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VARIABILITY OF THE SHARE OF HEARTWOOD ON THE STEM CROSS-SECTION OF DOUGLAS FIR (*PSEUDOTSUGA MENZIESII* VAR. *VIRIDIS* FRANCO) IN POLAND

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Abstract. This paper presents the results of investigation into the variability of the share of heartwood on the stem cross-section of Douglas fir in Poland. The research was conducted in Douglas fir stands in the IV and V age classes. The feature was analysed on increment cores taken from the trees at 1.3 m level from the base of the stem, in the N and S direction. The differences of the share of heartwood between Douglas firs of the V and VI age classes as well as between the trees growing in moderate and broken crown closure were not significant. No significant differences occurred between specimens of different vitality, either; however, the trend towards increasing the share of heartwood in weak trees with relation to normal and lush ones was noticeable. No significant correlations between the share of heartwood and crown parameters were noted. Three regions were distinguished in the territory of Poland: the southern and north-western ones, where Douglas firs have a higher share of heartwood on the stem cross-section, and the central-western one, where the share is lower.

Key words: Douglas fir, heartwood, Poland

INTRODUCTION AND AIM

The issues of timber preservation and protection are related to its natural durability, regarded as susceptibility to factors which damage timber. Among important factors which increase timber durability is the presence of coloured heartwood. In Poland, the economically significant coniferous species which form coloured heartwood are pine and larch. Considering an increasing demand of industry for timber along with the postulate of forest durability, more and more significance is being attached to the cultivation of fast-growing species, such as Douglas fir (*Pseudotsuga menziesii* var. *viridis* Franco), which has been cultivated in Poland for over a hundred years. The stock of heartwood on stem for fir and Douglas fir jointly in 2004, in the V and older age

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classes, amounted to about 2.5 mln m^3 [Leśnictwo 2005]. Expectedly, in the near future the harvesting of Douglas fir timber and its importance in timber industry are going to increase. The knowledge of variability of the share of heartwood in Douglas fir timber is going to have practical significance for timber protection and conservation.

The aim of the present study is analysis of variability of the share of heartwood on the stem cross-section of Douglas fir (*Pseudotsuga menziesii* var. *viridis* Franco) in Poland.

METHODS

Field work was carried out in 28 selected forest stands (Table 1). The selection criteria were: age, which could not be lower than 80 years, and the presence of several dozens of Douglas fir trees in a stand. In each stand, 30 trees belonging to the main stand (towering, dominant and co-dominant trees) were selected randomly [Wąsik 2006]. It was assumed that they should grow in sections with the largest share of Douglas fir; the micro-sites extreme with regard to topography and soil were disregarded. Such a method of tree selection was dictated by enormous differentiation of stand species composition and the spatial distribution of Douglas fir in a stand. On selected trees, measurements were taken of, among others, breast-height diameter, crown height, length and width as well as bark thickness. Moreover, tree vitality was assessed considering such features as crown size, needle loss and type of tree top. Each tree was qualified to one of three vitality groups: lush, normal or weak. From each of the first 15 trees measured, two increment cores were taken - on the northern and southern sides – by means of Pressler's borer.

On smoothed surfaces of the increment cores, the width of the zone of sapwood was measured exact to 1 mm. The calculation of the share of heartwood was based on the sizes of the surface of the stem cross-section under bark and of the surface of heartwood. The diameter of the stem under bark was the difference between the size of the breast-height diameter in the N-S direction and the sum of bark thickness in these two directions. The diameter of heartwood was calculated as the difference between the stem under bark and the sum of the width of the sapwood zones on the two increment cores taken from the timber.

The procedures following were applied in statistical analyses [Stanisz 1998, Statistica... 2004]. The accordance of empirical distributions with the normal distribution was assessed by means of Shapiro-Wilk's test; the uniformity of variance was assessed by means of Levene's test. The significance of differences between the average values of two trials whose distribution was in accordance with the normal one was verified using the t-Student test for independent trials and using U Mann-Whitney's test when the assumptions of the parametric test were not fulfilled. The significance of differences between the means for many trials whose distributions remained in accordance with the normal one were verified using the analysis of variance; in the case of the lack of accordance with the normal distribution – using Kruskal-Wallis' test.

The degree of interdependence of two variables was determined on the basis of Pearson's coefficient of linear correlation. For testing statistical hypotheses, the significance level $\alpha \leq 0.05$ was assumed.

