; p = 0.713). They point to the same level of damage to the regeneration layer as a result of using both work technologies (Fig. 4).

Table 7. Results of testing the significance of differences between average values of the share of damaged regeneration layer
Tabela 7. Wyniki testowania istotności różnic wartości środkowych udziału uszkodzonych odnowień

Results of Kruskal-Wallis' test Wyniki testu Kruskala-Wallisa		Results of multiple comparisons Wyniki porównań wielokrotnych			
statistics H statystyka H	value p wartość p	value 'p'	WINCH	NIAB	HYPRO
5.824	0.054	WINCH		+	+
		NIAB	0.222		+
		HYPRO	1.000	0.065	

DISCUSSION

The level of damage to trees as a result of using both technologies should be considered high, as it exceeds the practically assumed level of 5%. Field research has shown that the damage oscillated at the level of 5.1 to as much as 11.3% on over 60% of the manipulation plots. The earlier research of the early pine stand thinnings carried out by the authors [Sowa and Stańczykiewicz 2005] using identical methods showed that 3% of trees were damaged with a light cable winch technology powered by a chainsaw engine of 1-ton towing power. The horse skidding technology compared in this study caused damage to circa 4.5% of trees. The higher level of damage described in this study could probably be the result of technical characteristics of the applied machines and, consequently, the way of carrying out works. Large towing power (ca 3 tons and 6 tons) of cable winches which were used in the process was the reason why manual releasing of the skidded material from between the trees which were on its way was less frequently necessary than in case of the previously described technologies. Tree stumps of the skidded stems and whole trees were hauled over the obstacles (tree trunks or – less frequently – tree roots) and were consequently injuring the remaining trees. Research carried out in fir stands [Stańczykiewicz 2011 a] showed that it is possible to carry out harvesting in a way that the damage level will not exceed 5% both in case of using the cable winch and the processor. The proper work technique of a logger is crucial here, as he is supposed to fell trees in directions which are possibly the same as the direction of the subsequent skidding. It should also be underlined that the seniority of the machine operator may influence work effects, not only in the economic but ecological sense as well. Observations made during field works showed that the way of unfolding the cable of the winch may influence tree injuries. The cable should be unfolded with the possibly smallest number of bends on tree stems growing directly next to the subsequent skidding route. The analysis of Table 3 makes us raise the following question why the level of damage was highest on plots where HYPRO processor was involved in works. One of the aspects influencing such a phenomenon was probably a short hauling cable which made it impossible to skid trees located within a larger distance from the route. Such a situation forced the operator to use the aggregate deep within manipulation plots, which could result in larger amount of damage.

In spite of some minor differences, the areas of injuries and their height described in this study can be considered the same. First and foremost, the medians of the height of injuries in both technologies oscillate within 0.13 m (Table 5), while the medians of the injury areas are at the level of 35 cm^2. Analogical research carried out in the fir stands [Stańczykiewicz 2011 a] displayed differences which occurred to be significant. In the quoted research, the median of the injury height was ca 0.33 m, and the median of the injury area was different by 80 cm^2. Among all the injuries catalogued in this research, most severe ones (area of over 100 cm^2) constituted 23% in case of cable winch technology and 28% in case of processor technology [Suwała 1999]. The percentage of such injuries in the fir stands was 27% and 34% accordingly. The reason for smaller percentage of severe injuries in case of pine stands was their thicker outer bark as compared to firs (predominantly at the foot of stems) as well as fewer roots protruding from the soil.

Contrary to trees, the regeneration layer damage observed in this study in all stands should be considered satisfactory. The recommended practical level of 10% was only exceeded in case of the plots were HYPRO processor was operating. The damage level oscillated at the level between 11 and even 27% on 33% of the researched manipulation plots in comparison to the tree layer. Such result seems to confirm the above-mentioned observations regarding the reasons for the results obtained with HYPRO processor technology. Therefore, the results obtained from the plots where NIAB processor was used should be considered promising, and the damage level in case of HYPRO technology should be possible to decrease. The analysis of damage with regards to the damage class of regeneration (Table 6), allowed to observe that, analogically to previous research by Sowa and Stańczykiewicz [2007] as well as Stańczykiewicz [2006, 2010, 2011 a], the highest level of damage was observed in the class of destroyed trees (from 2.1 to 10.3%), and the lowest in the class of trees with breaks (total share of the damaged trees oscillated within 0.5-1.6%). Taking into account the class of trees out of plumb and trees with torn off bark, the percentage of the latter (0.0-2.9%) was smaller than the percentage of trees out of plumb (1.5-4.0%). An utterly opposite tendency was observed in fir stands [Stańczykiewicz 2011 a]. In general, the percentage of trees with torn off bark was higher than the percentage of trees out of plumb. On the basis of the observations made during field research, it can be assumed that such a phenomenon could be the result of more dense vegetation cover in pine stands, which prevented tearing off bark while direct contact of the skidded material against trees growing along the skidding route. Consequently, more trees out the perpendicular could be observed during damage assessment.

