Drewno 2021, Vol. 64, No. 208
DOI: 10.12841/wood.1644-3985.348.01

RESEARCH PAPERS

Włodzimierz Stempski, Krzysztof Jabłoński, Jakub Jakubowski

EFFECTS OF STRIP ROADS ON VOLUME INCREMENT OF EDGE TREES

An analysis was made of 13-year wood volume increments on pine trees growing in the immediate vicinity of strip roads, at distances of 2-4 m and 8-10 m (the control). The widths of the strip roads were 3.5 m (short wood extraction with a forwarder) and 2.5 m (long wood skidding with an agricultural tractor), and they were cut during the first thinning. Also, compensation for the lost wood, resulting from increased growth of trees near the strip roads, was estimated. Tree volumes were calculated by the tree section method, based on measurements of yearly tree rings, taken with an electronic caliper on wood disks cut from the centers of 2-meter-long tree sections taken from sample trees. The percentage compensation for volume losses was calculated by comparing the increased volume increment of edge trees with the volume (and its 13-year lost increment) of trees removed from the strip roads. The study showed an increased volume increment of edge trees compared with trees growing deeper in the stand. In the case of wider strip roads, the increased volume increment was also present on trees growing at a distance of about 3 m from the strip roads. After 13 years the increased volume increment on trees bordering the strip roads and growing at a distance of 2-4 m from the strip roads compensated for 35% (wider strip roads) and 28% (narrower strip roads) of the lost wood volume and its unrealized increment.

Keywords: strip roads, wood increment, sunlight influx

Włodzimierz Stempski✉ (*wlodzimierz.stempski@up.poznan.pl*), Krzysztof Jabłoński (*krzysztof.jablonski@up.poznan.pl*), Jakub Jakubowski (*jakub.jakubowski@up.poznan.pl*), Faculty of Forestry and Wood Technology, Poznań University of Life Sciences, Poznań, Poland

Introduction

Strip roads are generally regarded as a solution that makes wood extraction easier. However, considering the fact that they are mainly used in improvement cuttings (thinnings), their main role is to limit damage caused by wood harvesting [Rzadkowski 1997]. Containing damage from tree felling and wood extraction is one of the main aims of sustainable forestry [Sist and Nguyen-Thé 2002]. Damage from wood harvesting cannot be completely avoided and its volume varies [Vasiliauskas 2001], being also affected by strip roads [Fries 1976; Gullison and Hardner 1993; Athanassiadis 1997; Košir 2008]. Extensive research has shown that the least damage to the tree stand is caused by the cut-to-length method [Sirén 2000; Limbeck-Lilienau 2003; Slamka and Radocha 2010]. In this method wood extraction is usually performed by forwarders, which due to their considerable dimensions require strip roads with specific parameters, designed and made according to certain rules. Today, the rules for designing and cutting strip roads in state forests in Poland are laid down in Regulation No. 35 of the Director General of the State Forests of 2016 [Zarządzenie… 2016]. The Regulation introduced an obligation to open tree stands in the State Forests with a network of strip roads, and defined new rules to replace the former ones, which were more than 20 years old [Rzadkowski 1995]. The new rules were made necessary by a dynamic increase in the number of specialized wood harvesting machines, which began in 2007–2008 and is still continuing [Kusiak 2008; Skarżyński and Brzózko 2010; Nowacka and Moskalik 2012; Żabierek and Wojtkowiak 2012; Jodłowski and Moskalik 2016; Mederski et al. 2016]. The main reasons for this increase include the lack of labor to harvest wood with chain saws, and the larger quantities of wood harvested in general, a challenge that can only be faced using machine-based technologies.

Strip roads occupy a certain area in the stand, and this area is strongly dependent on the strip road width. The Regulation of 1995 [Rzadkowski 1995] indicated a 4 m width as the standard for harvesters and forwarders working in lowlands. That width, combined with a 20 m distance between strip roads, results in a 20% decrease in the productive area of the tree stand. This is one of the reasons why strip roads were not commonly used in practice [Laurow 1996; Jodłowski 2010; Stempski 2014a, b]. Today strip roads are an obligatory measure and their width may even reach 5 m [Zarządzenie… 2016].