Table 1. Site and stand characteristics and location of sample plots
Tabela 1. Lokalizacja oraz charakterystyka siedliskowo-drzewostanowa powierzchni badawczych

No. Lp.	Forest district, subdistrict, division Nadleśnictwo, leśnictwo, oddział	Altitude, exposure, relief Wysokość n.p.m., ekspozycja, rzeźba terenu	Douglas fir age Wiek daglezji	Species composition Skład gatunkowy	Site type STL	Soil type Typ gleby	Stand density Zwarcie
1	Tomaszów Lubelski, Hrebenne, 356c	200, ---, hilly – pagórkowaty	100	5 Db, 3 So, 1 Bk, 1 Dg	Lśw	brown acid – brunatna kwaśna	broken – przerywane
2	Krasiczyn, Bełwin, 101a	350-450, S-E, steep slope – stok stromy	107	8 Bk, 1 Md, 1 Dg	Lwyż	brown leached – brunatna wyługowana	moderate – umiarkowane
3	Dukla, Odrzykoń, 87b	400, S, slanting slope – stok pochyły	105	7 Dg, 2 So, 1 Jd	Lwyż	brown acid – brunatna kwaśna	broken – przerywane
4	Lesko, Manasterzec, 26a	400-450, S, slanting slope – stok pochyły	120	6 Jd, 1 So, 1 Md, 1 Bk, 1 Dg	Lwyż	brown acid – brunatna kwaśna	broken – przerywane
5	Sucha, Mosorne, 68y	600, N-W, gentle slope – stok łagodny	120	9 Dg, 1 So	LMG	brown podzolic – brunatna bielicowana	broken – przerywane
6	Ujsoły, Złatna, 59a	620-760, W, precipitous slope – stok spadzisty	100	10 Dg	LG	brown acid – brunatna kwaśna	broken – przerywane
7	Bardo Śląskie, Dębowina, 225g	450, N-E, precipitous slope – stok spadzisty	90	6 Dg, 3 Św, 1 Bk	LG	brown acid – brunatna kwaśna	broken – przerywane
8	Bystrzyca Kłodzka, Lasówka, 309c	720-750, S-E, gentle slope – stok łagodny	107	9 Dg, 1 Św	LMG	brown acid – brunatna kwaśna	broken – przerywane
9	Jugów, Ścinawka Dolna, 118f	420, W, slanting slope – stok pochyły	90	6 Dg, 3 Św, 1 Md	LMG	brown acid – brunatna kwaśna	moderate – umiarkowane
10	Kamienna Góra, Podlesie, 268d	580-680, E, steep slope – stok stromy	96	7 Dg, 3 Św	BMG	brown acid – brunatna kwaśna	broken – przerywane
11	Rybnik, Książnice, 102a	204-311, ---, flat – płaski	100	7 Dg, 2 Db, 1 Św	LMśw	ground gley, proper – gruntowo glejowa, właściwa	moderate – umiarkowane
12	Tułowice, Szydowiec, 151g	185, ---, even – równy	80	8 Dg, 2 Św	LMśw	brown acid – brunatna kwaśna	broken – przerywane
13	Oleśnica, Dąbrowa, 63j	200, ---, plan – równinny	100	6 So, 3 Dg, 1 Bk	Lśw	brown acid – brunatna kwaśna	moderate – umiarkowane
14	Lwówek Śląski, Gradówek, 308k, 308cx	300, W, slanting slope – stok pochyły	110	3 Św 3 Bk 2 Dg 1 Md	Lwyż	brown acid – brunatna kwaśna	moderate – umiarkowane
15	Jarocin, Cielcza, 180a	---, N, lowland undulating – nizinny falsity	96	9 Dg, 1 Db	LMśw	fawn, podzolic – płowa, bielicowana	broken – przerywane
16	Sława Śląska, Stare Strącze, 331l	87, ---, flat – płaski	86	7 Dg, 2 Św, 1 Db	Lśw	brown acid – brunatna kwaśna	broken – przerywane
17	Kościan, Olejnica, 256h	70-90, ---, flat – płaski	96	7 Dg, 2 Db, 1 So	LMśw	podzolic proper – bielicowa właściwa	broken – przerywane
18	Nowa Sól, Mirocin, 176h	95, ---, flat – płaski	88	4 Db, 3 Dg, 2 So, 1 Md	LMśw	brown podzolic – brunatna bielicowana	moderate – umiarkowane
19	Lubsko, Jeziory Dolne, 24i	86, ---, flat – płaski	115	5 Dg, 3 Db, 2 Bk	LMśw	fawn proper – płowa właściwa	moderate – umiarkowane
20	Rzepin, Kunowice, 190d	80, ---, even – równy	110	10 Dg	Lśw	brown – brunatna	broken – przerywane
21	Choszczno, Ziemomyśl, 883g	100, ---, even – równy	113	10 Dg	Lśw	brown podzolic - brunatna bielicowana	broken – przerywane
22	Międzyzdroje, Warnowo, 62f	10, ---, flat – płaski	117	10 Dg	LMśw	rusty, rusty-brown – rdzawa, rdzawo-brunatna	broken – przerywane
23	Sławno, Jarosławiec, 85c	120, ---, flat – płaski	115	10 Dg	LMśw	brown acid – brunatna kwaśna	broken – przerywane
24	Gdańsk, Renuszewo, 94c	146, ---, flat – płaski	120	8 Dg, 1 Bk, 1 So	Lśw	brown acid – brunatna kwaśna	moderate – umiarkowane
25	Łopuchówko, Wojnowo, 169c	86, ---, flat – płaski	103	6 Dg, 4 So	Lśw	brown leached – brunatna wyługowana	broken – przerywane
26	Miradz, Młyny, 109a	105, ---, flat – płaski	115	4 So, 3 Dg, 3 Db	LMśw	brown, proper – brunatna, właściwa	broken – przerywane
27	Lipka, Białobłockie, 153d, 153g	120, ---, lowland undulating – nizinny falisty	94	6 Dg, 4 So 9 Dg, 1 Bk	BMśw	rusty, rusty-brown – rdzawa, rdzawo-brunatna	broken – przerywane
28	Kwidzyn, Gonty, 237f	---, ---, lowland undulating – nizinny falisty	105	10 Dg	Lśw	fawn, proper – płowa, właściwa	broken – przerywane

