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DIFFERENTIATION OF TREE DIAMETERS AT STRIP ROADS IN A YOUNG PINE TREE-STAND

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Abstract. The investigation was conducted in a 32-year-old pine stand, growing on a fresh coniferous site in western Poland. The strip roads in the stand had been designed and cut along tree rows 5 years prior to the investigation. The analysis focused on trees growing at 12 strip roads, in 3-meter-wide stripes on both sides of the strip roads and in control zones, half-way between each two neighbouring strip roads. The trees growing on the stripes along the strip roads were divided into three zones corresponding to tree rows. The first zone (I) was formed by trees growing in the row directly at the strip roads, while the zones two (zone II) and three (zone III) were formed by trees growing in the second and third rows of trees away from the strip roads, respectively, on both sides of the strip roads. The average distances of the zones two and three from the strip roads were 1.5 and 3 m, respectively. The diameters at breast height (DBH) of all the trees growing in the respective zones were measured. Moreover, the widths of the strip roads were measured, which resulted in dividing the strip roads into two groups: the wider strip roads (average width 3.6 m) and the narrower ones (average width 2.9 m). The statistical analysis showed significant differences in DBH values between the analysed zones, for nine of the strip roads. Both in the case of the wider strip roads, as well as in the case of the narrower ones, the trees growing directly along the strip roads were usually thicker than the more distant trees. A statistically significant difference between the DBH values of trees from zone I and II was found for one strip road. In most cases the trees from zone I were statistically thicker than the trees growing in the control zone.

Key words: strip roads, thinning, diameter at breast height (DBH)

INTRODUCTION

Intermediate cuttings carried out in pine tree-stands of younger age classes affect their future growth. This effect results basically from two premises. First, removing some of the trees from the stand changes the ecological conditions, in which the remaining trees must grow. The amount of light reaching the tree crowns is changed, as well as the competition conditions for water and nutrients. Finally, the cutting itself results

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in some stress to the remaining trees, as they must accommodate to a sudden change in the conditions mentioned above. The other premise is of a more technical character and results from the use of technical equipment on the one hand and from the necessity to open the tree stand, on the other hand.

Technically advanced machines and devices which are becoming more and more commonly used in intermediate cuttings can cause some damage to the forest site [Sauter and Busmann 1994, Gapšyté 2003, Suwała 2003]. In order to contain this damage, the area, in which the machines move within the stand, must be limited to permanent routes – strip roads. For many years, the role of the strip roads was to allow the machines extracting the wood to enter the stand. Today, strip roads are not only used for transportation operations, but also, more and more often, for technological ones. Bearing that in mind, the strip roads are a vital element in the practical execution of intermediate cuttings. They also drew a great deal of attention in the past. Strip roads enjoyed a special interest in mid 90's, when the State Forests purchased 15 forwarders Timberjack 1010, thus showing the direction for future developments in wood harvesting and transport technologies. The rich literature on this subject covers a wide spectrum of problems concerned with strip roads, from their role and the technical aspects of their cutting [Moskalik and Sadowski 1995, Porter 1995, Zarzycki 1995, Rzadkowski 1997 a, b] to the assessment of the effects of technologies using strip roads on the environment [Paschalis and Porter 1994, Suwała 1995, Laurow 1996, Paschalis 1997, Porter 1998].

Strip roads have, generally speaking, three main parameters: width, distance between them and shape with the layout relative to the rows of trees. The width of strip roads depends directly on the width of the machines used. The distance between strip roads is determined by the reach of the boom with a harvesting head or a grapple at its end. The shape of the strip roads depends on many factors, mainly on the terrain and tree-stand conditions, and it may be of a strict geometrical form, or it may take into account natural variations in stand density. In the latter case, it is possible to cut the strip road in such a way that it can go through natural clearings in the stand, which is suggested by the "Recommendations for the designing and making of strip roads" [Rzadkowski 1995].

The opening of a tree stand by cutting strip roads in it causes an edge effect on the border between the strip road and the stand. This effect results from a change in ecological conditions, especially the amount of light reaching the crowns of the trees growing directly at the strip road. The reaction of the trees growing at the strip road is a subject of scientific research and the results have been inconclusive so far. Some researchers indicate an amplified growth effect on trees growing directly at strip roads [Horák and Novák 2009, Wallentin and Nilsson 2011]. Others report the opposite [Yilmaz i in. 2010]. The effect of strip roads on the growth of neighbouring trees depends on many factors, also on their width [Giefing et al. 2003]. The majority of investigations into the relation between the strip road and the trees growing in its neighbourhood has focused on spruce, and there are not many publications focusing on pine which is the dominant tree species in the Polish forests.

