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STRIP ROAD IMPACT ON SELECTED WOOD DEFECTS OF NORWAY SPRUCE (*PICEA ABIES* (L.) H. KARST)

Creating strip roads in second age class stands is an indispensible operation for carrying out thinning. It is especially important in places where there is an intention to do a first thinning using mechanised thinning operations. Felling trees to create strip roads results in altered conditions for the tree growth of neighbouring trees. In particular, this is due to an increase in exposure to sunlight. This can lead to changes in the growth of trees and consequently changes in the morphology of the trunk and the development of defects. The objective of this paper was to analyse the frequency of the presence of particular defects in the structure and shape of spruce in a five-year period after the creation of a strip road. The research was carried out in an artificially regenerated spruce stand within the spruce's natural, northern habitat in Poland. A 34-year-old stand underwent a systematic thinning scheme which involved the removal of every eighth tree row. The analysis was carried out on trees growing both adjacent to the strip roads (which had a greater growing area around them and greater access to sunlight) as well as trees from further within the stand. Diameter growth was taken in three places: at breast height, in the middle of the trunk between breast height and the base of the crown, as well as at the base of the crown. The average incremental growth, pith eccentricity taper and ovality were calculated. No statistically significant difference in defects between the trees growing by the strip road and those growing further in the stand was observed. Greater taper on mid-tree logs in comparison to butt logs was observed. Insignificant changes in the morphology of the trunks, supports the validity of cutting strip roads in second age class stands.

Keywords: wood quality, thinning operation, strip road, wood defects, Norway spruce (*Picea abies* (L.) H. Karst)

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Introduction

The management of multifunctional forests is integrally connected with the ability to access the stand via strip roads, the presence of which is crucial to the effective and balanced management of stands. Creating strip roads is an interference within an ecosystem which may lead to the creation of side effects characterised by a change in the tree microclimate as well as a disruption in the growth and development of trees [Delgado et al. 2007] and it may even lead to the disruption of the integrity of the stand ecosystem [Buckley et al. 2003]. A consequence of this process could be wood of a different quality as compared to wood logged from deeper within the stand away from the strip road [Macdonald, Hubert 2002]. Modern logging technology (not including cable yarders) is directly reliant upon access to stands in the form of strip roads. Strip roads in lowland stands can be established at different stages: 1) during the natural regeneration process tied in with the final felling of the shelter trees, 2) during the first late cleanings with merchantable timber removal [Giefing et al. 2003] as well as 3) during the early, first commercial thinning [Bembenek et al. 2011; 2013a].

The reaction of the trees to the creation of strip roads can be different depending on age and species. Research to date refers generally to the difference in the growth of trees as a result of the creation of strip roads [Matthies, Kremer 1997; Yilmaz et al. 2010]. However, there appears to be a gap in the research into the development of defects in trees growing close to strip roads. The natural reaction of trees to more favourable light conditions is increased growth which can lead to defects in the structure of the tree. This can be seen as an excessive average rate of growth. The felling of trees in order to make a strip road creates better growing conditions for adjacent vegetation. A one-sided increase in light and growing space could, however, generate additional defects: pith eccentricity, taper and ovality. Based on the previously quoted research as well as the acknowledged premise that increased access to light influences trunk shape, a hypothesis was made that trees growing adjacent to a strip road (SR) would develop the aforementioned defects in contrast to the trees growing deeper within the stand (ST). At the same time, it was also assumed that the size of these defects would increase on the higher part of the trees towards the trees' crown base, where the biggest impact of assimilates on annual ring increments is. Therefore, the aim of this paper was to describe the influence of strip roads on the development of specific tree structure and shape defects. In Poland, under binding technical conditions for plywood, ovality must be taken into consideration, although ovality is also important for sawtimber. All the identified structural defects are also taken into consideration within the quality classification of round wood in accordance with European standard PN-EN 1927-1.