Cutting a strip road, apart from reducing the productive area of the tree stand, changes the growing conditions of trees along the strip road [Stempski and Jabłoński 2014]. The crowns of these trees gain additional space, allowing more intensive growth. Many researchers report increased growth of edge trees (growth due to increased influx of sunlight) [Eriksson 1987; Isomäki and Niemistö 1990; Mäkinen et al. 2006; Horák and Novák 2009; Wallentin and

Nilsson 2011; Stempski 2013; Kuliešis et al. 2018]. However, some studies indicate the absence of such a phenomenon [Suwała 2007; Yilmaz et al. 2010].

The main purpose of this study was to determine the effect of strip roads on the growth of wood volume on trees growing along strip roads. Additionally, an attempt was made to calculate the extent to which the 13-year growth on trees along the strip road stimulated by increased influx of sunlight compensates for the volume lost due to strip road cutting.

Materials and methods

The study concerned a pine tree stand in the eastern part of the Notecka Forest. Thinning of the stand had been carried out 13 years earlier (at the age of 31 years) and strip roads had been cut. The work was done with chain saws using two methods [Pulkki 2004]: short wood, with wood extraction by a forwarder, for which 3.5 m-wide strip roads were made; and the whole tree method with extraction by an agricultural tractor, with 2.5 m-wide strip roads. In both methods the distance between the strip roads was 30 m.

For each strip road width, wood growth was studied on trees growing 0-1 m, 2-4 m and 8-10 m from the strip road. The 0-1 m zone covered the direct vicinity of the strip roads, including edge trees. The 2-4 m zone was adopted based on the relevant literature (the maximum distance affected by the strip road). In the 8-10 m zone, the growing conditions of the trees were unaffected by the strip roads (this zone served as a control). Wood increment measurements were performed on sample trees selected on the basis of DBH values of trees growing in the analyzed zones. The trees were required to represent average DBH diameters, larger diameters (average plus standard deviation) and smaller diameters (average minus standard deviation), with three trees from each distance zone. Tree heights were taken from tree height curves calculated for 20% of trees growing in each distance zone. Square polynomial curves were used as the height equations:

for the 3.5 m strip roads:

$$y=-0.0043\,x^2+0.3975\,x+10.221 \quad \text{(distance 0-1 m)} \tag{1}$$

$$y=-0.0059\,x^2+0.4675\,x+9.5632 \quad \text{(distance 2-4 m)} \tag{2}$$

$$y=-0.0376\,x^2+1.3909\,x+3.0457 \quad \text{(distance 8-10 m)} \tag{3}$$

for the 2.5 m strip roads:

$$y=-0.0114\,x^2+0.6102\,x+8.2529 \quad \text{(distance 0-1 m)} \tag{4}$$

$$y=-0.0378\,x^2+1.4654\,x+1.7573 \quad \text{(distance 2-4 m)} \tag{5}$$

$$y=-0.0229\,x^2+0.9142\,x+6.7116 \quad \text{(distance 8-10 m)} \tag{6}$$

The wood increment measurements were performed on wood disks taken from mid-sections of 2 m-long wood pieces from sample trees. The disks were polished before measuring, and wood increment measurements were taken with an electronic caliper and a 4× magnifying glass in the W-E and N-S directions (the directions had been marked on the sample trees before felling). For each strip road width, measurements were taken on 45 felled sample trees (5 strip roads × 3 distance zones × 3 trees).

The volume of each sample tree at the beginning and at the end of the wood increment period represented the sum of volumes of all the 2 m-long tree sections and the final shorter section. The volumes of the 2 m-long sections were calculated according to the Huber formula, and the volume of the shorter section was found with the cone volume formula.

Compensation for the lost volume of the final crop and useful trees was calculated according to the following formula:

$$C=\left[\frac{\left(Vi_{0-1}-Vi_{8-10}\right)+\left(Vi_{2-4}-Vi_{8-10}\right)}{L}\right]\cdot 100\,\% \qquad (7)$$

where: C is the compensation in %;

Vi is the 13-year tree volume increment from the 0-1, 2-4 and 8-10 m zones, in $m^3 \cdot ha^{-1}$;

L is the loss (sum of volumes of the final crop trees and useful trees removed from the strip road and the 13-year volume increment or the volume increment only).

In the calculations of compensation for volume loss by the increased growth of trees near the strip road, trees from the 2-4 m distance zone were also considered, because they also showed an increased volume increment (especially in the case of the wider strip roads).