The data come from management statements or plans of management of seed-producing stands.
Dane pochodzą z operatów urządzeniowych bądź planów zagospodarowania drzewostanów nasiennych.
Dg – Douglas fir, So – Scots pine, Bk – common beech, Św – norway spruce, Md – European larch, Db – oak, Jd – fir, Lśw – fresh broadleaved forest, LMśw – fresh mixed broadleaved forest, Lwyż - upland forest, LMG – mixed mountain forest, LG – mountain forest, BMG – mixed mountain coniferous forest, BMśw – fresh mixed coniferous forest.

RESULTS

The average share of heartwood on the stem cross-section for all the analysed trees was 70.4% (Table 2). The lowest average value – 53.0% was noted on a plot in Lesko, and the highest one – 78.1% in Rybnik. The standard deviation of the analysed feature between the plots was 4.9%, with the lowest differentiation of the feature on the plot in Sławno, and the highest in Lesko.

Table 2. Basic statistics of share of heartwood on analysed sample plots
Tabela 2. Podstawowe statystyki udziału twardzieli na badanych powierzchniach

Number and name of sample plot Numer i nazwa powierzchni badawczej	Minimum Minimum	Average Średnia	Maximum Maksimum	Standard deviation Odchylenie standardowe
1. Tomaszów	37.6	**73.4**	83.9	10.7
2. Krasiczyn	60.7	**72.4**	83.9	7.0
3. Dukla	47.9	**68.2**	86.0	11.9
4. Lesko	18.9	**53.0**	71.3	12.7
5. Sucha	60.5	**73.4**	90.5	7.2
6. Ujsoły	63.4	**70.0**	74.7	4.0
7. Bardo Śląskie	60.7	**73.4**	85.5	8.1
8. Bystrzyca Kłodzka	62.5	**74.5**	86.8	6.3
9. Jugów	58.7	**73.1**	86.8	9.4
10. Kamienna Góra	68.9	**75.1**	82.3	4.0
11. Rybnik	55.6	**78.1**	92.8	11.7
12. Tułowice	35.1	**66.0**	78.2	10.5
13. Oleśnica Śląska	52.7	**68.2**	81.9	9.4
14. Lwówek Śląski	60.2	**70.7**	79.9	5.6
15. Jarocin	56.6	**64.9**	74.3	5.2
16. Sława Śląska	64.7	**72.5**	78.8	5.0
17. Kościan	55.5	**69.6**	80.0	6.3
18. Nowa Sól	51.0	**67.0**	83.0	7.6
19. Lubsko	51.6	**68.1**	75.7	6.2
20. Rzepin	48.6	**70.1**	83.0	10.3
21. Choszczno	61.8	**70.2**	79.0	5.2
22. Międzyzdroje	42.7	**62.5**	72.0	8.5
23. Sławno	64.2	**71.2**	78.1	3.9
24. Gdańsk	61.6	**73.4**	86.4	7.4
25. Łopuchówko	62.0	**74.8**	88.3	8.2
26. Miradz	60.5	**72.7**	84.0	7.0
27. Lipka	53.5	**69.8**	81.7	7.3
28. Kwidzyn	66.7	**76.2**	86.8	5.5
Average – Średnia	18.9	**70.4**	92.8	4.9