The purpose of the investigation was to find an answer to the question on the effect of strip roads on the DBH distribution of neighbouring trees. That effect was analysed five years after the strip roads had been cut.

MATERIAL AND METHODS

The investigations were carried out in the Oborniki Forest District, the Regional Directorate of State Forests in Poznań, in spring 2013. The experimental plot was located in subcompartment 47d, in a 32-year-old pine stand, growing on a fresh coniferous site. The average diameter at breast height was 10 cm and the average height amounted to 12 m. The strip roads in the stand were cut parallely to the tree rows in 2008.

The investigation covered trees growing along 12 strip roads. For each of the strip roads the trees were measured on 3-metre-wide stripes on both sides of the strip road and on a control zone, halfway between two neighbouring strip roads. The trees from the stripes along the strip roads were divided into three zones, depending on their distance from the strip road. Zone 1 (I) included the trees bordering the strip road, zones 2 (II) and 3 (III) included the trees growing in rows 2 and 3, counting from the strip road, on both sides, respectively. Zones 2 and 3 were 1.5 m and 3 m distant from the strip road, respectively.

The diameters at breast height (DBH) were measured on all trees growing in the specified zones. The measurements were taken in two directions on every tree: parallelly and perpendicularly to the strip road.

Also, in the course of the field investigations, the width measurements of all the strip roads were taken, every 10 metres along the strip road, giving at least a dozen of results for each of the strip roads.

The results of the measurements underwent a thorough statistical analysis, using the application Statistica v.10. Depending on the character of the data distribution, one-factor ANOVA or its nonparametric equivalent – the Kruskal-Wallis test – was applied. The significance of the differences between the widths of the strip roads was assessed with the U Mann-Whitney test. The significance level of $\alpha = 0.05$ was applied for all computations.

RESULTS

The strip roads, depending on their widths, were divided into two groups: the wider and the narrower ones. The wider strip roads were numbered from 1 to 8, whereas the narrower ones were marked with numbers from 9 to 12. The average width of the wider strip roads was 3.6 m, while that of the narrower ones amounted to 2.9 m. The differences in width were statistically significant (the U Mann-Whitney test value was U = 555.000, and the significance level for the test result was $p = 0.0000$). The widths of the wider strip roads varied between 2.7 m and 4.6 m, while those of the narrower strip roads oscillated from 2.6 to 3.9 m. The strip roads were cut by removing whole rows of trees and the differences in their width values resulted partly from cutting trees from two rows instead from one or were caused by the fact that the rows of trees were not always parallel to each other. For the majority of the strip roads the variability of their widths was insignificant (the coefficients of variability did not exceed 10%), and only in the case of the strip road 8, a slight variability was observed.

For the majority of the wider strip roads, the trees growing in the specified stripes along them reacted with different growth in diameter. The trees growing directly at the strip roads were the thickest. The lowest values were observed on trees growing inside the tree stand, i.e. in the control zone (IV), while the trees growing 1.5 and 3 m away from the strip roads (zones II and III) showed similar diameters (Table 1). The trends presented above were true for the average DBH values, calculated for all strip roads of this group. In the case of particular strip roads, analysed separately, the results sometimes differed from the general trends. For example, in the case of two strip roads (numbers 5 and 8) the largest DBH values were found for the trees growing in zone II, and in the case of strip road 7, the thickest trees were found in zone III (Table 2). The trees growing in the control zone always showed the smallest diameters, and in the case of strip road 2, the diameters consistently diminished towards the inside of the stand. The diameter variability levels for this group of strip roads varied between "small" and "average" – the values of the coefficients of variability oscillated around or slightly exceeded 20%. No larger differences between the particular zones were found (Table 1).