Materials and methods

The research was carried out in a premature spruce stand located in a lowland area of northern Poland (54_24’ 57” N, 20_7’ 31” E) in Zaporowo Forest District (Regional Directorate of the State Forests Olsztyn). The area of the stand was 4.96 ha. The stand was created artificially in 1974 by the planting of 3125 trees per hectare with a spacing of 2.5 m between tree rows and 1.5 m between individual trees. The stand was established on post-agricultural land, the soil was rich, over optimal fertility for spruce. Prior to the carrying out of this research, there had been no history of logging in this area. Furthermore, abiotic factors such as wind and snow as well biological factors such as insects, mushrooms and game were found to have not had an influence on the diversity of the area.

Annual rainfall within the research area is 750 mm and the average annual temperature is 6–7 degrees Celsius. The vegetation period lasts around 200 days. The average number of days with a strong wind (over 10 m/s) is 40–50 days per year.

In early spring 2004, a systematic thinning was carried out on every eighth tree row. The trees were cut with a chainsaw, and the timber was extracted with the Ponsse S15 forwarder (weight 14 t, capacity 12 t) during dry weather conditions. Via this process, 5 m wide strip roads were created, spaced 20 m apart (as measured from axis to axis). After the creation of the strip roads, when 5 annual increments had appeared (in spring 2009), measurements of breast high diameter were taken across the entire stand. Using the established Kraft classification system [Kraft 1884], the biosocial position of each tree was established and the trees were also divided into two groups: 1) trees adjacent to the strip road (SR) and 2) trees from deeper within the wood stand (5–10 m from the axis of the strip roads) (ST) (table 1).

Table 1. Tree characteristics (whole stand)
Tabela 1. Charakterystyka drzew (cały drzewostan)

Localization *Lokalizacja*	Number of trees *Liczba drzew* [$n \cdot ha^{-1}$]	Breast height $d_{1.3}$ *Pierśnica* [cm]			Standard deviation *Odchylenie standardowe*
		Mean *Średnia*	Maximum *Maksimum*	Minimum *Minimum*	
Along strip road (SR) *Wzdłuż szlaku operacyjnego (PS)*	235	23.6	35	11	5.86
In the stand (ST) *W drzewostanie (WD)*	1030	23.9	40	9	6.95

Next, under the Urich I method, 9 sample trees were taken from each of the two groups (in total 18 trees). Three trees were assigned to each of the three first classes of the Kraft classification system. Three sample discs were cut from each tree at three different heights: diameter at breast height ($d_{1.3}$), halfway between breast height and the crown base ($d_{1/2cb}$) as well as at the crown base (d_{cb}). Each disc was measured for incremental growth accurate to the nearest 0.01 mm.

On the sample trees, the measurement of defects was carried out according to EN 1310 [1997] specifications. The analysis embraced:

a) The average annual increment of growth rings (diameter change). Annual growth was measured in four directions (north, south, east and west) for each year in the five-year period after the strip roads were created. Within the same method, the last 5 increments were measured from the last 5 years before the strip roads were created. After carrying out the Bartlett test, the need to carry out logarithmic transformation of some variables emerged. Two-way ANOVA [Searle 1971] was carried out to test the effect of the location (l) and the biosocial class (c). The first experimental factor appears on two levels: l_1 – strip road and l_2 – wood stand, and the second factor appears on three levels, each corresponding to the three classes of the Kraft classification system (cj, j = 1,2,3). It was assumed that the increments of the growth rings y_{ijk} in k'th replication can be written in the following form:

$$y_{ijk} = m + l_i + c_j + (lc)_{ij} + e_{ijk} \tag{1}$$

Where: m – general mean,
l_i – location effect (factor l), i = 1, 2,
c_j – j effect (j being the corresponding class in the Kraft classification system) (factor c), j = 1, 2, 3,
$(lc)_{ij}$ – second rate interaction effects,
e_{ijk} – random errors.

