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Butt rot occurrence in plus trees of Silver fir *Abies alba* Mill. and Norway spruce *Picea abies* (L.) from the Carpathians

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Abstract. Due to its hidden character, butt rot occurrence is not commonly included in the assessment of plus trees' health status. Thus, the trees' varied susceptibility to wood decay is not a target of breeding efforts. The aim of the study was to determine the extent of butt rot in fir and spruce plus trees from Carpathian seed stands. We employed the novel and non-invasive diagnostic method of sonic tomography to determine presence and severity of decay at the base of 110 plus trees of silver fir and 42 of Norway spruce.

Butt rot in various stages of development occurred in 63% of investigated fir trees and in 45% of spruce trees. The proportion of damaged wood on the tomogram ranged from 0–38% in fir and 0–47% in spruce with similar average proportions of solid wood in all forest districts. The vast majority of trees was in the range of 80–90% solid wood. Plus trees of fir and spruce were affected by butt rot to a similar extent and the degree of damage increased with age in both species.

However, a large variation in susceptibility to butt rot was found between individual trees leading to the conclusion that the identification of old trees, which wood is not decayed, may be the basis for further research on the resistance to butt rot.

Keywords: butt rot, sonic tomography, plus trees, resistance, *Abies alba*, *Picea abies*

1. Introduction

Management of Poland's State Forests includes selective tree breeding programs, founded on two approaches: the population selection process in seed stands and the selection of individual plus trees. The main objectives of selection include intensification of production and improvement of tree qualitative traits. On the other hand, issues such as tree resistance to biotic factors are recognised to a lesser extent. As indicated by research results, the selection of forest trees with regard to resistance should be focused on individual trees rather than on population (Delatour et al. 1998). Therefore, in the assumed model of forest tree selection, plus (mother) trees should primarily be of interest when breeding for resistance.

Good health condition is a decisive factor in the selection of plus trees (General Directoriate of The State Forests (Dyrekcja Generalna Lasów Państowych 2013)). In the selection process, as a rule, the health status of trees is evaluated with reference to any visible external symptoms of infection caused by harmful organisms. However, internal rot of tree heartwood (physiologically not active) can develop for a long time without rapid effects on a tree's life functions. As a result, in an affected tree, the disease process can progress with no visible symptoms of rot fungi activity, what allows the tree to live to an old age, regardless of advanced decay inside its stem. Due to the latent nature of decay, incidence of butt rot has often been neglected in the previously mentioned evaluations of health condition of plus trees. Therefore, differential susceptibility of forest trees to butt rot has not been a part of the ongoing selection activities.

Norway spruce *Picea abies* (L.) H. Karst. and the European silver fir *Abies alba* Mill. are considered to be the main forest forming species in Poland's mountainous regions. Norway spruce is often infected by root rot and butt rot fungi, hence, this species has been the focus of majority

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of studies on butt rot disease (Norokorpi 1980; Krzan 1985; Stenlid, Wästerlund 1986; Kohnle, Kändler 2007; Mattila, Nuutinen 2007). Rot disease problem has not been fully recognised in the case of silver fir. In the subject literature, some fungal species that cause butt rot in silver fir have been described (Siwecki, Krzan 1983); however, no information has been provided on the extent of damage they cause in silver fir stands. The results of tomography analysis indicate that butt rot disease can affect silver fir in the same way as Norway spruce, especially when the trees reach old age (Niemtur et al. 2013; Niemtur et al. 2014).

The aim of the present study was to assess the extent of butt rot incidence in silver fir and Norway spruce plus trees selected in mountainous seed stands, with the use of a novel diagnostic method – sonic tomography. When compared to traditional methods applied for the diagnosis of tree diseases, sonic tomography allows for more accurate detection of position and extent of butt rot inside the trunk of a tree. At the same time, due to non-invasive measurement method, it is possible to diagnose especially valuable tree specimens such as plus trees, without disturbing the integrity of internal tissues of the trunk.