Figure 1 shows that in almost half of the Douglas firs under analysis the share of heartwood did not exceed 70% of the stem cross-section and that in 11% of the trees the share was higher than 80%.

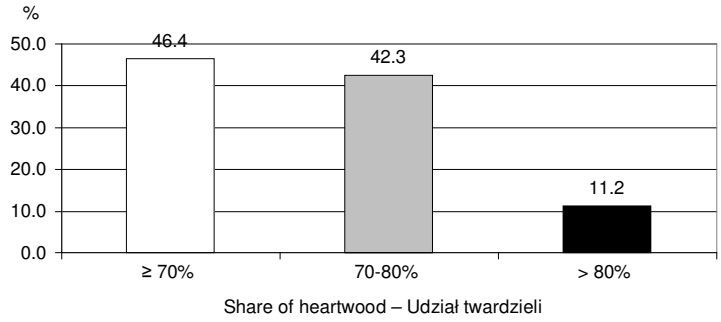

Fig. 1. Share of trees in heartwood share classes
Rys. 1. Frekwencje drzew w klasach udziału twardzieli

The average share of heartwood in trees of the V age class reached 70.8% and was by 0.7% higher than the VI class; however, these differences were not significant ($p = 0.7746$). Similarly, no significant differences were noted between trees growing in moderate and broken stand density ($p = 0.8297$); the average values amounted to, respectively, 71.3% and 70.1%.

In order to investigate into the relations between the share of heartwood on the stem cross-section and the parameters of the crown, analysis of correlation was applied. The values received were not significant and the strength of the correlation was weak (Table 3).

Next, relations were analysed between the condition of the trees and the share of heartwood. There were 77 trees (18.3%) trees of lush vitality, 303 trees (72.1%) subsumed under the group of trees of normal vitality and 40 trees (9.5%) subsumed under the group of trees of weak vitality. Statistical analysis did not show significant differences in the share of heartwood between these groups of tree vitality ($p = 0.0626$). There is, however, a clear tendency towards increasing the share of heartwood on the stem cross-section of weak trees, as illustrated in Figure 2. The weak Douglas fir trees have the share of heartwood by about 2% higher than the trees in the remaining two groups.

Table 3. Correlations of heartwood share and crown parameters
Tabela 3. Korelacje udziału twardzieli i parametrów korony

	Crown length Długość korony		Relative crown length Względna długość korony		Crown width Szerokość korony	
	r	p	r	p	r	p
Share of heartwood Udział twardzieli	–0.0474	0.333	–0.0504	0.304	–0.0426	0.385

r – value of coefficient of correlation, p – significance level.
r – wartość współczynnika korelacji, p – poziom istotności.

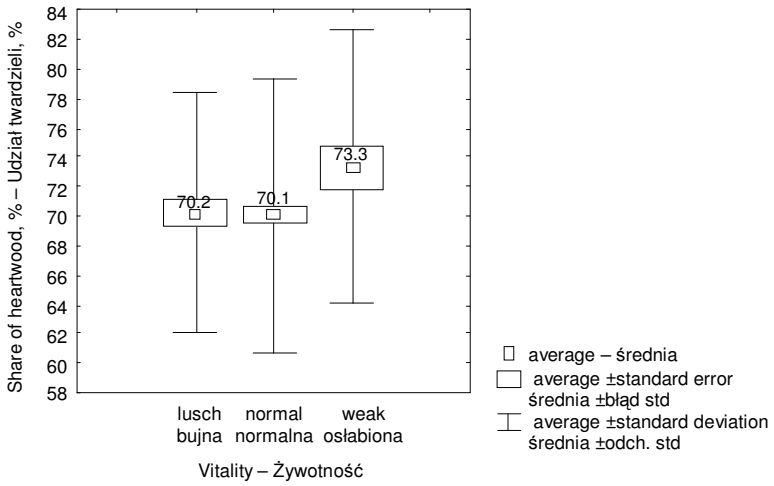

Fig. 2. Share of heartwood in trees of different vitality
Rys. 2. Udział twardzieli u drzew o różnej żywotności