The post hoc Tukey HSD test was used to compare the significance of the differences among the means.

b) Pith eccentricity (x), the distance of the pith from the geometric centre:

$$x = \sqrt{(\bar{r}_{N-S} - r_S)^2 + (\bar{r}_{E-W} - r_W)^2} \tag{2}$$

Where: r – radius (mm),
E – east, W – west, N – north, S – south.

c) Taper (t) (mm m^{-1}):
– sections of the butt log – L1, namely the difference between $d_{1.3}$ and the diameter $d_{1/2cb}$ divided by the number of meters between the measured diameters,

- sections of the mid log – L2, namely the difference between $d_{1/2cb}$ and the diameter at the base of the crown d_{cb} also divided by the number of meters between the measured diameters,
- as well as the whole log L3, between $d_{1.3}$ and d_{cb},

$$t = \frac{d_1 - d_2}{l} \tag{3}$$

Where: d_1 – the diameter of the base of the measured section ($d_{1.3}$ v $d_{1/2cb}$),
d_2 – the diameter at the top of the measured section ($d_{1/2cb}$ v d_{cb}).

d) Ovality (s):

$$s = \frac{d_1 - d_2}{d_1} \tag{4}$$

Where: d_1 – the greatest cross section diameter,
d_2 – the smallest cross section diameter.

After checking for normality (Kolmogorov-Smirnov test) and homogeneity of variance (Bartlett test), two-way ANOVA with the use of a model (1) was used to analyse taper, ovality and pith eccentricity. For each of the two tree groups (SR and ST), the average values of taper in the butt log and mid log of the trunk were compared (t test). The same test was administered to compare the taper on the entire log from SR and ST trees. Statistical analysis was carried out using programme R supported by a stats package as well as agricolae [Anonymous 2012].

Results and discussion

Rate of Growth

Based on the analysis of the measurements, no significant difference was observed in the annual growth rates between all of the trees in the five-year period before the creation of the strip roads. Before the operation, the trees grew in comparable conditions in terms of individual site and soil conditions.

A detailed analysis of incremental growth after the creation of the strip road (taking into account the following years and the biosocial position of the trees) revealed a difference in the observed interactions in relation to the location of the samples (fig.1).

Additionally, smaller increments (a general growth reduction) after thinning (fig. 1) may suggest harmful effects to the roots or soil compaction by the heavy forwarder (ca. 26 tonnes with load).

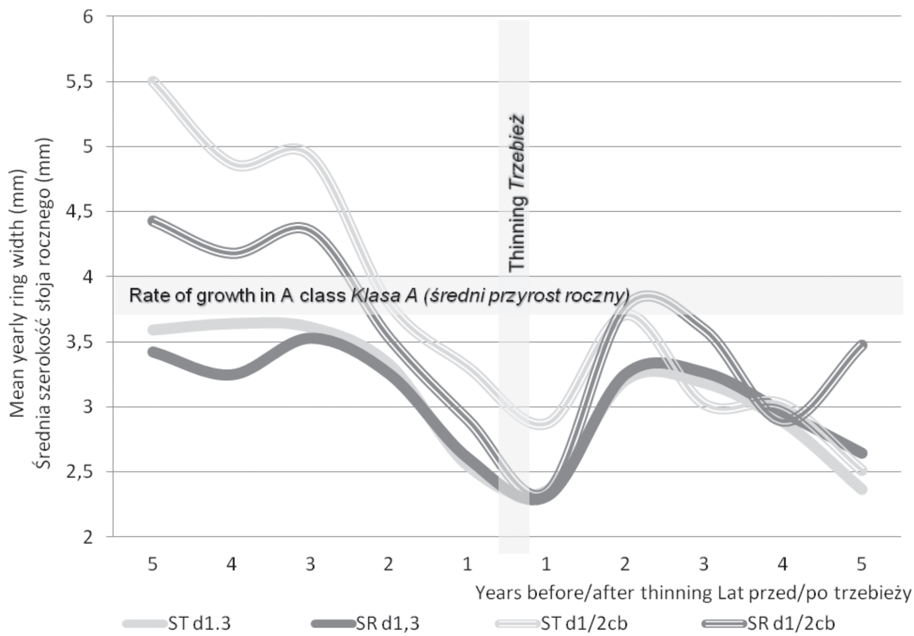

Fig. 1. Trend of mean annual ring width on $d_{1.3}$ and $d_{1/2cb}$ (SR: trees along strip roads; ST: trees within the stand); rate of growth in A class marked as ≤ 4 mm
Rys. 1. Średni przyrost roczny na wysokości pierśnicy i w 1/2 podstawy korony; zaznaczono granicę średniego przyrostu rocznego klasy A ≤ 4 mm