The objective of the study was to recognise the complete butt rot problem concerning the plus trees of Norway spruce and silver fir, as well as to comprehensively determine the differences between individual trees with regard to decay progression in the tree butt. Identification of trees devoid of decayed wood can be a basis for further research on butt rot resistance, with special attention focused on the genetic factor.

A relationship between tree age and butt rot damage extent in the tree trunk was also determined using the data available from the register of plus trees.

2. Methods

2.1. Study object

The study was carried out on Norway spruce and silver fir plus trees (mother trees) growing in the mountainous forest districts, situated within the areas administered by the Regional Forest Directorates (Regionalna Dyrekcja Lasów Państwowych (RDLP)) in Katowice, Kraków and Krosno.

Sonic tomography measurements comprised 110 silver fir plus trees growing in 10 forest districts: Sucha, Ujsoły (RDLP Katowice), Gromnik, Łosie, Nawojowa, Piwniczna (RDLP Kraków), Bircza, Lesko, Stuposiany and Ustrzyki-Dolne (RDLP Krosno), as well as 42 Norway spruce plus trees from 3 forest districts : Wisła, Ujsoły (RDLP Katowice) and Nowy Targ (RDLP Kraków). In the case of Norway spruce, all the plus trees growing in the study area were included in the study (other specimens registered in various databases were either wind-thrown or had died due to insect infestations).

2.2 Sonic measurements

Butt rot incidence on tree trunk cross-section was detected with the use of the PiCUS Sonic Tomograph, Argus Electronic, Rostock, Germany. The instrument measures the velocity of sound in wood, which depends on its characteristics, and provides information on the presence of decay, extent of wood damage and rot position in the cross-section of the tree trunk. The method is non-invasive and therefore has no negative effects on the health status of the examined trees. A detailed description of tomography mechanism of action is available in the paper by Chomicz (2007).

Sonic measurements were performed on standing trees, at a height 10 cm above the ground (at a slope side). In keeping with the PiCUS Sonic Tomograph manual, there were 8–10 designated measurement points, depending on the thickness of the trunk. At each measurement point, an electrode was inserted until it reached the wood, and then it was connected with a magnetic sensor. The sonic impulse was instigated three times at each measurement point by tapping with a metal hammer (version Lite). The geometry of the cross-section was determined using a digital PiCUS Caliper that measured the distances between the measurement points. After sending a radio signal from the sensors to the computer, the respective tomograms were generated by PiCUS Expert software, v. Q72.

2.3. Tomogram interpretation

A tomogram represents the visualization of wood condition in the tree cross-section at the measurement point. The colour scale displayed in the tomogram identifies the wood areas with different levels of decay due to pathogenic fungi. The analysis of colours in the tomograms allowed identification of 3 categories of wood: solid (*S*) - with no decay – dark or light brown, damaged (*D*) – blue and purple, not identified (*N*) – green. Implication of green colour shown in the tomogram depends on wood damage type and should be considered at an individual tree level. Green often indicates the transitional area in between solid and damaged wood; however, it can also demonstrate early stages of fungal infection (additional information can be found in the PiCUS Sonic Tomograph manual). The proportions of wood from the designated categories were computed by PiCUS Expert software as the percentage area of a given colour in the total area of the tomogram. The share of a given wood category was displayed in the tomogram as the legend (band of colours in the upper part of the tomogram).

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2.4. Statistical analyses

Statistical analysis was performed based on the results of the shares of solid (S) wood in the tomograms. Given that the obtained data concerned percentage values, variance was stabilised by transformation according to the Bliss formula:

$$S = arc \sin \sqrt{x},$$

where:
S – solid wood share,
x – percentage of solid wood in the tomogram, expressed as a decimal number

The Student's t–test was used for two independent samples to assess the significance of differences between silver fir and Norway spruce with regard to butt rot extent. Analogous differences between the tree species with reference to specific forest districts were tested using one-way analysis of variance (ANOVA).