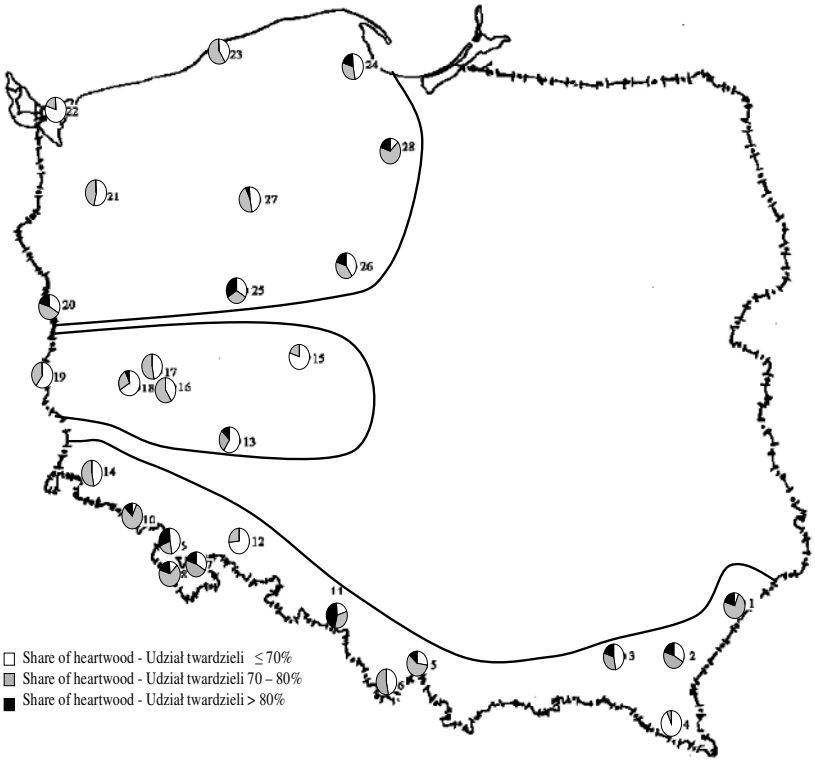

Fig. 3. Differentiation of share of heartwood in sample plots under analysis
Rys. 3. Zróżnicowanie udziału twardzieli na badanych powierzchniach

The spatial differentiation of the share of heartwood in the research area is presented in Figure 3. The symbols stand for frequencies of trees in the distinguished classes of the share of heartwood. The results obtained allowed for distinguishing three areas in which Douglas fir shows differences in the analysed feature: the southern area, the central-western one and the north-western one. In the stands of the southern area (sample plots 1-12 and 14), located in the highlands and mountains, the dominant Douglas fir trees were ones whose heartwood zone exceeded 70% of the stem cross-section. The share of heartwood did not exceed this value in most of the trees only on two plots (4 and 11). On sample plots in the central-western area (plot 13 and 15-19), located in the Wielkopolska and Śląska Lowland and in the Wał Trzebnicki ridge of hills, almost half or over half of the trees had the share of heartwood below 70% of the stem cross-section. Moreover, on plots 15, 16, 17 and 19, no tree had the share of heartwood over 80% and on plot 18 only one Douglas fir tree did.

In the stands located in the north-western area (plots 20-28), located in the Pobrzeże Słowińskie coast and the lake districts of Pojezierze Pomorskie and partly Pojezierze Wielkopolskie, the differentiation of the feature had a certain direction. In the eastern and southern parts of the distinguished area, the dominant Douglas fir trees had a higher share of heartwood while towards the north-west the share was decreasing.

DISCUSSION

The timber of Douglas fir is regarded as very durable, which is connected with the presence of coloured heartwood [Chylarecki 2004].

In the present research, the share of heartwood on the stem cross-section was on average 70.4%. Similar results were obtained by Kydryńska-Michałowska [1962], who analysed the technical properties of Douglas fir in the Ujsoły Forest District (RDLP Katowice – the Regional Directorate of State Forests Katowice). Slightly higher values than the ones received in the present research were obtained by Wieruszewski [2004], who examined 23 trees on four sample plots in the northern and central-western part of Poland. The average values from the measurements taken by the quoted author ranged between 84.1-86.3%. Discrepancies between the research quoted and the present study may be due to different methods and number of samples.