The increase in volume increment on trees from the 0-1 m and 2-4 m distance zones, expressed in $m^3 \cdot ha^{-1}$, was calculated by multiplying the volume increase of one tree (average increase for 15 sample trees in each distance zone) by the number of trees in the particular distance zone. The zone areas were found by multiplying their total widths (2 and 4 m, because the zones were located on both sides of the strip roads) by the total length of strip roads per hectare.

Also, the relative 13-year volume increments on trees growing in the 0-1 m and 2-4 m zones were calculated, taking the 13-year single tree volume increment in the 8-10 m distance zone as the reference value (100%). In the calculations of relative wood volume increment values for a single tree at 5, 10 and 13 years (depending on the distance from the strip road) after the cutting of strip roads, the reference value (100%) was equal to the average sample tree volume at the time of the cutting of strip roads.

Statistical verification of the results was performed by checking the significance of the differences between the 13-year volume increment values at different distances from the strip road. One-way analysis of variance (the F test) was used for the analysis. The calculations were performed with the Statistica 12 application [StatSoft 2014]. The adopted significance level was $\alpha = 0.05$.

Results and discussion

The study showed larger wood volume increments in the case of trees growing along the strip roads (Table 1). In the case of 3.5 m-wide strip roads the difference between trees growing directly along the strip roads and those in the 2-4 m distance zone was 25%, while it reached 48% when comparing volume increments on trees directly adjacent to the strip roads and those in the 8-10 m zone. In the case of the narrower strip roads, the differences slightly exceeded 35% and 37%, respectively. Although the differences seemed considerable, they were not statistically significant (Fig. 1a, b). Larger volume increments on trees growing at the edge of strip roads were also reported by Wallentin and Nilsson [2011], Horák and Novák [2009] and Kuliešis et al. [2018].

Table 1. 13-year volume increments [$m^3 \cdot tree^{-1}$]

Strip road width [m]	Distance from strip road [m]		
	0-1	2-4	8-10
3.5	0.083447	0.066975	0.056315
2.5	0.069049	0.050998	0.050267

*Sum of differences between 13-year increments of trees along the strip road vs. trees 8-10 m away and between trees 2-4 m away vs. those 8-10 m away.

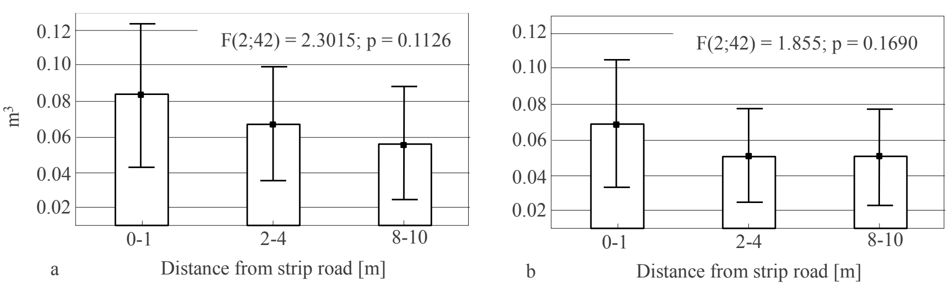

Fig. 1. Average (±SD) 13-year volume increments [$m^3 \cdot tree^{-1}$], F-test values and test probability p-values for the differences between increments

The study also showed greater volume growth on the wider strip roads compared with the narrower ones. Although in the case of the wider strip roads the trees in each distance zone were thicker than in the case of narrower strip roads, the differences were largest (17%) at the edge of the strip roads, and smallest (11%) for trees deeper in the stand (in the 8-10 m zone). This indicates the effect of strip road width on wood volume increment. The effect of this factor, among others, on wood volume increment of Scots pine trees 5 years after the cutting of strip roads in late cleanings was studied by Giefing et al. [2003]. The results obtained by those researchers showed no significant effect (it was found in only one location).