Also, the effect of tree age on the degree of butt rot was tested. The tree age was determined based on data compiled in the register of plus trees (Forest Research Institute, Poland). For the purpose of the study, tree age recorded in the register was adjusted to the year of analyses (2016). The plus trees examined were divided into specific age groups (each with similar number of trees). Three age groups of silver fir were distinguished:

- 1 – from 91 to 122 years old (36 trees),
- 2 – from 126 to 134 years old (39 trees),
- 3 – from 141 to 158 years old (35 trees).

In view of the fact that compared to silver fir, a smaller number of Norway spruce plus trees were examined that had 51 years maximum age difference between each other (maximum 67 years between silver fir trees), Norway spruce trees were divided into two groups:

- 1 – from 117 to 137 years old (18 trees),
- 2 – from 141 to 168 years old (16 trees).

The age groups were compared with regard to the average share of solid wood in the tomogram. Silver fir trees were tested using one-way ANOVA and those of Norway spruce – by means of Student's t-test for two independent groups.

All the calculations were performed using Statistica 9.0 software.

3. Results

Norway spruce and silver fir plus trees were affected by butt rot at similar levels. The average share of solid wood in the silver fir trees examined was 84.7%, and in Norway spruces was 85.9% (Table 2). The difference between the two species were not statistically significant ($p = 0.205$). In the most damaged fir tree, the image of decayed wood covered 38% of the tomogram area (plus tree no. 6201, Forest District Lesko; Table 1A), whereas, in the case of Norway spruce, it was 47% (plus tree no. 7992, Forest District NowyTarg; Table 1B). More number of Norway spruce plus trees were recorded with no signs of butt rot (no damaged wood in the tomogram, 55% of examined Norway spruce trees) compared to silver fir (37%). However, in both tree species, similar proportions of trees with butt rot of limited extent (0 to 10% of damaged wood in the tomogram, silver fir: 72% of trees, Norway spruce: 74% of trees) were observed.

The average share of solid wood in the tomogram was similar in all the forest districts that were studied and mostly, the

Table 1. The share of solid (*S*) damaged (*D*) and unidentified (*U*) wood on the tomograms and the age of investigated plus trees (*PT*)

A. Silver fir

Forest District	*PT* No.	The share of wood			Age	Forest District	*PT* No.	The share of wood			Age
		S	*D*	*U*				*S*	*D*	*U*	
		[%]			[years]			[%]			[years]
Bircza	4376	80	9	11	127	Nawojowa	7169	87	3	10	119
Bircza	4377	67	13	20	127	Nawojowa	7170	92	0	8	119
Bircza	4378	92	2	6	127	Nawojowa	7171	98	0	2	119
Bircza	4379	65	11	24	127	Piwniczna	4150	68	19	13	153
Bircza	6731	100	0	0	158	Piwniczna	4151	76	12	12	153
Bircza	6732	53	32	15	158	Piwniczna	4152	88	3	9	153
Bircza	6733	75	7	18	158	Piwniczna	4153	95	0	5	153