The share of heartwood showed relatively slight differentiation between the analysed populations, which is reflected in a low coefficient of variability (7.0%). Larger differentiation occurred within the sample plots. The fact that the value of the coefficient of variability was higher on the plot in Lesko than on the others may be due to the presence of two slightly younger trees in the group under research.

No significant differences concerning the share of heartwood were noted between the stands of the V and VI age classes, which allows for the conclusion that in older trees this feature becomes established and assumes a similar level. This is confirmed by the research done by Kydryńska-Michałowska [1962], whose results for 73 trees were similar to those in the present study; Wieruszewski [2005] conducted research in stands aged 83-90 years and obtained slightly higher values.

The obtained coefficients of correlation between the share of heartwood and crown parameters were not significant and remained within the range of a faint correlation [Stanisz 1998]. The conclusion is that crown formation in older Douglas fir trees will

not have a significant influence on the share of sapwood and heartwood on the stem cross-section. However, it is possible that in stands of younger age classes the reduction of the crown may affect the formation of heartwood. Such a reaction was examined by Pazdrowski [2004] in brashed pine trees. The author noted that after 36 years from brashing, consisting in shortening living crowns in various degrees, a higher share of heartwood was found in brashed pine trees than in unbrashed ones.

The present research did not show any significant differences of the share of heartwood between Douglas fir trees of varying vitality; however, a tendency towards increasing the share of this zone was noted in weak trees. Similar results for pine trees from southern Poland were obtained by Niedzielska et al. [2001]; trees of lush vitality in relation to the weak ones had the share of sapwood by 5% higher on the radius.

Analysis of the spatial differentiation of the share of heartwood in Douglas fir in Poland allowed for distinguishing three areas: the southern and north-western ones, where the share of heartwood was higher, and the central-western one, where it was lower. This division is similar to the dendroclimatic regions distinguished for Douglas fir by Feliksik and Wilczyński [2004]. These authors showed a strong influence of thermopluvial conditions on the physiological processes in this species. Therefore it seems that changing climatic conditions are the factor which may have an influence on the formation of the share of heartwood in Douglas fir.

CONCLUSIONS

1. The average share of heartwood on the stem cross-section in all analysed Douglas fir trees was 70.4%, reaching – in particular sample plots – the values ranging from 53.0% to 78.1%.

2. No significant relations were found between crown parameters and the share of heartwood in the analysed trees; the formation of crown sizes by means of the regulation of stand density in older Douglas fir stands should not influence this feature of timber.

3. In the area of Poland there were distinguished three areas: the southern and north-western ones, where the share of heartwood was higher, and the central-western one, where it was lower. These areas may be helpful for timber industry enterprises looking for Douglas fir timber with a higher or lower share of heartwood, responsible for different degrees of durability and susceptibility to saturation.

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ZMIENNOŚĆ UDZIAŁU TWARDZIELI NA PRZEKROJU POPRZECZNYM STRZAŁ DAGLEZJI ZIELONEJ (*PSEUDOTSUGA MENZIESII* VAR. *VIRIDIS* FRANCO) NA TERENIE POLSKI

Streszczenie. W pracy przedstawiono wyniki badań zmienności udziału twardzieli na przekroju poprzecznym strzał daglezji zielonej z terenu Polski. Badania prowadzono w drzewostanach daglezjowych V i VI klasy wieku. Badaną cechę określano na odwiertach pobranych z drzew za pomocą świdra przyrostowego, z wysokości 1,3 m od podstawy pnia, z kierunków N i S. Nie stwierdzono istotnych różnic udziału twardzieli między daglezjami V i VI klasy wieku oraz wzrastających w zwarciu umiarkowanym i przerywanym. Różnice istotne nie wystąpiły również między osobnikami o różnej żywotności, zaznaczyła się jednak tendencja do zwiększania udziału twardzieli u drzew osłabionych w stosunku do normalnie i bujnie rozwiniętych. Nie stwierdzono istotnych korelacji pomiędzy udziałem twardzieli a parametrami koron drzew. Na terenie Polski wyróżniono trzy obszary: południowy i północno-zachodni, gdzie daglezje mają większy udział twardzieli na przekroju poprzecznym strzał, oraz środkowo-zachodni, charakteryzujący się udziałem mniejszym.

Słowa kluczowe: daglezja zielona, twardziel, Polska

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