CONCLUSIONS

1. Due to the use of the processor technology and the cable winch technology for pine stands thinnings, slightly above 6% of the trees remaining after the operations were damaged. Detailed analyses showed that the difference between the damage levels of the two technologies is not significant.
2. Using cable winch technology for harvesting in all analysed stands caused larger injuries than in case of using the processor technology. Detailed analyses of the medians of injury areas did not point to any significant differences.

3. Analyses of the results of applying both technologies allowed for a conclusion that injuries located higher were the injuries due to harvesting by means of the processor technology. However, from the statistical point of view, the difference occurred to be insignificant.

4. As a result of using both the processor technology and cable winch technology, the damage level of the regeneration layer did not exceed 10%. Detailed analyses prove that the estimated values of damage can be assumed as oscillating at the same level.

5. Most commonly observed type of damage to the regeneration layer as a result of thinning with the use of both technologies were destroyed trees, trees out of plumb and trees with torn off bark.

6. From the ecological point of view, both manual-machine technologies involving the use of processors and cable winches can be recommended for practical use. Nevertheless, particular attention should be paid to the correct working technique of the logger who cooperates with the operators of machines aggregated with farm tractors (directions of felling trees should be the same as the direction of subsequent skidding).

ACKNOWLEDGEMENTS

The authors of this study would like to express their sincere acknowledgements to: Włodzimierz Grzebieniowski from Z.U-P. “WRZOS” s.c. company with its seat in Tarnów, Andrzej Paszenda from P.P.U.H. “ZUPIL” company with its seat in Rudy Raciborskie as well as all the workers involved in field works, for their professional attitude towards the scientific-practical cooperation, their understanding, patience and notable support in organising and carrying out research within the 2007-2010 research project.

REFERENCES

Athanassiadis D., 1997. Residual stand damage following cut-to-length harvesting operations with a farm tractor in two conifer stands. Silva Fenn. 31, 461-467.

Butora A., Schwager G., 1986. Holzernteschäden in Durchforstungsbeständen. Berichte 288, 1-47.

Giefing D.F., 1994 a. Ciągniki rolnicze w procesie pozyskiwania drewna [Farm tractors in timber harvesting]. Przegl. Techn. Roln. Leśn. 10, 22-23 [in Polish].

Giefing D.F., 1994 b. Badania eksploatacyjne procesora HYPRO [Field tests of tractorprocessor HYPRO]. Przegl. Techn. Roln. Leśn. 12, 20-22 [in Polish].

Glazar K., Maciejewska M., 2009. Ecological aspects of wood harvesting and skidding in pine stands with use different technologies. Acta Sci. Pol., Silv. Colendar. Rat. Ind. Lignar. 8 (3), 5-14.

Hakansson M., 1989 a. Field studies of small processors. Small Scale Forestry 1, 14-20.

Hakansson M., 1989 b. A processor with winch and step feeding [NIAB thinning processor]. Small Scale For. 2, 16-19.

Hoffman L., Mederski P.S., Bembenek M., Szumicki D., 2007. Analysis of damage to remaining pine stand following various thinning operations. Logging and wood processing in Central Europe. CULS Prague, Czech Rep. 37-41.

Johansson J., 1997. Small tree harvesting with a farm tractor and crane attached to the front. J. For. Eng. 1 (8), 21-33.