The difference in volume increment on trees growing at distances of 2-4 m and 8-10 m from the narrower strip roads (Fig. 1b) was small, while in the case of the wider strip roads the difference was noticeably larger (Fig. 1a). This indicates the effect of strip roads not only on edge trees, but also on those growing somewhat farther from the strip road. In the case of the narrower strip roads, the strip road effect was observed on the edge trees only. In Finland, the effects of the width of so-called corridors (removed rows of trees playing the role of strip roads) in a schematic and semi-schematic thinning on the volume increment of Scots pine and Norway spruce were studied by Mäkinen et al. [2006]. The schematic thinning was carried out by cutting 3-, 4- and 5-meter--wide corridors, with distances between them of 6, 8 and 10 m respectively. In the case of the semi-schematic thinning the corridors were 2, 3 and 4 m wide, the distances between them were 8, 15 and 20 m respectively, and selective thinning was performed in the areas between the corridors. The results of those experiments showed larger volume increments on trees bordering the corridors. For the 3-5 m wide corridors and 8-20 m spacing the volume increment of edge trees was 40-60% larger than that of trees growing deeper in the stand. The researchers also proved that the effect of the corridors reached 3-4 m, although at that distance it was noticeably smaller than on the edge trees.

Relative volume increment values 5, 10 and 13 years after cutting are presented in Figure 2. Similarly as in the case of the absolute increment values, the largest differences were found for edge trees. The volume of those trees after 13 years was over 280% of the initial value, i.e. from the time at which the strip roads were cut (100%), while in the case of trees from the 8-10 m zone the increase was only 235% (Fig. 2a). A similar trend was observed for the narrower strip roads, but the changes were smaller (Fig. 2b). The increment curves in Fig. 2 indicate that the reaction of the edge trees was more pronounced later, i.e. after 10 or 13 years. Similar results were obtained by Mäkinen et al. [2006] (see above), who found an increase in volume in their subsequent research after 8-10 years. In Sweden similar results were reported by Eriksson [1987], who analyzed the diameter increase on spruce trees along 3.5- and 5-meter-wide strip roads.
Isomäki and Niemistö [1990] reported increased growth on edge spruce trees as early as a year after strip roads were cut.

The relative 13-year volume increment values are presented in Figure 3. It can be seen that in the case of the wider strip roads their effect was not limited to the edge trees, but it was also observed on trees at a distance of 2-4 m. The relative volume increment of the edge trees by the wider strip roads reached 148% of the increment measured on trees growing at a distance of 8-10 m, while

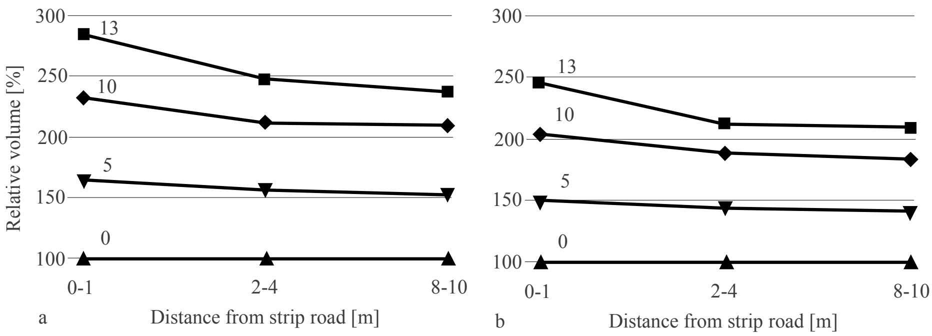

Fig. 2. The effect of strip roads on volume increment after 5, 10 and 13 years (a – wider strip roads, b – narrower strip roads). Volumes of individual trees [$m^3 \cdot tree^{-1}$] in successive measurements were compared with their initial volume at the time of treatment onset (100%). Numbers above the left ends of the lines are the number of years since treatment onset

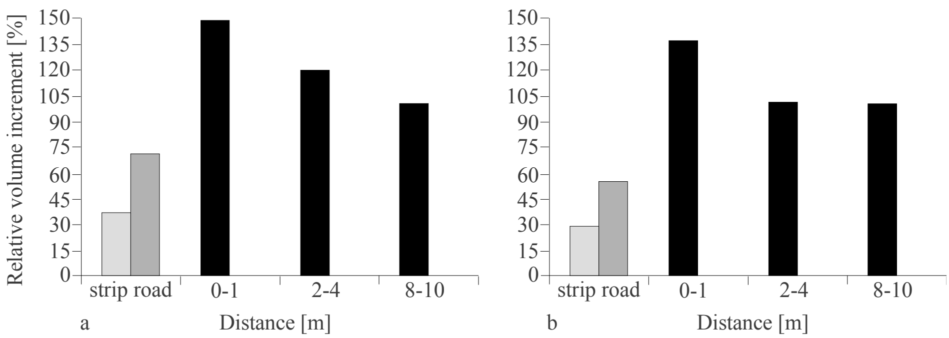

Fig. 3. The effect of the strip road width (a – wider, b – narrower) on the relative volume increment. Volume increment [$m^3 \cdot ha^{-1}$] at a distance of 8-10 m was taken as 100%. Values for strip roads are proportions of losses of volume (higher bar) and volume together with its increment (lower bar) compensated for by the accelerated tree volume increment in the 0-1 m and 2-4 m distance zones on both sides of the strip road. We assume that trees removed from strip roads would grow as fast as the trees 8-10 m away

