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ORIGINAL RESEARCH ARTICLE

Occurrence of the silver fir (*Abies alba* Mill.) butt rot in protected areas

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Abstract. The aim of the study was to analyse butt rot incidences in silver fir stands of selected nature reserves and national parks. The study included 11 stands in Carpathian forests and for comparison 4 stands outside the Carpathians. To identify butt rot in fir trees, we used the non-invasive method of acoustic tomography. We tested 30 randomly selected fir trees in each of the 15 stands using Picus Sonic tomography to determine butt rot occurrence and to assess the proportion (%) of healthy wood in cross-sections of the tree trunk. The results indicate significant differences in the frequency of butt rot in silver fir at the individual level as well as the population level. This variability in frequency was not dependent on geographical location of the investigated stands.

Key words: silver fir, butt rot, nature reserve, national park, acoustic tomography, Picus Sonic, Carpathians

1. Introduction

Silver fir *Abies alba* Mill. is one of the main forest-forming tree species in the Carpathian region. It holds the second position after the common beech with regard to the area covered and standing volume (Niemtur 2007). In 2006, forest stands with silver fir dominance, typical for the Carpathians landscape, covered app. 21% of the area of the Carpathians in Poland. This indicates a distinctive decrease with comparison to 1967, when fir stands grew on app. 28.3% of the area. In the 1960s and 1970s, accelerated dieback of silver fir stands occurred in the Carpathians as a result of combined negative effects of biotic and abiotic factors (Zięba 2010).

After their perilous phase, at the present time, silver fir stands indicate visible symptoms of recovery in terms of regeneration and development. All this goes to show that in the future, the importance of silver fir will increase, also because of widespread dieback of spruce stands and their all-encompassing reconstruction into mixed stands with a considerable share of silver fir (Niemtur 2007; Jaworski, Pach 2014).

In managed forests, even though silver fir trees grow slowly in the first class of age (1–20 years), they form bulky volume stands in mature phase. Silver fir trees produce larger timber volume than that of pine trees, and given appropriate site conditions, fir production can be even higher than that of Norway spruce (Dobrowolska 1999). Stand productivity is associated with the quality of timber obtained. Silver fir timber reminds spruce in terms of the look and technical features, and therefore, it can be used for same purposes as that of spruce (Surmiński 1983). However, in spruce stands, big timber losses have been observed due to wood rot occurring regularly in the most valuable bottom part of the trunk. Wood decay processes progress significantly with stand age (Norkorpi 1979; Bernadzki 2003).

The susceptibility of Norway spruce *Picea abies* (L.) Karst. to wood decay caused by fungi is commonly known, and thus the majority of studies on butt rot have been focused on this species (Norokorpi 1979; Stenlid, Wästerlund 1986; Krzan 1985; Mattila, Nuutinen 2007; Kohnle, Kändler 2007). On the other hand, the significance of butt rot problem in silver fir has not been ad-

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equately recognised. In subject literature, a number of fungi have been reported as the prospective cause of wood decay in silver fir. However, there is a lack of information on the extent of damage caused by fungal activity in silver fir stands. In comparison to Norway spruce, there has been reported lesser vulnerability of silver fir to wood decay (Kohnle, Kändler 2007). Quite the opposite, the results of the study carried out with the use of sonic tomography in managed forests of the Żywiec and Silesian Beskid indicated that butt rot problem concerned spruce and fir trees to a similar degree (Niemtur et al. 2013).

Taking into consideration the lack of tree stumps in unmanaged forests, analysis of butt rot frequency in these areas have to be performed on standing trees. Up-to-date studies on standing trees have been essentially based on examination of core samples extracted at breast or root collar height (Krzan 1985). The method involves mechanical intrusion inside living tree tissues and, consequently, can add to disease spreading. Furthermore, it has been estimated that core sampling at breast height allows for identifying only 50% of real pathogen damages (Stenlid, Wästerlund 1986). In the protected areas, such as national parks and nature reserves, butt rot damage assessments involve avoiding destructive research methods and can be performed by means of a non-invasive procedure with the use of sonic tomography.

The aim of the present study is to identify in selected national parks and nature reserves, silver fir individual trees or stands representing low susceptibility to butt rot. The results obtained can serve as preliminary data for further studies on possibilities of breeding silver fir genotypes less vulnerable to fungal pathogens that cause butt rot.