Table 1. Basic statistical characteristics of DBH values of trees in different zones
Tabela 1. Podstawowe charakterystyki statystyczne pierśnic drzew w strefach

Zone Strefa	Number of observations Liczba obserwacji	Average Średnia cm	Standard deviation Odchylenie standardowe cm	Coefficient of variability Współczynnik zmienności %
Wider strip roads 1-8 – Szlaki szersze 1-8				
I	1 012	13.21	2.76	20.87
II	1 039	12.77	2.54	19.86
III	1 027	12.79	2.59	20.23
IV	1 065	12.23	2.67	21.97
Narrower strip roads 9-12 – Szlaki węższe 9-12				
I	592	10.95	2.36	21.60
II	660	10.66	2.36	22.19
III	677	10.26	2.33	22.70
IV	730	9.95	2.32	23.36

Table 2. DBH values of trees growing at the wider strip roads, cm
Tabela 2. Pierśnice drzew rosnących przy szerszych szlakach zrywkowych, cm

Zone Strefa	Number of strip road – Numer szlaku							
	1	2	3	4	5	6	7	8
I	13.60	14.75	13.53	14.32	12.62	13.70	12.01	11.57
II	12.88	13.72	13.16	13.58	12.91	12.91	11.92	11.64
III	12.46	13.32	13.17	13.81	12.79	13.52	12.30	11.30
IV	12.71	13.31	12.57	13.57	12.45	12.73	11.41	10.18

The differentiation in thickness on the trees growing at various distanced from the strip roads was also found along the narrower strip roads. For all them, the trees growing in zone I showed the largest DBH values (Table 1). Similarly to the situation in the group of the wider strip roads, the smallest diameters were found inside the stand, and at each of the strip roads the diameter decreased as the distance from the strip road increased. Compared to the group of the wider strip roads, the variability of the DBH values was larger here, with the coefficients of variability at the bottom range (21-24%) of the "average" variability class.

In general, in both groups of the strip roads, the statistical analysis showed significant differences between DBH values on trees growing in different zones. In a few cases however these differences were insignificant, namely between the zones II and III in the group of the wider strip roads and between zones I vs. II and III vs. IV in the group of the narrower strip roads (Table 3).

Table 3. Results of significance test for differences in DBH values between different zones (calculated p values for $\alpha = 0.05$)
Tabela 3. Wyniki testu istotności różnic pierśnic drzew między strefami (obliczone wartości p dla $\alpha = 0,05$)

Zone Strefa	I	II	III	IV
		Wider strip roads 1-8 – Szlaki szersze 1-8		
I		**0.0011**	**0.0022**	**0.0000**
II	**0.0011**		0.9976	**0.0000**
III	**0.0022**	0.9976		**0.0000**
IV	**0.0000**	**0.0000**	**0.0000**	
		Narrower strip roads 9-12 – Szlaki węższe 9-12		
I		0.2234	**0.0000**	**0.0000**
II	0.2234		**0.0157**	**0.0000**
III	**0.0000**	**0.01576**		0.1019
IV	**0.0000**	**0.0000**	0.1019	

Values in bold – differences are statistically significant.
Wartości pogrubione – różnice statystycznie istotne.

The results presented above were obtained based on the data from all strip roads in a given group. When the statistical analysis was performed for each individual strip road, the picture similar to the one described above was true for one strip road only (Number 12) from the group of the narrower strip roads. Apart from that, the differences between diameters of trees from different zones were not always significant. In the group of the wider strip roads, no significant differences between tree diameters were found for the strip roads 4 and 5, and in the case of the narrower strip roads – for the strip road 11 (Table 4). For the strip roads 9 and 10, significant differences were found only between zones I and IV, as well as between II and IV. For all the remaining wider strip roads,

Table 4. Results of significance tests for differences in DBH values between different zones for different strip roads
Tabela 4. Wyniki testów istotności różnic pierśnic drzew między strefami dla poszczególnych szlaków

Zone Strefa	I	II	III	IV	Zone Strefa	I	II	III	IV
	Strip road 1 – Szlak 1 (*p* = 0.0012)					Strip road 2 – Szlak 2 (*p* = 0.0000)			
I		–	+	+	I		+	+	+
II	–		–	–	II	+		–	–
III	+	–		–	III	+	–		–
IV	+	–	–		IV	+	–	–	
	Strip road 3 – Szlak 3 (*p* = 0.0121)					Strip road 4 – Szlak 4 (*p* = 0.0577)			
I		–	–	+	I		–	–	–
II	–		–	–	II	–		–	–
III	–	–		–	III	–	–		–
IV	+	–	–		IV	–	–	–	
	Strip road 5 – Szlak 5 (*p* = 0.4270)					Strip road 6 – Szlak 6 (*p* = 0.0011)			
I		–	–	–	I		–	–	+
II	–		–	–	II	–		–	–
III	–	–		–	III	–	–		–
IV	–	–	–		IV	+	–	–	
	Strip road 7 – Szlak 7 (*p* = 0.0268)					Strip road 8 – Szlak 8 (*p* = 0.0000)			
I		–	–	–	I		–	–	+
II	–		–	–	II	–		–	+
III	–	–		+	III	–	–		+
IV	–	–	+		IV	+	+	+	
	Strip road 9 – Szlak 9 (*p* = 0.0101)					Strip road 10 – Szlak 10 (*p* = 0.0003)			
I		–	–	+	I		–	–	+
II	–		–	+	II	–		–	+
III	–	–		–	III	–	–		–
IV	+	+	–		IV	+	+	–	
	Strip road 11 – Szlak 11 (*p* = 0.0729)					Strip road 12 – Szlak 12 (p = 0.0000)			
I		–	–	–	I		–	+	+
II	–		–	–	II	–		+	+
III	–	–		–	III	+	+		–
IV	–	–	–		IV	+	+	–	