in the case of the narrower strip roads the value was 11 percentage points lower. For the wider strip roads, also, the increment of the trees from the 2-4 m distance zone was clearly larger than that measured on trees growing at a distance of 8-10 m (by 19%), while only a slight difference (1%) was recorded for the narrower strip roads.

Figure 3 shows values of compensation for the lost volume 13 years after the cutting of strip roads. Taking the loss as the sum of volumes of the final crop and useful trees removed from the strip roads and their 13-year unrealized increment, the compensation was 36% for the wider strip roads and 28% for the narrower ones (Fig. 3). In a study reported by Mäkinen et al. [2006], in most cases the compensation was 40% after 19 years. Some comment seems to be needed regarding the lower compensation value found for the narrower strip roads, as seen in Figure 3. This seems illogical, as a smaller strip road width means fewer trees removed and a smaller volume loss. This was indeed the case, as the loss in the case of the narrower strip roads was 12.7 $m^3 \cdot ha^{-1}$, while it reached 22.2 $m^3 \cdot ha^{-1}$ for the wider strip roads. The lower compensation value, despite the smaller loss, in the case of the narrower strip roads resulted from the fact that the effect of the strip road was limited to the edge trees only, while in the case of the wider strip roads the effect was also observed on trees growing at a distance of 2-4 m from the strip road (Fig. 3). In effect, the total increase of volume increment in the wider strip road scenario was almost 75% greater than in the case of narrower roads. The results are in agreement with those reported by Mäkinen et al. [2006], who found the compensation for lost volume after 19 years to be below 25% for narrower corridors and 40–70% for wider ones.

The larger compensation percentage values in Figure 3 refer to the situation where the loss consists of the 13-year volume increment of the final crop and useful trees removed from the strip roads (the wood was sold, so the loss consists of the wood increment only). Under this assumption, the compensation after 13 years would be about 70% and 54% for the wider and narrower strip roads, respectively (Fig. 3). A possibility of obtaining 100% compensation for the volume loss caused by cutting strip roads was reported by Kuliešis et al. [2018]. The authors studied a Norway spruce plantation where strip roads were created at the time of establishment of the plantation by leaving every sixth row free of trees. The strip roads were 3.5 m wide, and thinning was applied with varying intensity and frequency. Measurements were taken over 24 years, between years 15 and 39 of the plantation's life. The results showed a noticeable increase in the volume increment on the edge trees compared with the trees growing in the second and third rows from the strip roads (by 43% or 78%, depending on the thinning method). With such a considerable increase in volume increments, the compensation for losses caused by the strip roads reached 100% between years 28 and 39 of the plantation's life. In the present study, with the same 3.5 m strip road width, the losses in wood volume were compensated much more slowly; among other possible reasons, this may be the result of smaller volume increment dynamics in pine compared with spruce.

Conclusions

Strip roads were found to have an effect on the volume increment of trees growing in their vicinity. Trees bordering strip roads presented distinctly larger volume increment values than trees growing deeper in the stand.

With the wider strip roads, a larger volume increment was also found on trees growing 2-4 m from the strip road. The effect of the narrower strip roads was limited to the edge trees only.

The investigations showed that compensation for the lost volume of trees removed from strip roads could be provided by the increment stimulated by increased influx of sunlight on the edge trees. The increased volume increment of trees growing 0-1 m and 2-4 m from the strip roads partly compensated for the lost wood volume and its lost increment. The compensation values measured after 13 years were about 35% and almost 30% for the wider and narrower strip roads respectively.

The results on compensation for increment loss may be a good argument in forestry practice for the use of wider strip roads as required by professional forest machines. These strip roads cause larger volume losses, but provide a larger volume compensation (over time) than narrower strip roads.