2. Methods

Research plots

The study was carried out in the years 2010–2013 in silver fir stands or those with prevailing silver fir share. In the Carpathian natural-forest region, there were selected tree stands in Gorce National Park and in 10 nature reserves as representative for the whole mountain range in the region – from the Żywiec Beskid Mts. (reserves Oszast and Śrubita) to the Bieszczady Mts. (reserves Hulskie and Sine Wiry) (Fig. 1). Besides, the study comprised silver fir stands situated in the National Parks: Karkonosze, Góry Stołowe and Świętokrzyski. Additionally, there was included silver fir stand in Jata nature reserve situated beyond silver fir natural range (Fig. 1). Characteristics and location of the research plots are presented in Fig. 1 and Table 1.

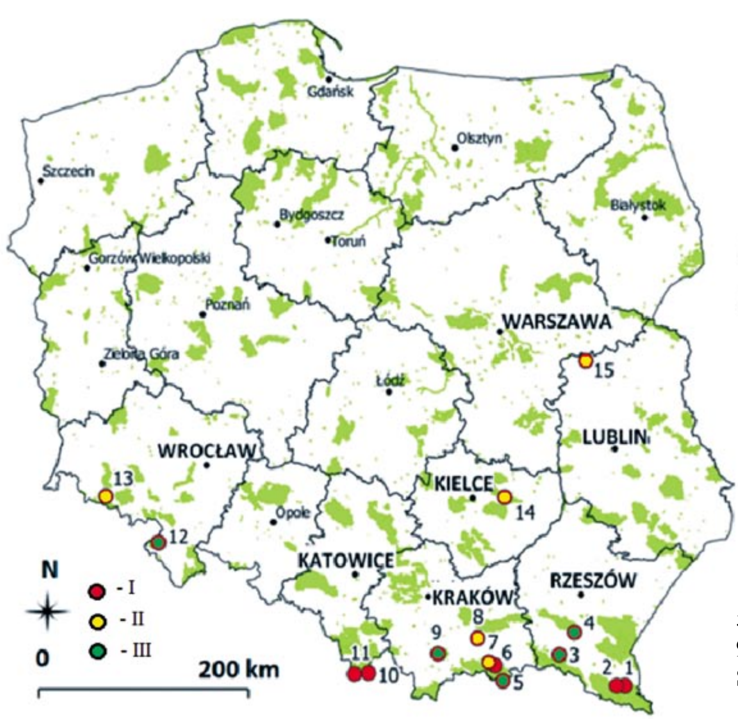


Figure 1. Location of research plots I, II, III – plot evaluation categories (see Results)

1 – Hulskie, 2 – Sine Wiry, 3 – Cergowa G., 4 – Kretówki, 5 – Hajnik, 6 – Uhryń, 7 – Barnowiec, 8 – Białowodzka G., 9 – Gorce NP, 10 – Oszast, 11 – Śrubita, 12 – Góry Stołowe NP, 13 – Karkonosze NP, 14 – Świętokrzyski NP, 15 – Jata

Table 1. Characteristics of research plots

No	Reserve/National Park	Height a.s.l.	Exposure	Coordinates		Main species of stands	Area ha	Year of creation
1	Hulskie	800	W	49°15′20.9″N	22°33′11.4″E	Bk, Jd	189.87	1983
2	Sine Wiry	750	SW	49°15′41.4″N	22°25′28.7″E	Bk, Jd	450.49	1987
3	Cergowa G.	650	N	49°32′7.8″N	21°42′17.2″E	Bk, Jd, Jw	61.35	1963
4	Kretówki	400′	NE	49°42′50.7″N	21° 54′45.1″E	Bk, Jd	95.27	1959
5	Hajnik	700	SE	49°19′50.54″N	20°57′38.57″E	Jd	16.9	1974
6	Uhryń	750	NW	49°27′44″N	20°51′32″E	Bk, Jd	16.52	1957
7	Barnowiec	860	NE	49°29′17.8″N	20°46′20.6″E	Bk, Jd, Jw	21.61	1924
8	Białowodzka Góra	400	NE	49°41′23″N	20°37′53″E	Bk, Jd	67.74	1961
9	Gorce NP	750	SW	49°34′28″N	20°05′39″E	Jd	-	1981
10	Oszast	925–1147	NE	49°25′54″N	19°11′16″E	Bk, Jd, Św, Jw	48.8	1971
11	Śrubita	780–960	N	49°24′22″N	19°0′42″E	Bk, Jd	25.86	1958
12	Góry Stołowe NP	720	flat	50°29′32″N	16°19′28″E	Jd	-	1993
13	Karkonosze NP	500	N	50°50′16″N	15°38′50″E	Bk, Jd	-	1959
14	Świętokrzyski NP	570	S	50°53′39″N	20°54′37″E	Jd	-	1924
15	Jata	170	flat	51°57′53.9″N	22°12′41.6″E	Jd	1116.8	1933