+ – różnice statystycznie istotne.
+ – statistically significant differences.

in three cases significant differences were found between two zones only – between zones I and IV (strip roads 3 and 6) and between the zones III and IV (strip road 7). As for the two remaining strip roads of this group, significant differences were found between the control zone and all the other zones (strip road 2) and between zones I vs. III and I vs. IV (strip road 1).

RECAPITULATION AND CONCLUSIONS

The results of the investigation showed that trees growing near strip roads had larger DBH values than trees more distant, growing inside the tree stand. This situation was not true however for all the investigated twelve strip roads, as in two cases the largest DBH values were measured at a distance of 1.5 m from the strip road, and in one case as far as 3 m away. As for the other nine strip roads, the thickest trees grew directly at the strip roads, with one exception only, where trees growing 1.5 m from the strip road were significantly thicker than the trees closer to the strip road. In the latter case the difference slightly exceeded 1 cm, whereas in the case of the other 9 strip roads the differences in DBH values rarely exceed 0.5 cm (maximum difference was 0.8 cm). The results indicate some inconsistency in DBH growth trends, five years after the cutting strip roads.

Increased DBH values on trees bordering strip roads were reported by Kremer and Matthies [1997], Mäkinen er al. [2006], Horák and Novák [2009]. In Poland, similar results were obtained by Stempski et al. [2010]. The investigations were carried out in conditions similar to those reported in this paper, and the results obtained showed larger differences between DBH values of trees growing directly at strip roads compared to those which were measured 3 m away from the strip road.

Generally, the least diameters were found on trees growing halfway between the neighbouring strip roads. The DBH values of those trees were for 6 out of 9 strip roads (for which the statistical analysis showed significant differences in diameters between zones) statistically significantly smaller than the DBH values measured on trees growing up to a distance of 3 m away from the strip road. It is doubtful that these significantly smaller diameters of the trees from the control zone resulted from the presence of the strip roads. The majority of researchers are of the opinion that the effect of the strip road applies to the trees growing very close to the strip roads, maximum up to 3 meters away [McCreary and Perry 1983, Isomäki and Niemistö 1990]. It seems that in this case, the reason may be a poorly performed thinning 5 years earlier, which is confirmed by the data presenting tree numbers in different diameter classes in the different zones (Fig. 1, 2). The frequency curves of the trees indicate a definite advantage of the thinnest trees (in the 4-6 and 61-8 cm DBH classes) in zone IV (the control) related to the other zones. In the case of the wider strip roads (Fig. 1) there were twice as many trees in the 6.1-8 cm DBH class in the control zone as in the other was even more distinct in the case of the thinnest trees (DBH values between 4 and 6 cm). There were a 100% more of them in zone IV than in zone I and over 1000% more than in zones II and III. Also, in the case of the narrower strip roads (Fig. 2) a similar situation was observed, though with generally lower DBH values of the trees the differences were not so distinct. The data show that inside the tree stand, regardless of the way the thinning performed, there were many more thin trees than in the area along the strip road. This fact caused a statistically significant differentiation of DBH values of trees between different zones, though such differences between zones I, II and II were noted for three strip roads only.

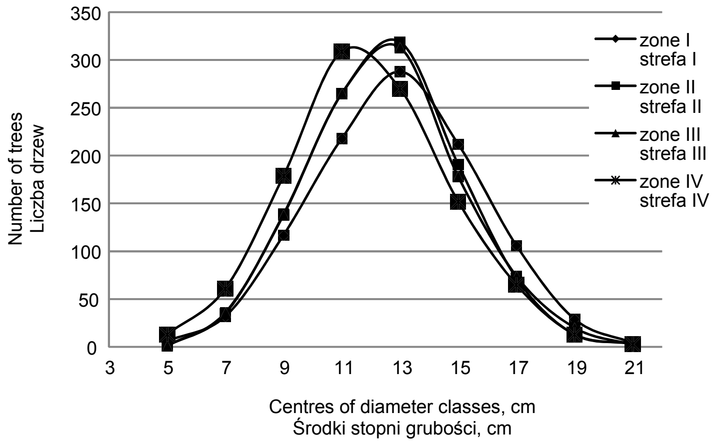

Fig. 1. Tree frequency curves for wider strip roads
Rys. 1. Krzywe frekwencji drzew dla szerszych szlaków zrywkowych