The lowest level of interaction was seen at $d_{1.3}$, with a higher rate of interaction at crown base $d_{cb,}$ whilst the highest was observed in the middle $d_{1/2cb}$. The increase in living space for the SR trees seems to have had a relatively delayed effect on the growth of the trees, as it was only in the third and fifth year that significantly larger increments were seen in $d_{1/2cb}$ (0.57, p = 0.0447 and 0.96 mm, p = 0.0065 respectively). Earlier, in the first 2 years following the creation of the strip roads, as well as in the fourth year, the trees grew at the same rate as the ST trees. It would appear that the reaction of the spruce to the presence of strip roads is slower than its reaction to wounds it has sustained. Wounds sustained during mechanised thinning operations caused a decrease in radial growth of about 10–50% in the five-year period after they were sustained [Isomäki, Kallio 1974].

The initial lack of uniform changes in the incremental growth of trees following the creation of a strip road can be considered predictable. Giefing et al. [2003] came to similar conclusions carrying out research on pine trees growing adjacent to strip roads of various widths. However, this does not mean that there was no growth reaction in the SR trees. In the initial period, the changes may have been slow due to the time required for the tree to build its crown in the direction of the newly formed gap. Identifying the beginning of the reaction growth process is a complicated task and requires a longer time period, as well as the implementation of segment regression models consisting of several straights [Jastrzębowski, Klisz 2012].

The higher incremental growth rates in years 3 and 5 after the creation of the strip roads could be the beginning of the formation of wider growths. Borowski [1974] claimed that the greatest incremental growth rates could be observed 9–12 years after the creation of strip roads. The growth increments recorded in the presented research, including those in the last of the five-year period for $d_{1/2cb}$ and d_{cb}, are lower than the normative values for class A (≤ 4 mm). To sum up, it is possible to argue that if the SR spruces were to experience higher incremental growth in later years, their wood may deteriorate in quality.

An uneven grain leads to the lumber of the tree cracking and warping. This specific trait (uneven grain) coupled with an increase in average incremental growth requires analysis under PN-EN 1927-1 specifications. Furthermore, with increased annual incremental growth in spruce wood, there is a decrease in the quality of the mechanical properties of the wood, namely the modulus of elasticity in static bending (MOE), maximum crushing strength in compression parallel to the grain (Cmax), as well as to a lesser extent, the modulus of rupture in static bending (MOR) [Zhang 1995].

Eccentric pith

Pith eccentricity was present in all the cross-sections, however, the statistical analysis did not confirm the presence of a difference between the biosocial position and the size of these defects in either the SR or the ST trees. The graphical interpretation of the direction of the movement of the pith in relation to the geometric centre of the cross-section revealed certain properties (fig. 2).

Table 2. Relative eccentricity (mean) at different heights along the stem; for SR and ST, Kraft classes 1, 2 and 3
Tabela 2. Względne przesunięcie rdzenia (średnie) na badanych wysokościach z uwzględnieniem drzew PS i WD w trzech klasach Krafta

Kraft Class *Klasa Krafta*	Trees along strip road (SR) *Drzewa przy szlaku (PS)*			Trees in the stand (ST) *Drzewa w drzewostanie (WD)*		
	$d_{1.3}$	$d_{1/2cb}$	d_{cb}	$d_{1.3}$	$d_{1/2cb}$	d_{cb}
I Dominant *I Górujące*	0.0472	0.0465	0.0402	0.0678	0.0431	0.0545
II Codominant *II Panujące*	0.0469	0.0339	0.0290	0.0297	0.0530	0.0443
III Intermediate *III Współpanujące*	0.0329	0.0265	0.0461	0.0569	0.0310	0.0487

$d_{1.3}$ – breast height; $d_{1.3}$ – *pierśnica*
$d_{1/2cb}$ – halfway up the pruned trunk; *pll – połowa oczyszczonej strzały*
d_{cb} – crown base; d_{cb} – *podstawa korony*