Notes: Bk – *Fagus sylvatica* L., Jd – *Abies alba* Mill., Św – *Picea abies* (L.) Karst, Jw – *Acer pseudoplatanus* L.

Tomographic evaluations

Butt rot incidence in tree trunk cross-section was determined by means of the Picus Sonic Tomograph (Argus Electronic, Rostock, Germany). The apparatus records differences in the speed of sound wave transmission in wood depending on its features, and in a non-invasive way collects information on rot occurrence and infection size in tree trunk cross-section. Detailed description of the Picus Sonic Tomograph and the principles of how it works are available at the producer's webpage: http://www.argus-electronic.de.

In each tested stand, tomographic evaluations were carried out on 30 randomly selected silver fir trees growing in the immediate vicinity. Concurrently, tree height and diameter at breast height (DBH) were measured, and tree age was determined using Pressler increment borer.

Tomographic data were collected at the height of 10 cm above the ground level. In accordance with the producer's manual, on trunk circumference line, there were marked 8–10 measuring points depending on tree thickness. The point number 1 was always established at the northern side of the trunk. At each point, there was introduced an electrode that contacted trunk wood, and then the electrode was magnetically contacted with a sensor. At each measuring point, three sonic impulses were induced with the use of a hammer (version Lite). The geometry of trunk cross-section was projected using appropriate distances between the measuring points, determined using a Picus caliper. Sensor information was radio transmitted to Picus Expert computer software (version Q72), which generated tomograms of silver fir trunk cross-sections.

Tomogram examinations

A tomogram gives an image of tree trunk cross-section at the point of measurement. Different colours visible in the tomogram indicate different stages of wood decay caused by the activity of pathogenic fungi. The colours observed in the images obtained from each tree allowed for distinction of three wood categories: healthy (with no signs of decay) – dark and light brown colour, damaged wood – blue and purple, and unknown – green. The percentage of each category in the total area of cross-section was automatically computed by Picus Expert software.

Based on the results of tomogram examinations in 30 silver fir trees in each stand observed, the mean share

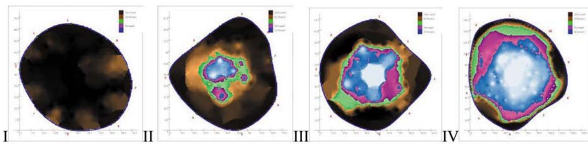


Figure 2. Tomograms of firs in health classes: Class I – 100% of undamaged wood; class II – 76–99% of undamaged wood; class III – 50–75% of undamaged wood; class IV – <50% of undamaged wood

of healthy wood and the coefficient of variation for this feature were determined. Altogether, tomograms of 450 silver fir trees from 15 stands were analysed.

In line with tomogram results, tested trees were assigned to four classes of wood health: I class – 100% of healthy wood; II – 76–99%; III – 50–75%; IV – less than 50%. The examples of tomograms presented in Fig. 2 demonstrate decay ranges observed in the health classes.

Designed for valuation of silver fir trees on different areas studied, there was used tree scoring system for the specimens assigned to the above health classes: when in class I – 10 points, II – 7 points, III class – 4 points, and IV – 0 points. The total score of 30 silver fir trees represented the stand damage extent in a given study area.

Statistical analyses

Investigated fir stands were compared in terms of the average (for 30 trees) share of healthy wood on the tomogram. Mean comparisons were carried out with the use of one-way analysis of variance (ANOVA). Post-hoc analysis was performed using Tukey's tests. Based on the results obtained, determination of homogeneous groups were made, that is, silver fir stands not significantly different with regard to a given feature.

Analogous comparisons were performed for the determined tree health classes. Taking into account different numbers of trees in the classes (class I – 73, II – 159, III – 162, IV – 56 trees), the differences between the mean values were tested with the use of the Kruskal–Wallis test (nonparametric equivalent for one-way ANOVA). There were determined statistically significant differences between the classes with regard to the mean values of: healthy wood share determined in the tomogram, tree age and DBH. Post-hoc analysis of mean ranks for all samples was performed with the use of multiple comparison tests with computed Z statistics as described by Siegel, Castellan (1988).