Forest District	*PT* No.	The share of wood *S*	*D*	*U*	Age	Forest District	*PT* No.	The share of wood *S*	*D*	*U*	Age
			[%]		[years]				[%]		[years]
Bircza	6734	56	29	15	158	Piwniczna	4154	93	1	6	153
Bircza	6736	77	8	15	158	Piwniczna	4155	76	7	17	153
Bircza	6737	91	2	7	158	Piwniczna	7177	100	0	0	134
Bircza	6738	90	2	8	158	Piwniczna	7178	69	9	22	134
Bircza	9314	100	0	0	130	Piwniczna	7179	70	11	19	134
Bircza	9315	97	0	3	130	Piwniczna	7180	79	0	21	134
Bircza	9316	98	0	2	130	Stuposiany	6078	89	5	6	153
Bircza	9317	81	10	9	130	Stuposiany	6079	67	23	10	153
Bircza	9318	79	3	18	130	Stuposiany	6080	100	0	0	153
Gromnik	3099	94	0	6	153	Stuposiany	6081	77	19	4	153
Gromnik	3100	74	19	7	153	Stuposiany	6082	62	27	11	153
Gromnik	3104	59	32	9	153	Stuposiany	6083	68	19	13	153
Gromnik	3105	77	13	10	153	Stuposiany	6084	59	22	19	153
Gromnik	3106	75	9	16	153	Stuposiany	6085	89	4	7	153
Gromnik	7122	100	0	0	104	Stuposiany	6086	84	9	7	153
Lesko	6199	95	0	5	131	Stuposiany	6087	73	11	16	153
Lesko	6201	53	38	9	131	Stuposiany	6089	100	0	0	154
Lesko	6204	74	13	13	131	Stuposiany	6090	74	16	10	154
Lesko	6207	83	0	17	131	Sucha	5454	77	7	16	126
Lesko	6210	100	0	0	141	Sucha	5456	100	0	0	126
Lesko	6211	94	1	5	129	Sucha	5457	98	0	2	126
Lesko	6213	87	5	8	129	Sucha	5458	89	1	10	126
Łosie	7150	88	4	8	122	Sucha	5459	100	0	0	126
Łosie	7151	100	0	0	122	Sucha	5460	100	0	0	126
Łosie	7152	67	22	11	122	Sucha	5461	91	2	7	126
Łosie	7153	82	8	10	122	Sucha	5465	71	16	13	126
Łosie	7154	100	0	0	122	Sucha	9521	100	0	0	103
Łosie	7155	75	16	9	122	Sucha	9523	89	2	9	103
Łosie	7156	77	16	7	122	Sucha	9524	100	0	0	103
Łosie	7157	100	0	0	122	Sucha	9525	100	0	0	103

Forest District	*PT* No.	The share of wood			Age	Forest District	*PT* No.	The share of wood			Age
		S	*D*	*U*				*S*	*D*	*U*	
		[%]			[years]			[%]			[years]
Łosie	7158	100	0	0	122	Sucha	9526	86	5	9	103
Łosie	7159	73	16	11	122	Ujsoły	2956	72	22	6	157
Łosie	7160	97	0	3	122	Ujsoły	5491	80	9	11	108
Nawojowa	4160	89	1	10	148	Ujsoły	5496	70	17	13	148
Nawojowa	4161	100	0	0	148	Ustrzyki D.	4249	100	0	0	128
Nawojowa	4162	92	2	6	128	Ustrzyki D.	4250	70	18	12	128
Nawojowa	4163	100	0	0	128	Ustrzyki D.	4251	56	27	17	128
Nawojowa	4164	83	6	11	128	Ustrzyki D.	6218	88	1	11	107
Nawojowa	4165	69	7	24	128	Ustrzyki D.	6219	89	4	7	107
Nawojowa	4166	100	0	0	128	Ustrzyki D.	6220	78	12	10	112
Nawojowa	4167	63	33	4	128	Ustrzyki D.	6221	100	0	0	112
Nawojowa	7161	95	0	5	109	Ustrzyki D.	6222	100	0	0	112
Nawojowa	7162	92	0	8	119	Ustrzyki D.	6223	79	8	13	112
Nawojowa	7163	100	0	0	129	Ustrzyki D.	6224	97	0	3	112
Nawojowa	7164	86	3	11	134	Ustrzyki D.	6225	86	10	4	112
Nawojowa	7165	93	0	7	134	Ustrzyki D.	6226	88	1	11	107
Nawojowa	7166	100	0	0	114	Ustrzyki D.	6227	56	35	9	91
Nawojowa	7167	90	3	7	114	Ustrzyki D.	6228	100	0	0	91