References

Athanassiadis D. [1997]: Residual stand damage following cut-to-length harvesting operations with a farm tractor in two conifer stands. Silva Fennica 31 [4]: 461-467

Eriksson H. [1987]: New results from plot no. 5 at Sperlingsholm estate in southwestern Sweden in the European stemnumber experiment in *Picea abies*. Scandinavian Journal of Forest Research 2: 85-98. DOI: 10.1080/02827588709382448

Fries J. [1976]: Views on the choice of silvicultural methods and logging techniques in thinning. Forestry Commission Bulletin No. 55: 95-101

Giefing D. F., Karaszewski Z., Ziemski Z. [2003]: Wpływ szlaków zrywkowych założonych w czasie czyszczeń późnych na kształtowanie się niektórych cech drzew (The effect of strip roads established during late cleanings on the selected parameters of trees). Sylwan 147 [3]: 11-18. DOI: 10.26202/sylwan.2003023

Gullison R., Hardner J. [1993]: The effects of road design and harvest intensity on forest damage caused by selective logging: empirical results and a simulation model from the Bosque Chimanes, Bolivia. Forest Ecology and Management 59 [1-2]: 1-14. DOI: 10.1016/0378-1127(93)90067-W

Horák J., Novák J. [2009]: Effect of stand segmentation on growth and development of Norway spruce stand. Journal of Forest Science 55 [7]: 323-329. DOI: 10.17221/61/2008-JFS

Isomäki A., Niemistö P. [1990]: Effects of strip roads on the growth and yield of young spruce stands in southern Finland. Folia Forestalia 756: 1-36

Jodłowski K. [2010]: Szlaki zrywkowe w różnych kategoriach cięć (Strip roads in different categories of cuttings). Biblioteczka leśniczego. Zeszyt 316. Wydawnictwo Świat, Warszawa

Jodłowski K., Moskalik T. [2016]: Uszkodzenia drzew i gleby w procesie pozyskiwania drewna (Damage to soil and trees in the wood harvesting process). Biblioteczka leśniczego 381. Wydawnictwo Świat, Warszawa

Košir B. [2008]: Damage to young forest due to harvesting in shelterwood systems. Croatian Journal of Forest Engineering 29 [2]: 141-153

Kuliešis A., Aleinikovas M., Linkevičius E., Kuliešis A.A., Saladis J., Škėma M., Šilinskas B., Beniušienė L. [2018]: The Impact of Strip Roads on the Productivity of Spruce Plantations. Forests 9 [10], 640. DOI: 10.3390/f9100640

Kusiak W. [2008]: Tendencje na rynku harwesterów i forwarderów w Polsce (Trends in harvester and forwarder markets in Poland). In: Romankow J. (ed.), Bezpieczeństwo pracy w nowoczesnym leśnictwie (Work safety in modern forestry). Katedra Inżynierii Środowiska Pracy UP, Poznań: 24-36

Laurow Z. [1996]: Szlaki zrywkowe w procesie pozyskiwania drewna. Część I. Definicje i znaczenie (Strip roads in the wood harvesting process. Part 1. Definitions and meaning). Przegląd Techniki Rolniczej i Leśnej 5: 17-18

Limbeck-Lilienau B. [2003]: Residual stand damage caused by mechanized harvesting systems. In: Limbeck-Lilienau B., Steinmuller T. and Stampfer K. (eds.), Proceedings of high tech forest operations for mountainous terrain. 5–9 Oct. Schlaegl-Austria

Mäkinen H., Isomäki A., Hongisto T. [2006]: Effect of half-systematic and systematic thinning on the increment of Scots pine and Norway spruce in Finland. Forestry 79 [1]: 103-121. DOI: 10.1093/forestry/cpi061

Mederski P.S., Karaszewski Z., Rosińska M., Bembenek M. [2016]: Dynamika zmian liczby harwesterów w Polsce oraz czynniki determinujące ich występowanie (Dynamics of harvester fleet change in Poland and factors determining machine occurrence). Sylwan 160 [10]: 795-804. DOI: 10.26202/sylwan.2016030

Nowacka W., Moskalik T. [2012]: Las miejscem pracy – nowy zawód, nowe możliwości (Forest as a place of work – a new career, new possibilities). Studia i materiały CEPL w Rogowie 32 [3]: 215-221