All tests were performed using the tools available in Statistica 9 software.

3. Results

The tomograms obtained indicated considerable variability of butt rot frequency observed in the analysed stands (Table 3). Differences were notable both at an individual tree level in the groups of 30 silver fir trees and between the 15 stands tested. The largest differences with regard to the number of trees with decaying wood were observed in Uhryń (Table 2, Fig. 3A) and in Gorce National Park (Table 2, Fig. 3B).

Large differences were also found between silver fir trees in nature reserves Uhryń and Hajnik – also situated in the Beskid Sądecki Mts. (Leluchowskie Mts.) In Hajnik, no damage was observed in 10 silver fir trees (100% of healthy wood in trunk cross-section), whereas in Uhryń, among 30 tested trees, only 1 showed no symptoms of butt rot infection (Table 2, Fig. 3) – even though site conditions were similar in both nature reserves. The results of tree valuation in Uhryń showed the lowest score when compared to the rest of the areas analysed, that is, 98 points (Table 2); while in Gorce National Park, the trees tested scored 266 points, and in Hajnik – 213 points. An important factor was the age of examined silver fir trees, which on average ($n = 30$) was: Uhryń – 135 years, Hajnik – 79 years and Gorce National Park – 99 years. However, tree age as a decisive factor for the extent of butt rot infection in silver firs does not clarify why the firs examined in nature reserves Oszast and Śrubita (30 specimens in each) scored the same number of points – 121. These reserves were considerably different in terms of silver fir age – 109 and 150 years, respectively (Table 3).

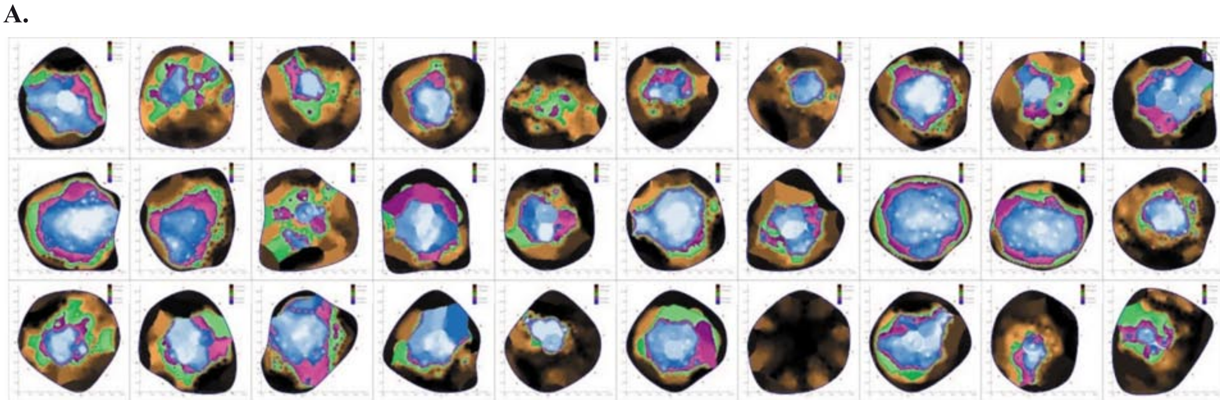
The results of tree valuation carried out based on the scoring system showed no relationship between butt rot infection intensity in the wood of silver fir and distribution of silver fir stands in the nature reserves and national parks observed (Fig. 4).

The stands examined differed significantly with regard to the mean percentage share of healthy wood evaluated in tree cross-section tomograms (ANOVA $F = 8489.470$; $p < 0.000$). The largest difference was observed between silver fir trees in Uhryń, the most damaged by butt rot, and the Gorce National Park, the least affected by rot (Table 3, $p < 0.000$). Post-hoc tests allowed for the distinction of four homogeneous groups with reference to the stand percentage mean share of healthy wood in silver fir trunk cross-section. The groups comprised silver fir stands from different locations in the Carpathian region and also those from the areas outside the region. The differences reliant upon