B. Norway spruce

Forest District	*PT* No.	The share of wood			Age	Forest District	*PT* No.	The share of wood			Age
		S	*D*	*U*				*S*	*D*	*U*	
		[%]			[years]			[%]			[years]
Nowy Targ	5303	100	0	0	134	Wisła	5187	100	0	0	141
Nowy Targ	5306	69	15	16	134	Wisła	5193	72	10	18	141
Nowy Targ	5307	100	0	0	134	Wisła	5197	87	3	10	141
Nowy Targ	5325	100	0	0	124	Wisła	5198	100	0	0	141
Nowy Targ	5332	65	23	12	119	Wisła	5201	73	20	7	136
Nowy Targ	7991	100	0	0	152	Wisła	5207	100	0	0	136
Nowy Targ	7992	45	47	8	152	Wisła	5214	100	0	0	136
Nowy Targ	7993	59	27	14	152	Wisła	5215	89	5	6	136
Nowy Targ	7994	86	0	14	-	Wisła	5216	81	7	12	136
Nowy Targ	7996	100	0	0	152	Wisła	5219	100	0	0	136
Nowy Targ	7997	63	17	20	152	Ujsoły	5483	68	12	20	128
Nowy Targ	7998	100	0	0	117	Ujsoły	5484	100	0	0	128
Nowy Targ	8200	100	0	0	117	Ujsoły	5485	62	28	10	128

Forest District	*PT* No.	The share of wood			Age	Forest District	*PT* No.	The share of wood			Age
		S	*D*	*U*				*S*	*D*	*U*	
		[%]			[years]			[%]			[years]
Nowy Targ	8201	83	0	17	-	Ujsoły	5487	69	15	16	128
Nowy Targ	8202	86	2	12	-	Ujsoły	5492	74	10	16	168
Nowy Targ	8203	100	0	0	-	Ujsoły	5493	100	0	0	168
Nowy Targ	8205	55	24	21	-	Ujsoły	5494	100	0	0	168
Wisła	92	100	0	0	149	Ujsoły	2956	82	7	11	-
Wisła	2928	100	0	0	142	Ujsoły	2957	65	26	9	-
Wisła	2930	100	0	0	137	Ujsoły	5495	91	0	9	148
Wisła	5177	82	7	11	141	Ujsoły	5471	100	0	0	-

solid wood proportions ranged from 80 to 90% (Table 1). In the case of silver fir, the highest average percentages of solid wood in the tomogram were observed in the Forest Districts (FDs): Nawojowa (90.5%) and Sucha (92.4%), whereas the lowest were observed in FDs: Gromnik (79.8%), Stuposiany (78.5%) and Ujsoły (74%, yet the latter FD was represented by only three plus trees). The highest percentage of Norway spruce solid wood was observed in FD Wisła (91.7%). The differences between the forest districts with regard to solid wood in the tomogram were not statistically significant, both for silver fir ($F = 1.698$; $p = 0.099$) and Norway spruce ($F = 1.006$; $p = 0.375$). The largest differences in terms of butt rot incidence and damage extent were observed between plus trees growing within the area of individual forest district. Considerable differences were also observed between trees in a given stand, representing similar age and growing under comparable site conditions (e.g., silver fir plus trees no. 6731 and 6732 in FD Bircza; Norway spruce plus trees no. 7991 and 7992 in FD Nowy Targ).

The average proportion of solid wood in the tomogram decreased with age of tree (Fig. 1). This relationship was statistically significant in silver fir ($F = 4.749$; $p = 0.011$). Considerable differences were found between the youngest (1) and oldest (3) silver fir groups ($p = 0.008$). Differences between Norway spruce plus trees were not statistically significant ($p = 0.779$).