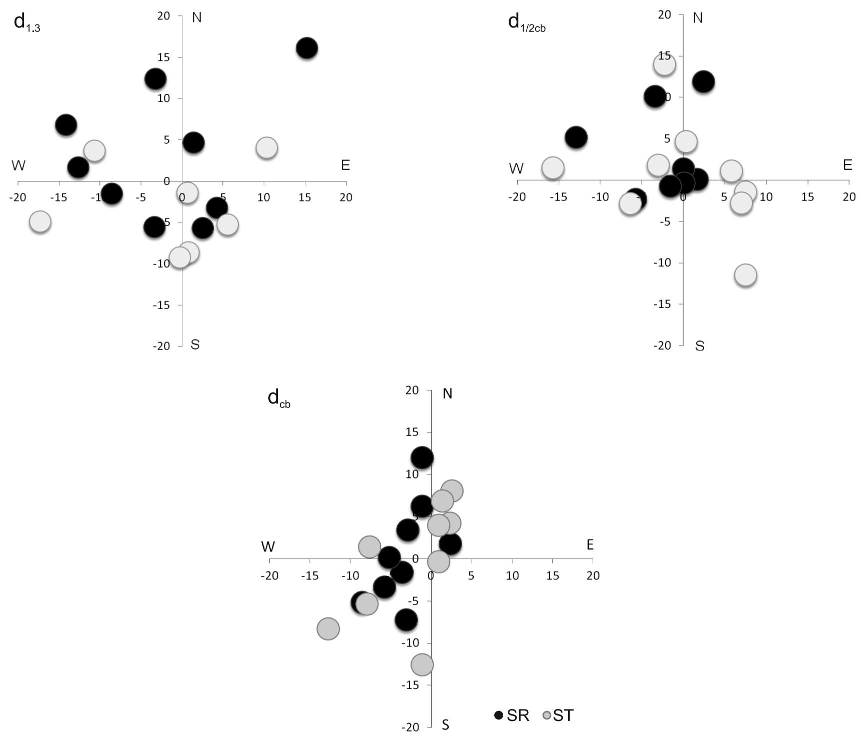

Fig. 2. Direction of pith movement (mm) in relation to the geometric centre of the trunk cross-section at $d_{1,3}$, halfway up the pruned trunk $d_{l/2cb}$, and at crown base d_{cb}
Rys. 2. Kierunek przesunięcia rdzenia (mm) względem geometrycznego środka przekroju pnia na wysokości $d_{1,3}$ – pierśnica, $d_{l/2cb}$ – połowa oczyszczonej strzały, d_{cb} – podstawa korony

Despite the absence of significant differences in the size of the eccentric pith in three cross sections ($d_{1.3}$, $d_{1/2cb}$, d_{cb}) of the SR and the ST trees, it was observed that from the crown base d_{cb} of the SR trees, in 8 out of 9 cases the pith had moved in an easterly direction (strip roads run in a north-south direction).

At the same time, it must be stressed that of significance to the analysis of the influence of strip roads on the formation of defects is the fact that the piths of these 8 SR trees had moved in the direction of the stand (in the opposite direction to the opening created by the strip road). As the trees were on both sides of the strip road, this suggests that trees are generally under significant influence of the winds dominating in Poland (westerly and north-westerly).

The regularity exhibited by d_{cb} is of high interest as the greatest pith eccentricity is usually observed at stump height and diminishes on moving up the stem (as observed on pines) [Mäkinen 1998]. The same author highlights that it is difficult to clearly describe the influence of a single factor in the formation of pith eccentricity. In the aforementioned research papers, the movement of the pith in the lower sections of the stump sample discs was directionless. A more certain order only occurred at the crown base. This could indicate that the crown, which is developing and growing towards the strip road, will gradually increase the width of its wood in that direction. Liese and Dadswell [1959] observed that wider rings were on the sunny side of the bole, and concluded that directional warming (light) may influence asymmetric growth.

The degree of pith eccentricity is an index of the wood quality of the trunk and a result of its strong relationship with the reaction wood [Akachuku, Abolarin 1989; Ren et al. 2006]. The mere development of this defect is associated with several factors analysed both together and separately, such as tree lean, slope and wind [Kellogg, Barber 1981]. The influence of greater living space in the form of a strip road can form an additional element, which over a longer period of time, can contribute to pith eccentricity.