Kocel J., 2005. Prywatny sektor usług leśnych w latach 1999-2003 [Private sector of forest services in 1999-2003]. Leśn. Pr. Bad. 66 (2), 17-34 [in Polish].
Lindroos O., Lidestav G., Norfjell T., 2005. Swedish non-industrial private forest owners: a survey of self-employment and equipment investments. Small-scale Forest Economics, Magagement and Policy 4 (4), 409-426.
Moskalik T., 2008. Możliwości zastosowania harwestera Ponsse Beaver z głowicą EH-25 oraz procesora HYPRO 300 przy pozyskiwaniu drewna w trzebieżach wczesnych [The possibilities of using Ponsse Beaver harvester with EH25 head and Hypro 300 processor in timber harvesting in the early thinning]. In: Tendencje i problemy techniki leśnej w warunkach leśnictwa wielofunkcyjnego. Poznań, Poland, 44-50 [in Polish].
Paschalis P., Porter B., 1994. Próba oceny uszkodzeń drzew w wyniku prac zrywkowych w sosnowych drzewostanach przedrębnych [An attempt at assesment of tree injuries as resulted from skidding operations in premature Scots pine stands]. Sylwan 138 (9), 17-21 [in Polish].
Pulkki R.E., 2004. Glossary of forest harvesting terminology. [online], www.flash.lakeheadu.ca.
Sowa J.M., Stańczykiewicz A., 2005. Determination of selected logging technologies impact, in thinned coniferous stands, on damage level of trees. In: Proceedings of the International Scientific Conference on the Ecological, Ergonomic and Economical Optimization of Forest Utilization in Sustainable Forest Management. Kraków-Krynica, Poland, 275-281.
Sowa J.M., Stańczykiewicz A., 2007. Determination of the impact of selected logging technologies on the tree damage level in thinned mountain stands. In: Proceedings of the 40th International Symposium on Forestry Mechanization FORMEC'07. Vienna, Austria, 1-9.
Sowa J.M., Kulak D., Szewczyk G., 2007. Costs and efficiency of timber harvesting by NIAB 5--15 processor mounted on a farm tractor. Croat. J. For. Eng. 28 (2), 177-184.
Sowa J.M., Szewczyk G., 2008. Czasochłonność pozyskiwania drewna z użyciem procesora NIAB 5-15 w drzewostanach trzebieżowych [Time consumption of timber harvesting by means of the NIAB 5-15 processor in mature stands]. Acta Agr. Silv. 46, 53-66 [in Polish].
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 Agr. Silv. Ser. Silv. 44, 91-116 [in Polish].
Stańczykiewicz A., 2010. Damage to trees and regeneration layer resulting from timber harvesting with the use of equipment aggregated with farm tractors in thinned mountain stands. In: Proceedings of the International Symposium on Forestry Mechanization FORMEC 2010. [CD] Padova, Italy, 1-10.
Stańczykiewicz A., 2011 a. Damage to trees and regeneration layer resulting from timber harvesting with the use of equipment aggregated with farm tractors in thinned fir stands. In: Technology and ergonomics in the service of modern forestry. Wyd. UR, Kraków, 253-268.
Stańczykiewicz A., 2011 b. Badania nad optymalizacją proekologicznej technologii trzebieży drzewostanów iglastych z zastosowaniem procesorów zagregowanych z ciągnikami rolniczymi [Research on optimization of pro-ecological thinning technology in coniferous stands using processors aggregated with farm tractors]. In: Sprawozdanie końcowe z realizacji projektu badawczego nr N309 4235 33 przeprowadzonego w latach 2007-2010. Maszyn. KULiD, 1-122 [in Polish].
Stańczykiewicz A., Sowa J.M., Szewczyk G., 2011. Uszkodzenia drzew i odnowienia w wyniku ręczno-maszynowego pozyskania drewna z wykorzystaniem urządzeń agregowanych z ciągnikami rolniczymi [Damage to trees and regeneration as a result of motor-manual timber harvesting using equipment aggregated with farm tractors]. Sylwan 155 (2), 129-137 [in Polish].
Suwała M., 1999. Uszkodzenia drzew i gleby przy pozyskiwaniu drewna w późnych trzebieżach drzewostanów sosnowych [Damage of trees and soil caused at timber harvesting in late thinnings of pine stands]. Pr. Inst. Bad. Leśn. Ser. A, 873, 1-83 [in Polish].
Walczyk J., 1997. Procesory tworzone na bazie ciągników rolniczych [Processors aggregated with farm tractors]. Przegl. Techn. Roln. Leśn. 3, 18-21 [in Polish].

Zastocki D., 2001. Małe i średnie prywatne firmy leśne w pozyskiwaniu drewna – stan obecny i perspektywy rozwoju [Participation of small and medium-size forest firms in wood harvesting – the present state and the future]. Sylwan 145 (11), 39-47 [in Polish].

WPŁYW POZYSKANIA DREWNA Z UŻYCIEM URZĄDZEŃ AGREGOWANYCH Z CIĄGNIKAMI ROLNICZYMI NA POZIOM USZKODZEŃ DRZEW I ODNOWIENIA W TRZEBIEŻACH DRZEWOSTANÓW SOSNOWYCH

Streszczenie. Badania zostały przeprowadzone w drzewostanach sosnowych, w których zrealizowano selekcyjne trzebieże wczesne i późne. Podczas realizacji zabiegów wykorzystano procesory okrzesująco-przerzynające NIAB 5-15 i HYPRO 450 oraz wciągarkę linową FRANSGÅRD V-6000 GS agregowane z ciągnikami rolniczymi. Pozyskanie drewna przeprowadzono technologiami w ramach systemu drewna krótkiego z wykorzystaniem procesorów oraz w ramach systemu drewna długiego z wykorzystaniem wciągarki linowej. Pozyskane drewno było zrywane na składnice w drugim etapie w sposób podwieszony z wykorzystaniem przyczep samozaładowczych lub w sposób półpodwieszony z wykorzystaniem wciągarki linowej. Pozyskanie drewna z wykorzystaniem procesorów spowodowało uszkodzenia drzew w granicach od 3,1 do 11,3%, a w technologii z wciągarką od 3,0 do 10,9%. Poziom szkód w warstwie odnowienia zawarł się w przedziale od 4,1 do 27,1% na powierzchniach, na których zastosowano procesory. Na powierzchniach, gdzie drewno pozyskano z wykorzystaniem wciągarki uległo zniszczeniu lub uszkodzeniu od 5,2 do 14,0% egzemplarzy rosnących pod okapem drzewostanu głównego.

Słowa kluczowe: procesor trzebieżowy, wciągarka linowa, ciągnik rolniczy, trzebieże wczesne i późne, uszkodzenia drzew i odnowienia

Accepted for print – Zaakceptowano do druku: 5.07.2012

For citation – Do cytowania: Stańczykiewicz A., Sowa J.M., Kulak D., Leszczyński K., 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.