Table 2. Tree valuation scores in studied silver fir stands

No	Reserve / National Park	Number of trees in health classes:				Sum of points
		I 100% 10 pts	II 75–99% 7 pts	III 50–76% 4 pts	IV <50% 0 pts	
1	Hulskie	0×10	11×7	12×4	7×0	125
2	Sine Wiry	1	6	14	9	108
3	Cergowa Góra	3	23	4	0	207
4	Kretówki	8	13	9	0	207
5	Hajnik	10	11	9	0	213
6	Uhryń	1	4	15	10	98
7	Barnowiec	2	10	12	6	138
8	Białowodzka G.	3	10	16	1	164
9	Gorce NP	23	4	2	1	266
10	Oszast	1	9	12	8	121
11	Śrubita	0	7	18	5	121
12	Góry Stołowe NP	7	18	5	0	216
13	Karkonosze NP	4	7	16	3	153
14	Świętokrzyski NP	8	13	3	6	183
15	Jata	2	13	15	0	171
	Total	73	159	162	56	

A.



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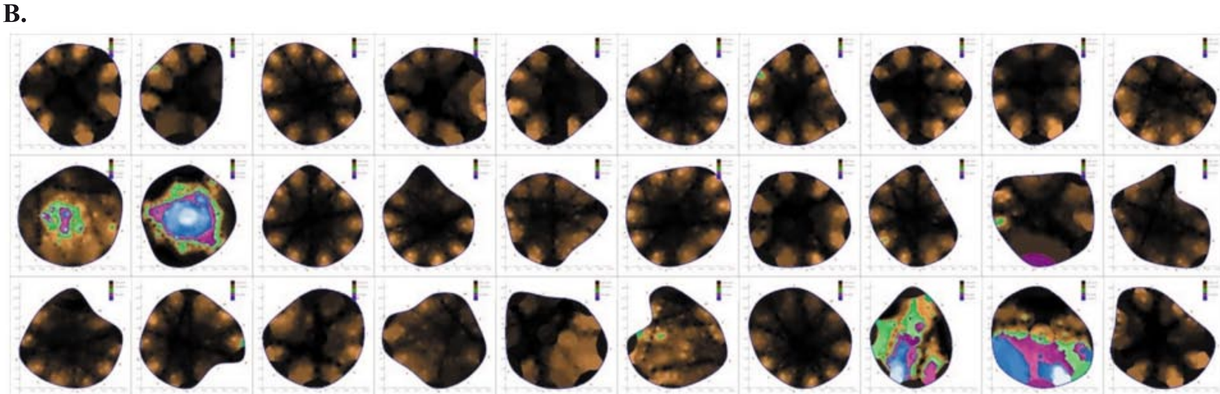

Figure 3. Tomograms of silver fir trees examined in: A. – Uhryń Reserve, B. – Gorce National Park

Table 3. Mean percentage of healthy wood on tomograms of 30 silver firs, DBH and age of examined trees

Reserve / National Park	Tree age	Diameter at breast height		Mean % share of healthy wood on 30 tomograms						R_{d_zp}
		d_{30} [cm]	Wz [%]	m_{30} [%]	Wz [%]	homogeneous groups Tukey HSD test				
I.										
Uhryń	135	75.4	30.3	58.2	33.7	X				**-0.669**
Sine Wiry	92	57.3	24.2	61.5	26.7	X	X			**0.377**
Oszast	109	59.5	34.5	61.7	32.9	X	X			-0.205
Śrubita	150	64.8	25.0	62.6	27.9	X	X			**-0.644**
Hulskie	124	69.0	31.0	63.5	33.3	X	X			**-0.366**
II.										
Barnowiec	145	73.5	25.2	67.7	27.1	X	X			**-0.341**
Karkonosze NP	95	44.5	24.1	72.1	26.3	X	X	X		**0.422**
Białowodzka G.	78	54.9	20.5	74.3	17.3		X	X		0.089
Świętokrzyski NP	121	58.2	38.1	74.8	33.14		X	X		**-0.436**
Jata	98	56.6	20.1	74.9	15.7		X	X		-0.032
III.										
Hajnik	79	59.1	23.1	84.0	17.9			X	X	-0.058
Kretówki	80	50.8	17.2	84.9	15.2			X	X	0.193
Cergowa G.	128	49.8	17.1	85.9	13.1			X	X	**-0.366**
Góry Stołowe NP	96	53.4	17.9	86.1	13.6			X	X	-0.212
Gorce NP	99	76.2	22.7	94.5	15.5				X	0.005

Notation: m_{30} –arithmetic mean (30 trees), Wz – coefficient of variation, R_{d_zp} – correlation coefficient of healthy wood percentage and DBH of 30 trees examined on experimental plots; I, II, III –stand evaluation categories as in Figure 1.