4. Discussion

The plus trees examined were affected by butt rot to different degrees. The proportions of damaged wood on the tomograms ranged from 0% to 38% in silver fir and 0% to 47% in Norway spruce. In comparison to the results of sonic tomography studies conducted in old silver fir and Norway spruce stands (Chomicz 2013; Niemtur et al. 2014), a considerable share of healthy or slightly damaged plus trees, as well as a high proportion of solid wood were observed in the tomogram under the conditions of the present study. Niemtur et al. (2014) investigated butt rot incidence in 15 silver fir stands under protection in Poland's national parks and nature reserves. In more than 100-year-old Carpathian stands (6), the share of silver firs not having butt rot (100% of solid wood on the tomogram) ranged from 0–10% of the total number of examined trees, and the average percentage of solid wood on the tomogram ranged from 58%–86%. Moreover, in 36 of the 180 silver fir specimens examined, butt rot was observed in more than half of the tomogram area (solid wood share was lower than 50%). Hence, in the present study, silver fir plus trees, that were investigated with the use of sonic tomography, showed comparatively better health condition. The share of silver fir specimens not affected by butt rot, assessed through analogous methodology that was used by Niemtur et al. (2014), was 24% of all the plus trees examined, and the average proportions of solid wood on the tomogram ranged from 74% to 92% (Table 2A). At the same time, there were no trees found with butt rot greater than one-half of the cross-section (the least share of solid wood observed on the tomogram was 53%; less than 60% share of solid wood on the tomogram was observed only in 6 of 110 silver fir specimens examined). In the case of Norway spruce, the results of the study conducted by Chomicz (2013) can be used as reference. In this study, the data was obtained on butt rot incidence in 12 Carpathian Norway spruce seed stands (100–170 years old). The observed Norway spruce specimens were affected by butt rot at different levels, and the proportion of trees with more than 6% damaged wood in the tomogram ranged from 47% to 87% of the total numbers of trees in the seed stands under the study. In the group of 360 inspected trees, the share of damaged wood in the tomogram ranging from 25% to 50% was recorded in 78 specimens, and 10 trees showed more than 50% damage. On the other hand, the average proportion of damaged wood

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Table 2. The share of solid (*S*) and damaged (*D*) wood on the tomograms

A. Silver fir

Forest District	Average share of wood [%]	
	S	*D*
Bircza	81.3	8.0
Gromnik	79.8	12.2
Lesko	83.7	8.1
Łosie	87.2	7.5
Nawojowa	90.5	3.2
Piwniczna	81.4	6.2
Stuposiany	78.5	12.9
Sucha	92.4	2.5
Ujsoły	74.0	16.0
Ustrzyki D.	84.8	8.3
Fir	84.7	7.4

B. Norway spruce

Forest District	Average share of wood [%]	
	S	*D*
Nowy Targ	83.0	9.1
Wisła	91.7	3.7
Ujsoły	82.8	8.9
Spruce	85.9	7.3