Taper

Comparing the logs of the trees within the stand with the logs of the trees close to the strip road, no statistically significant differences were observed in terms of ovality. The lack of difference concerns all the researched sections of the wood, irrespective of location and biosocial position.

Table 3. Taper of measured logs at different positions along the stem (L1: butt log $d_{1.3} - d_{1/2cb}$; L2: mid log $d_{1/2cb} - d_{cb}$; L3: whole log $d_{1.3} - d_{cb}$)
Tabela 3. Zbieżystość w poszczególnych kłodach (L1: kłoda odziomkowa – od pierśnicy do połowy długości pomiędzy pierśnicą a podstawą korony; L2: kłoda środkowa – od połowy długości pomiędzy pierśnicą a podstawą korony do podstawy korony; L3: cała kłoda – od pierśnicy do podstawy korony)

Localization *Lokalizacja*	Type of log *Kłody*	Taper *Zbieżystość* (mm m^{-1})	Standard deviation *Odchylenie standardowe*	L1 vs L2[a]	L3 vs L3[b]
SR *PS*	L1	5.27	1.53	0.0039**	0.5460
	L2	8.01	1.72		
	L3	6.18	1.32		
ST *WD*	L1	7.52	3.53	0.9911	
	L2	7.51	3.15		
	L3	6.85	2.79		

[a] n = 18(9L1 + 9L2), [b] n = 18(9L3(ST) + 9L3(SR))

However, statistically significant differences were observed between the butt log and mid log from the SR trees, p = 0.0039 (table 4). General conclusions cannot be reached here, however, one possible reason for this difference could be the significantly bigger radial growth at the mid height of the SR trees in the 3rd and 5th years after thinning. The relatively short 5-year period of influence of the strip road on the shape of the trunk did not cause any other discernible differences in reference to the ST trees. Pines are described as reacting in a similar way [Stempski et al. 2011]. In that particular research, an insignificantly greater ovality was observed adjacent to the strip road in the 7 years following its creation.

Ovality

Within the research, no difference in ovality was found between the trees from either of the analysed locations. In both the SR and ST trees, ovality was very small and the trunks maintained a shape resembling a circle [table 4]. A round trunk cross-section is typical for commercial softwoods grown under natural conditions where an equally small (4%) trunk defect has been diagnosed [Tong, Zhang 2008]. A lack of defects in the incremental growth rings around the pith area in comparison to the circumference area was also confirmed by Saint-André and Leban [2000]. They confirmed a clear elliptical shape of growth rings located closer to the circumference of spruce. Therefore, with growing age, an increase in ovality might be expected, which in turn could have a direct effect on the quality of the wood.

Table 4. Ovality (mean) at different heights along the stem
Tabela 4. Względne spłaszczenie (średnie) na badanych wysokościach

Kraft Class *Klasa Krafta*	Trees along strip road (SR) *Drzewa przy szlaku (PS)*			Trees in the stand (ST) *Drzewa w drzewostanie (WD)*		
	$d_{1.3}$	$d_{1/2cb}$	d_{cb}	$d_{1.3}$	$d_{1/2cb}$	d_{cb}
I Dominant *I Górujące*	0.0435	0.0455	0.0168	0.0312	0.0407	0.0208
II Codominant *II Panujące*	0.0257	0.0207	0.0248	0.0307	0.0247	0.0216
III Intermediate *III Współpanujące*	0.0344	0.0249	0.0131	0.1325	0.0402	0.0053

$d_{1.3}$ – breast height; $d_{1.3}$ – *pierśnica*
$d_{1/2cb}$ – halfway up the pruned trunk; *pll – połowa oczyszczonej strzały*
d_{cb} – crown base; d_{cb} – *podstawa korony*

The number of trees exposed to the risk of increased ovality could be reduced by an increased distance between the strip roads. Increasing this distance to a certain degree does not exclude the use of harvesters [Mederski 2006, Modig et al. 2012]. However, as Bembenek et al. [2013b] observed, there might be a situation where mechanical damage occurs as a result of pulling trees from inter-strip road areas. This could also result in the creation of different structural defects (e.g. ingrown bark, scars) which are characteristic of spruce stands exposed to low level mechanised forest operations [Michalec et al. 2013]. For this reason, it would seem purely academic to omit scars under PN-EN 1927-1 standards. This is a defect present on trees adjacent to the strip road which could equally have been caused by logging [Karaszewski et al. 2013a; 2013b] as well as by grazing and stripping. This situation is even more applicable to spruces which are commonly attacked by tree rot following stripping. Consequently, this leads to a depreciation in the quality and value of the timber.