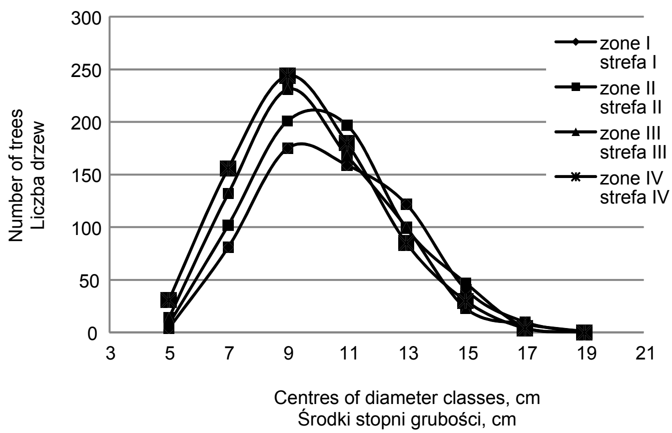

Fig. 2. Tree frequency curves for narrower strip roads
Rys. 2. Krzywe frekwencji drzew dla węższych szlaków zrywkowych

The results obtained allowed us to draw the following conclusions:

1. Five years after cutting strip roads, larger DBH values on trees growing directly at strip roads were observed for 9 out of 12 strip roads.

2. Statistically significant differences between zones up to a distance of 3 m away from the strip road were found for 3 strip roads only, and a statistically significant difference between zones I and II was observed for one strip road.

3. Trees growing inside the stand, in the control zone had statistically significantly lower BDH values for the majority of strip roads. This was caused by large numbers of the thinnest trees in this zone, which resulted from improperly performed thinning five years earlier.

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RÓŻNICOWANIE SIĘ STRUKTURY GRUBOŚCIOWEJ DRZEW ROSNĄCYCH PRZY SZLAKACH ZRYWKOWYCH W MŁODYM DRZEWOSTANIE SOSNOWYM

Streszczenie. Badania przeprowadzono w 32-letnim drzewostanie sosnowym, na siedlisku Bśw w zachodniej Polsce. Szlaki zrywkowe zaprojektowano w drzewostanie i wycięto wzdłuż rzędów drzew 5 lat przed wykonaniem badań. Analizą objęto drzewa przy 12 szlakach zrywkowych, rosnące w pasie drzewostanu szerokości około 3 m z jednej i drugiej strony każdego szlaku oraz w strefie kontrolnej znajdującej się w połowie odległości między dwoma sąsiadującymi ze sobą szlakami. Drzewa z pasa przyszlakowego znajdowały się w trzech strefach odległościowych wyznaczonych rzędami drzew. Pierwszą strefę (I) tworzyły drzewa rosnące w rzędzie wyznaczającym granicę przebiegu szlaku, kolejne strefy obejmowały drzewa rosnące w drugim (strefa II) i trzecim (strefa III) rzędzie z prawej i lewej strony szlaku. Strefy II i III znajdowały się w odległościach około 1,5 i 3 m od szlaku. Pomiarami pierśnic objęto wszystkie drzewa rosnące w przyjętych strefach odległościowych. Mierzono również szerokości szlaków. Podzielono je na dwie grupy: szlaki szersze – przeciętnie 3,6 m i szlaki węższe – 2,9 m. Dla dziewięciu szlaków, analiza statystyczna wykazała istotne różnicowanie się wartości pierśnic drzew między przyjętymi strefami odległościowymi. Na szlakach zarówno szerszych, jak i węższych, drzewa rosnące w ich bezpośrednim sąsiedztwie były na ogół grubsze niż drzewa rosnące w strefach bardziej od nich oddalonych. Statystycznie istotną różnicę w stosunku do drzew ze strefy II stwierdzono tylko w przypadku jednego szlaku. W większości drzewa ze strefy I były statystycznie istotnie grubsze od drzew rosnących w strefie kontrolnej.

Słowa kluczowe: szlaki zrywkowe, trzebież, pierśnica

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