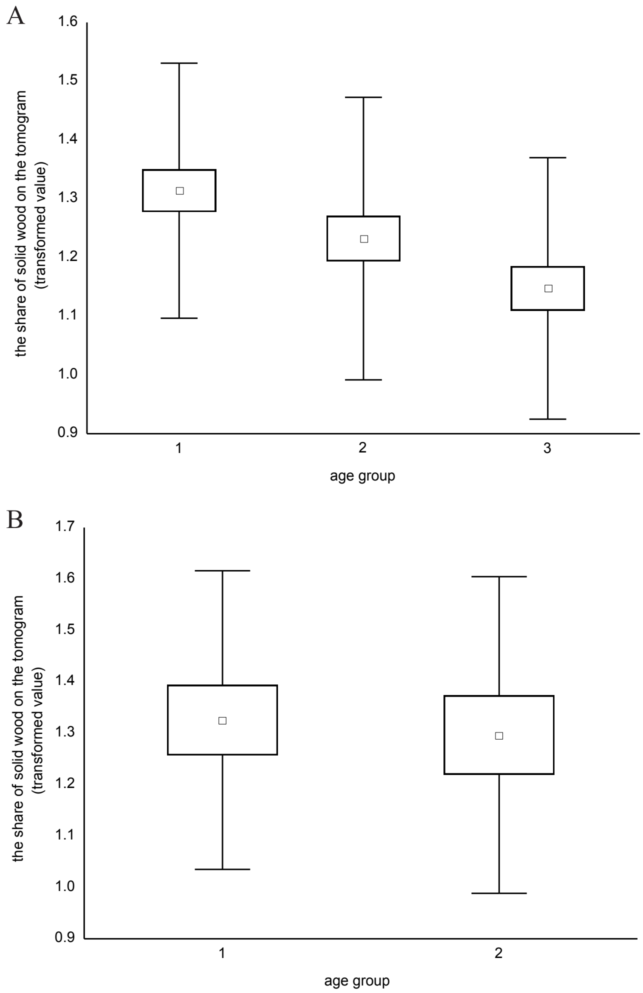

Figure 1. The average share of damaged wood on the tomogram in age groups of plus trees of A. Silver fir, B. Norway spruce (tag means the average, box – the standard error, whiskers – the standard deviation)

on the tomogram per Norway spruce stand ranged from 11% to 27%. In the present study, the share of Norway spruce plus trees affected by butt rot, assessed in the analogous way, was 38%, and only four Norway spruce trees out of the 42 investigated showed more than 25% damaged wood in the tomogram. Furthermore, butt rot higher than 50% was not recorded in the cross-section of any tree. The average percentage of damaged wood on the tomogram in individual forest districts under the study ranged from 4% to 9% (Table 2B).

The comparisons presented above indicate that the plus trees investigated in the present study were in better than average health condition with regard to butt rot occurrence. This confirms appropriate selection of plus trees, which by definition should be vigorous and in good physical condition (DGLP 2013). However, it must be noted that different levels of butt rot development were observed in quite a few plus trees examined in the present study (butt rot damage was observed on tomograms of 63% silver fir plus trees and 45% Norway spruce plus trees). At the same time, provided that wood decay processes are of hidden nature, this information is not currently included in the national register of forest basic material.

Silver fir and Norway spruce plus trees were similarly affected by wood decay in the butt part of the stem. As a matter of fact, it was observed that there were a few more Norway spruce trees not affected by butt rot when compared to silver firs (Table 1). However, one has to bear in mind that the results on Norway spruce were concluded based on a smaller sample, which was determined by the number of plus trees present in the study area (all of them were included in the study). Lately, a considerable number of Norway spruce plus trees have died, likewise many stands of this species affected by forest decline on large areas of Beskids. It is possible that, the dead Norway spruce specimens had been affected by butt rot and the investigated plus tree specimens represented a population with a superior health status. It should be emphasised that the differences observed between silver fir and Norway spruce trees with regard to butt rot incidence were not statistically significant.

Also, no statistically significant differences were found between the forest districts with regard to butt rot incidence. Hence, it was shown that there was no relation between butt rot incidence and stand geographic situation along the east–west axis (the Bieszczady Mts. – Silesian Beskids). No relationship between butt rot frequency and spatial stand distribution was observed by Niemtur et al. (2014) during a sonic tomography study carried out in selected national parks and reserves on silver firs under protection.

It was observed that the incidence of butt rot in Norway spruce and silver fir trees increased with the age of the tree (Fig. 1). In the case of silver fir, the proportion of solid wood on the tomogram was considerably greater in the youngest trees compared to oldest trees. The lack of statistically significant differences between the age groups of Norway spruce can be explained by lesser difference in age of Norway spruce specimens examined when compared to those of silver fir (the age of Norway spruce plus specimens ranged from 116 to 166 years and that of silver fir – from 91 to 158 years). Also, the number of trees of a given tree species that were statistically tested was different (information on tree age was available for 26 Norway spruces and 110 silver firs, Table 1). However, it should be noted that, in the present study, tree age was not determined based on precise measurements (tree-ring dating in samples obtained using the Pressler drill), but was evaluated at the time of plus tree selection. Inconsistency of tree age data could lead to underestimation of tree age effects on abundance of butt rot in the plus trees examined.