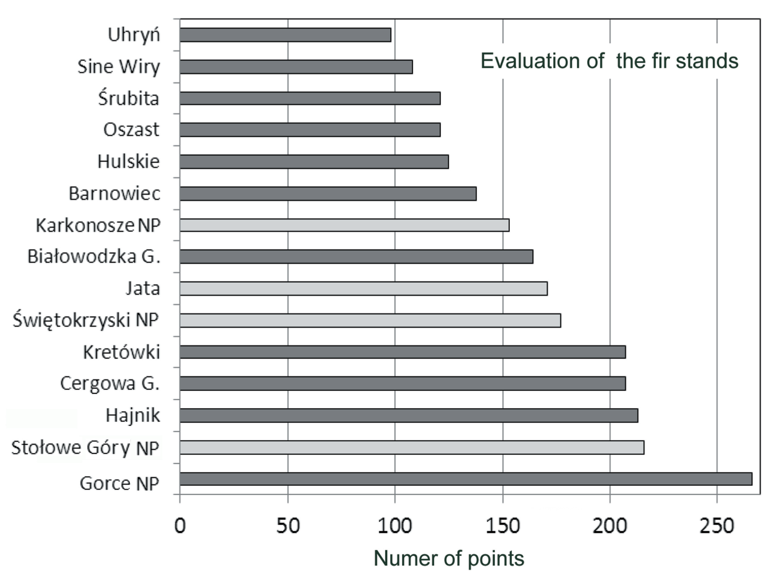

Figure 4. Evaluation of investigated stands in 11 nature reserves (marked darker) and 4 national parks.

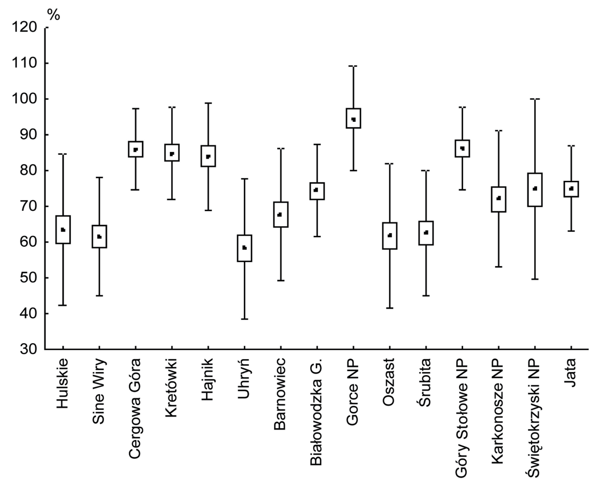

Figure 5. Percentage of healthy wood on tomograms: mean (tag), standard error (box), standard deviation (line segments)

stand geographical situation were not found, hence differentiation between the groups was indefinite (as a result, just three groups are presented in Fig. 1). Silver fir stands in the Carpathian region were not distinguishable from those in other regions (did not form a separate homogeneous group).

Even though no obvious trend was observed in the distribution of stands with analogous extent of butt rot infection, comparable damage amounts were noticeable in neighbouring stands, for example, those growing in nature reserves Hulskie and Sine Wiry or else Oszast and Śrubita (Fig. 4).

The correlation coefficients of the percentage of healthy wood in tree cross-section and tree DBH on a given area showed negative values and the relationships were statistically significant, however, only for silver firs older than 120 years. Younger trees did not show this kind of correlation or else – negative correlations as in the case of the Karkonosze National Park or Sine Wiry (Table 3).

Considerable differences in butt rot infection levels were observed in silver firs equally at a population (stand) level (Fig. 3 and 5) and between individual trees. Among 450 silver fir trees examined in 15 stands, there were observed 73 specimens showing no symptoms of decaying wood in their butts (I health class, Table 2) and 56 trees with one-half of wood in trunk cross-section affected by butt rot (IV health class, Table 2). Statistical analysis performed (Kruskal–Wallis test) showed, that trees in different health classes differed significantly with reference to: the age (H = 12.035; p = 0.007), DBH (H = 15.604; p = 0.001) and the percentage share of healthy wood (H = 303.399; p = 0.000).