Conclusions

The assumed hypothesis, which stated that greater access to sunlight through the creation of strip roads would create defects in the shape and structure of spruce trees was not confirmed (at least not statistically). One explanation for the obtained results is the relatively short period examined in the research. However, some trend was noted, namely a more intensive increment appearing in the last, fifth year of observation (SR $d_{1/2cb}$) (fig. 1). Besides the described delay in the growth reaction after the thinning took place, it will probably take time until the trees build up bigger crowns to cover new areas of light, and these asymmetric crowns may finally lead to pith eccentricity and ovality. In the 5 years following the creation of the strip road within the 34-year-old stand, no significant differences in pith eccentricity, taper and ovality were observed. The size of these defects was lower than their permitted levels for class A round timber under PN-EN 1927-1 [2008]. Insignificant changes in stump morphology support the validity of strip roads in second age class stands. Nevertheless, a tendency for the SR trees to have increased incremental growth, particularly in the middle of the trunk, as well as an increase in the taper of mid tree logs from the SR trees was observed. For this reason, it is crucial to continue research into this area, particularly since the described defects have been addressed and have limits placed on them under EU laws concerning the wood in circulation in Europe.

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WPŁYW SZLAKÓW OPERACYJNYCH NA WYBRANE WADY DREWNA ŚWIERKA POSPOLITEGO (*PICEA ABIES* (L.) H. KRAST)

Streszczenie

Zakładanie szlaków operacyjnych staje się niezbędne przy stosowaniu współczesnych technologii w gospodarce leśnej. Ich obecność to również zwiększony dostęp do światła dla drzew rosnących na ich skraju, co z kolei może wpływać na różnice we wzroście tych drzew w porównaniu z drzewami wewnątrz drzewostanu. Celem pracy była analiza częstości występowania niektórych wad budowy i kształtu mogących wpływać na jakość surowca drzewnego w 5 lat po wykonaniu zabiegu. Drzewostan świerkowy w wieku 34 lat został poddany trzebieży schematycznej poprzez wycięcie co 8. rzędu drzew. Analizie poddano drzewa rosnące przy szlaku PS (z asymetrycznie większymi stoiskami i dostępem do światła) oraz drzewa wewnątrz drzewostanu (WD 5–10 m od osi szlaku). Badano przyrosty na wysokości pierśnicy, w połowie długości między pierśnicą a podstawą korony i u podstawy korony oraz obliczono przeciętny przyrost, mimośrodowość rdzenia i zbieżystość. Nie zaobserwowano występowania statystycznie istotnych różnic pomiędzy analizowanymi cechami drzew PS i WD, jednakże u drzew rosnących PS zaobserwowano istotnie większą zbieżystość kłód środkowych w porównaniu z odziomkowymi. W krótkim okresie (5 lat) po założeniu szlaków w drzewostanie świerkowym II klasy wieku nie stwierdzono zatem statystycznie istotnych różnic w morfologii pni drzew rosnących przy szlaku i w drzewostanie. Niemniej jednak zaobserwowano: 1) tendencje do zwiększonych przyrostów u drzew PS (szczególnie w połowie pnia) w 5. roku po wykonaniu zabiegu oraz 2) wzrost zbieżystości kłód środkowych wyrobionych z drzew PS. Wyniki te sugerują przeprowadzenie podobnych badań w dłuższym odstępie czasowym (niż 5-letni) od założenia szlaków.

Słowa kluczowe: jakość drewna, trzebieże, szlak operacyjny, wady drewna, świerk pospolity (*Picea abies* (L.) H. Karst)

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