Pulkki R.E. [2004]: Glossary of forest harvesting terminology. Available from: http://flash.lakeheadu.ca/~repulkki/REP_terminology.pdf

Rzadkowski S. [1995]: Wytyczne do projektowania i wykonywania szlaków operacyjnych (Rules for designing and cutting strip roads). IBL, Warszawa

Rzadkowski S. [1997]: Leśne szlaki operacyjne (Forest strip roads). Las Polski 9: 19-20

Sirén M. [2000]: Silvicultural Result of One-Grip Harvester Operation. Journal of Forest Engineering 11 [2]: 7-14

Sist P., Nguyen-Thé N. [2002]: Logging damage and the subsequent dynamics of a dipterocarp forest in East Kalimantan (1990–1996). Forest Ecology and Management 165 [1-3]: 85-103. DOI: 10.1016/S0378-1127(01)00649-1

Skarżyński J., Brzózko J. [2010]: Harwestery do pozyskiwania drewna stosowane w polskich lasach. Część 1. Charakterystyka ogólna – nośniki (Harvesters for wood logging used in Polish forests. Part 1. General description, carriers). Technika Rolnicza Ogrodnicza Leśna 6: 11-14

Slamka M., Radocha M. [2010]: Results of harvesters and forwarders operations in Slovakian forests. Lesnícky časopis – Forestry Journal 56 [1]: 1-15

StatSoft [2014]: STATISTICA, data analysis, software system. Version 12. StatSoft Inc., Tulsa, OK, USA

Stempski W. [2013]: Wpływ szlaków zrywkowych na potencjał produkcyjny drzewostanu, cechy biometryczne i przyrosty drzew oraz wybrane wskaźniki jakości technicznej drewna drzew na pniu (Effects of skid trails on the tree stand productive potential, biometrical features, tree increment and selected technical quality indicators of standing trees). Wydawnictwo Uniwersytetu Przyrodniczego w Poznaniu, Rozprawy 464

Stempski W. [2014a]: Szlaki a potencjał produkcyjny drzewostanu (Strip roads and the tree--stand production potential). Drwal 9: 44-47

Stempski W. [2014b]: Czy zakładanie szlaków zrywkowych przynosi szkody w drzewostanie? (Does cutting strip roads bring damage to the tree stand?). Przegląd Leśniczy 12: 10-11

Stempski W., Jabłoński K. [2014]: Differentiation of tree diameters at strip roads in a young pine tree-stand. Acta Scientiarum Polonorum Silvarum Colendarum Ratio et Industria Lignaria 13 [1]: 37-46

Suwała M. [2007]: Wpływ uszkodzeń gleby przy pozyskiwaniu drewna w drzewostanach sosnowych w trzebieżach późnych na przyrosty drzew (Effect of soil disturbances by wood harvesting in late thinnings of pine stands on trees increment). Leśne Prace Badawcze 3: 99-116

Vasiliauskas R. [2001]: Damage to trees due to forestry operations and its pathological significance in temperate forests: a literature review. Journal of Forestry 74 [4]: 319-336. DOI: 10.1093/forestry/74.4.319

Wallentin C., Nilsson U. [2011]: Initial effect of thinning on stand gross stem-volume production in a 33-year-old Norway spruce (*Picea abies* (L.) Karst.) stand in Southern Sweden. Scandinavian Journal of Forest Research 26 [11]: 21-35. DOI: 10.1080/0282 7581.2011.564395

Yilmaz E., Makineci E., Demir M. [2010]: Skid road effects on annual ring widths and diameter increment of fir (*Abies bornmulleriana* Mattf.) trees. Transportation Research Part D Transport and Environment 15 [6]: 350-355. DOI: 10.1016/j.trd.2010.02.007

Zarządzenie nr 35 Dyrektora Generalnego Lasów Państwowych z dnia 29 czerwca 2016 r. w sprawie udostępniania drzewostanów siecią szlaków operacyjnych w jednostkach organizacyjnych Lasów Państwowych (Regulation No. 35 by the Director General of the State Forests)

Żabierek R., Wojtkowiak R. [2012]: The structure and distribution of harvesters and forwarders in individual Regional Directorates of the State Forests in Poland in the early 2010's. Acta Scientiarum Polonorum. Silvarum Colendarum Ratio et Industria Lignaria 11 [4]: 67-77

Submission date: 4.10.2019

Online publication date: 29.09.2021