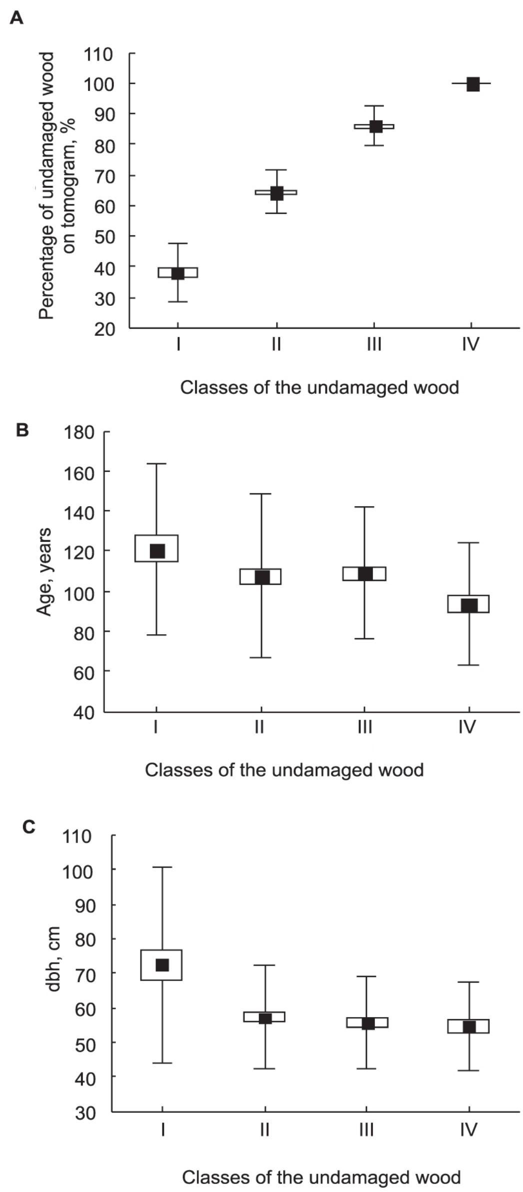

Figure 6. Percentage of healthy wood on tomograms (A), tree age (B) and DBH (C) in silver firs assigned to four health classes: mean (tag), standard error (box), standard deviation (line segments).

The differences in the percentage of healthy wood, mean tree age and mean DBH with reference to the health classes are presented below, in Fig. 6 A, B, C.

3. Discussion

In Poland, studies on butt rot frequency in silver fir trees growing within nature reserves and national parks have not so far been conducted on a wide scale. The present study comprises the first measurement trial to evaluate a range of butt rot occurrence in silver fir stands in advanced age.

The silver fir has been perceived as the 'ecological balance keeper' in our forests. This species is characteristic of good natural regeneration, its young growth stages are shade tolerant and it generally is receptive to silvicultural practices. The silver fir is superior for building multi-generation stands with differentiated structure, enhancing forest biodiversity. Besides representing ecological value, this tree species achieves high production results. It shows great adaptation capability and grows well even beyond its natural range (Jaworski et al. 1995; Dobrowolska 1999; Bijak 2010).

The importance of silver fir stands will increase in the future, taking into account large-scale dieback of spruce stands in mountainous regions, and also in view of currently carried out extensive conversion of spruce monocultures into mixed stands with substantial silver fir admixture (Jaworski, Pach 2014). Furthermore, in the context of ongoing climate changes, further decline of pine and spruce stands has been forecasted, whereas the silver fir has been listed among tree species capable of enduring changeable environment conditions (Kräuchi 1994; Ziemba 2010; Tinner et al. 2013; Jaworski, Pach 2014). Climate change will force adjusting tree species composition in reforestation areas, and consequently – the structure of future Carpathian tree stands. For the Carpathian Mts., there is predicted temperature increase by 2–4°C until the end of 21st century (IPCC 2013). Simultaneously, there are forecasted increased precipitation during the winter and decreased rainfall with irregular distribution in the vegetation season. At the same time, incidence of weather anomalies will grow, which will negatively affect ecosystems, especially in mountainous conditions (Gori 2013; Ciscar 2014).