Enhancement of butt rot incidence in aging forest stands has been reported by several authors (Bruchwald 1984; Krzan 1985; Rymer-Dudzińska 1986; Bernadzki 2003; Chomicz, Niemtur 2008; Chomicz 2013). Studies carried out in Finland allowed for the conclusion that butt rot problem arises in Norway spruce stands that were less than 100 years old, and probably concerns all the trees reaching age 300–400 years (Norokorpi 1980). In view of the latter, it can be stated that butt rot, in general, affects old trees and is associated with the progress of natural wood decomposition processes. There is a strong likelihood that trees absolutely resistant to wood rot caused by fungal activity do not exist, and with time each tree will decay. Nonetheless, research results show high variability between the specimens of Norway spruce and silver fir in terms of decay rates. In view of economic and ecological aspects of forest management, it makes a big difference if the tree starts to decay in the age of 100 or 160 years. This issue has currently become more and more vital in the context of the role of forests in reduction of carbon dioxide in the atmosphere. Research results indicated that trees of bigger size absorb carbon at higher rates (Stephenson et al. 2014), thus old stands could accumulate more carbon in comparison to younger ones (Luyssaert et al. 2008). At the same time, butt rot, which affects aging trees, is conjoined with carbon dioxide production, which is released during the process of decomposition of wood chemical compounds (Sierota 2012). Thus, the later the tree is infected by butt rot, the longer and more effectively it plays a role of carbon storage.

Considerable differences were found between individual trees with regard to susceptibility to butt rot. Same age trees growing under similar site conditions (in the same forest management unit) showed different levels of butt rot. The reasons behind varied resistance to butt rot, as well as earlier or later development of fungal decay (susceptible trees and resistant trees, respectively), have not been yet fully understood. Stronger resistance to butt rot can be a result of determined genetic wood features, or else – the effect of suitable external factors (e.g., better site conditions at a micro-scale; better quality of rhizosphere organisms, including myccorhizas; no mechanical damages to the tree - also in the past). In future research, special attention should be paid to the oldest plus trees in which wood has not decayed. First, vegetative progeny of such trees should be examined in seed plantations. Clones of the trees examined in the present study are probably too young to show variability with regard to a level of butt rot disease development. However, there exists a possibility that the clones of plus trees with no signs of wood decay, evaluated with the use of sonic tomography, have some features predisposing them to show lesser susceptibility to butt rot in the future, when compared to the progeny of other trees. Such features can concern the general health status or increment capability, and also physical and chemical wood properties. If this hypothesis is confirmed, wood resistance to butt rot could be linked to genetic mechanisms, since the clone shares the same genotype with its parent tree. Then, the next step could be a study on generative progeny of plus trees, so as to better understand a mechanism of inheritance of traits associated with butt rot resistance.

5. Summary and conclusions

- Butt rot at different developmental stages was observed in great part of the studied plus trees. Silver fir trees with damaged wood on the tomogram constituted 63% of the total number of examined specimens and those of Norway spruce constituted 45%.
- Plus trees showed better than average health condition with regard to butt rot incidence. There are noteworthy si-

zeable proportions of healthy or slightly damaged trees, as well as high share of solid wood on the tomograms.

- Silver fir and Norway spruce plus trees were similarly affected by wood decay in the butt of the tree trunk.
- No relationship between butt rot frequency and tree geographical situation along the east-west axis was observed (no statistical differences were found between the forest districts studied with regard to butt rot incidence in plus trees).
- Butt rot advancement increased with age of plus trees, both in silver fir and Norway spruce.
- Considerable variability of butt rot susceptibility was observed between individual tree specimens.
- The reasons behind butt rot resistance have not yet been fully understood. In further research, attention should be paid to the oldest plus trees with no decay symptoms. In seed plantations, vegetative progeny of these trees should be investigated first.

Conflict of interest

The authors declare no conflicts of interest.

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Authors' contribution

E.Ch-Z. – manuscript conception, sonic tomography measurements, preparation of the results, manuscript writing; S.N. – research conception; M.K., S.A. – sonic tomography measurements.