Assuming the most precautious prediction by the Intergovernmental Panel on Climate Change (IPCC 2013), that is, average temperature increase by 2°C at the end of 2100, it can be adjudged that altitudinal zonation in the Carpathian Mts. described by Hess (1965) will be shifted up. Therefore, it is highly probable that vegetation layers will react in the same way, and that tree species now occurring in the lower parts of the mountains will find appropriate climate conditions for their development at higher elevations. For the silver fir, this may result in enhanced competition with deciduous tree species growing at lower elevations, mainly the common beech, and also an increased share in forests at higher elevations.

The results of the present study showed no clear trend in geographical distribution of silver fir stands with analogous extent of butt rot infection. Also, no differences in this regard were found between Carpathian silver fir stands and those with other Poland's silver fir provenances. This means that variability of butt rot occurrence is not reliant upon local conditions.

The age of the stands examined was the factor with the biggest effect on butt rot frequency. Increasing butt rot incidence and effectual advanced wood decomposition have been well documented for spruce stands (Norokorpi 1979; Krzan 1985; Bernadzki 2003; Chomicz, Niemtur 2008; Niemtur, Chomicz 2008; Niemtur, Chomicz 2009). According to Norkopi (1979), butt rot problem starts to develop in spruce stands less than 100 years of age and most probably concerns all 300–400 years old spruce trees. Bernadzki (2003) concludes his studies on old pine stands growing on lowlands that upholding trees in forests until old age increases significantly the risk of butt rot infection. The author estimated probability of butt rot incidence of about 30% in 120-year-old and 60% in 200-year-old stands. Similar relationships were observed in managed silver fir stands examined during preliminary studies with regard to stand age and butt rot infection carried out in the Forest District Ujsoły (Niemtur et al. 2013).

The results of earlier studies conducted in spruce stands (Niemtur, Chomicz 2008), and in three silver fir seed orchards within the area of the Forest Districts Węgierska Górka, Limanowa and Baligród (Niemtur et al. 2011) indicated that in more than 90% of examined older trees, there occur pathological changes in tree butts. At the same time, individual silver fir specimens with no traces of damage were found, notwithstanding their old age.

The question of varied tree susceptibility to fungal pathogens was discussed, for example, by Pautasso et al. (2005). The authors believe that this variability is a direct result of natural defense strategy undertaken by forest ecosystems. The occurrence of spruce clones with lower vulnerability to damage due to *Heterobasidion parviporum* was described by Rodriguez et al. (2009). Żołciak et al. (2006) state fungal disease spread in pine reforestation areas is much influenced by individual tree features since not all trees growing in vicinity of *Heterobasidion annosum* infected stumps are affected by this fungus. On the other hand, genetic variability in pathogens has been widely documented (Łakomy 2007; Zamponi 2007; van Diepen 2013).

Nature protection in the national parks and reserves is among others connected with *in situ* conservation of genetic resources of tree ecotypes with capability to adapt to wide-ranging mountainous conditions. These invaluable genetic resources are guarded within the protected areas, and being excluded from national programs on seed selection, in practice they are not used in silviculture of multifunctional forests. This is a great loss since the trees growing within protected areas often have unique features and their genotypes could enhance biodiversity in reconstructed forests. The issue concerns particularly endangered tree species and those introduced into forests in the Carpathian and Sudety Mts. as a result of spruce forest reconstruction or afforestation of calamity areas. The silver fir is a good example of tree species whose area share in mountainous forests is constantly growing as a result of artificial and natural regeneration (Przybylska, Ziemba 2007). Identification and collection of silver fir seeds less susceptible to fungal pathogens (Rodriguez et al. 2009) could enrich genetic pool of forest breeding material and improve silviculture of new forest stands or else advance reconstruction of old ones.

5. Conclusions

Regardless of geographical location of the stands examined, the age of silver fir trees was the key factor that determined the extent of tree infection by butt rot pathogenic fungi that cause trunk wood decay.

However, in the above age-infection relationship, the exceptions were observed, which indicated responsibility of other factors involved in butt rot spreading.

Explanation of reasons behind the differences in the percentage share of healthy wood in tree trunk cross-section observed between individual silver fir trees as well as at a level of the stand within the areas studied needs further research.

The study carried out within the areas of nature reserves and national parks allowed for examination of silver fir trees much older than those growing in managed forests. The results obtained indicated that protected trees could be more than ever useful, especially in the studies on valuable tree genotypes.

Acknowledgement

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Authors' contribution

S.N. – concept, manuscript preparation care, participation in fieldwork, E.Ch. – participation in fieldwork, statistical analysis, M.K. – participation in fieldwork.

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