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OPTIMALIZATION OF THE NUMBER AND SIZE OF SAMPLE PLOTS FOR ESTIMATION OF THE QUALITY STRUCTURE OF STANDING SPRUCE TIMBER

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ABSTRACT

The present study concerns the determination of variability of spruce timber as a basis of optimalization of the number and size of sample plots. The plots might be used to estimate the quality structure of spruce timber for both scientific and practical purposes. Research was conducted at 6 one-hectare sample plots, divided into subplots, in the province of the Beskid Żywiecki Mts. in the Carpathian Region. The features under analysis showed considerable variability, particularly in the case of the least numerous classes and groups of timber. The analysed dependencies were described by means of expotential equations.

Key words: Norway spruce, timber quality, variability coefficients, number and size of sample plots

INTRODUCTION AND AIM

Standing timber assessment is the first task with regard to forest utilization which is performed in field. The data collected constitutes the basis for making plans of harvesting and transport costs, as well as preparing sale offers of timber at forest inspectorates. The results of the assessments are important for preparing the national balance of timber and constitute the basis for planning industrial production using timber. Since the traditional methods, especially the method of assessment of every single tree, carried out over the whole stand area, are very time-consuming, there is a need for simpler solutions, which could be used as an alternative. Sample plots which could serve not only for current assessment but also for analysis of the quality and size of timber bases may turn out to be such a solution in large areas with the predominance of single-species forest stands with little diversification of age. Assessment of quality and value of the volume of standing timber is becoming a more and more significant issue in the market economy. The aim of the present research was to determine the optimum number of sample plots with regard to their size, as a basis for assessment of the quality structure of timber of the forest timber base. The scope of the present research was limited to mature spruce stands in the Beskid Żywiecki Mts.

RESEARCH MATERIALS

In accordance with the nature and forest regionalization [8], the sample plots were located in the 4th Province of the Beskid Żywiecki Mts, in the VIII Carpathian Natural Forest Region. The area is built of magura and submagura beds (sandstone, shale and marl). It constitutes the highest situated part of the Beskidy Mts, and is characterized by the so-called topographic adolescence (deep valleys and steep river gradient). The area under research includes the mountain group of the Babia Góra (1725 m above sea level), the highest in the Outer Western Carpathian Mts; with Wielka Racza Mt (1234 m above sea level) to the south-west and the group of Pilsko Mt (1557 m above sea level) in between. Forests take up about 64% of this area. They are characterized mainly by mountain broadleaved forest sites and mixed mountain broadleaved forest sites, with a small share of mixed mountain coniferous forest sites as well as mixed upland forest sites and upland forest sites.

The research here was carried out at six sample plots located in spruce stands, three of which were set up in Myślenice Forest Inspectorate (the Regional Directorate of State Forests in Cracow) and the remaining three – in Jeleśnia Forest Inspectorate (the Regional Directorate of State Forests in Katowice). The characteristics of the sample plots, according to the data from forest management plans [4, 5], are provided in Table 1.

Table 1. Characteristics of sample plots

Forest inspectorate Forest district, Compartment	Altitude (m)	Exposure	Age (years)	Site type	Stand quality class	Forest density index	Stand density	Average breast height diameter (cm)	Average height (m)	Technical quality
Myślenice Sidzina 133b	950	W	90	LMG	II	1.1	full	33	28	1
Myślenice Sidzina 146a	1025-1050	N	100	BMG	II.5	1.1	full	39	27	2
Myślenice Sidzina 137a	1075	E	90	BMG	II.5	1.3	full	26	25	1
Jeleśnia Sopotnia Dolna 164a	1150	N	110	BMG	II	0.8	intermittent	36	31	2
Jeleśnia Sopotnia Dolna 160d	950	N	110	LMG	I	0.8	intermittent	43	35	2
Jeleśnia Sopotnia Dolna 150g	1025	S-W	115	LMG	II.5	0.9	moderate	35	29	3

Explanations:
LMG – mixed mountain forest BMG – mixed mountain coniferous forest

METHODS

Preliminary choice of stands for the purpose of the present research was made on the basis of forest management plans [4, 5]. Mature spruce stands aged 90 or older were selected. The decisive factor was good technical quality of stands, stated in forest management plans, which suggested the occurrence of greater variety of classes and groups of size and quality of timber, including high quality timber. Next, three stands were chosen at random in each of the two Forest Inspectorates.

Sample plots with the area of 1ha and a square shape (100 x 100 m) were located in the places most representative for the conditions in the stands with relation to stand density index, timber quality and species composition. Each plot was then divided into 100 subplots, every of 0.01 ha which were numbered and marked in their corners in field. The numbers followed along isohypses; and each following group of ten located below the previous one began on the same side of the large, one-hectare plot.

The following measurements and assessments were carried out, according to the rules of standing timber assessment [6, 10-12]:

- measurement of each tree of 7 or more cm thick in the breast height diameter;
- measurement of the height of each tree;
- assessment of standing timber in order to determine the class or group of the butt log according to size and quality.

The data was recorded according to the divisions into the small, one-are subplots.

For the purpose of the present research, the 0.01 ha plots, which are to be used in the future for other analyses of timber quality, were grouped by joining each consecutive five plots (i.e. plots from 1 to 5, from 6 to 10 etc.). As a result, each large, one-hectare plot was divided into twenty 0.05 ha units.

The trunk of every tree noted in the newly-formed 0.05 ha units underwent a simulated division into classes and groups of quality and size, possible to be distinguished along the whole tree up to its top. The starting point of the bucking was the quality and size class of the timber in the butt log, assessed during field work. Radwański's tables [7] were used for this purpose, which made it possible to determine the size and volume of each particular section of the stem in the course of bucking on standing trees.

In accordance with the Polish standards [6, 10], the following border values were adopted: for large-sized wood: minimum 14 cm under bark in the upper end; for middle-sized wood: from 14 cm under bark in the lower end to 5 cm under bark in the upper end. Large sized-wood and middle-sized wood together constituted commercial boles. Large-sized wood consisted of the following classes: WA0 and WB0, which comprised the best quality saw timber; WB1 – matchwood and WC0 – average quality saw timber. Middle-sized wood comprised only group S2 – pulpwood as well as a small amount of timber of group S1 – mine timber and S4 – fuel wood. The analysed material did not contain class WD – low quality saw timber or S3 – wood for making poles.

The received data was used to determine sums of volume of class and group according to quality and size as well as sums of commercial boles and of volume of whole trees within the 0.05 ha units. These units were then joined into larger ones, sized 0.10, 0.20, 0.30 and 0.50 ha. In the course of summing done within each one-hectare plot, the rules employed were the same as with the joining of the 0.01 ha units, i.e. they were joined consecutively along isohypses.

For the following sums of volume: of whole trees, of commercial boles and of timber classes and groups, obtained from all of the 0.05 ha units in both Forest Inspectorates taken together, Kołmogorow-Smirnow test was carried out to check whether the distribution of the sums of volume remains in accordance with the normal distribution on the significance level $p=0.05$. Mean values and standard deviations of the analysed parameters of timber were used to calculate variability coefficients. For each series, the coefficients were the basis for the determination of the minimum number of sample plots sized, consecutively: 0.05, 0.10, 0.20, 0.30 and 0.50 ha, to be set up in field in order to determine the sum of volume of whole trees, sum of volume of commercial boles or sum of volume of timber classes and groups, taking into consideration the assumed error. The errors were assumed on the level of 3, 5 and 10%, i.e. they reflected the precision which is most often required in scientific research and in practice [1]. The analysis was based on the following equation [2]:

$$n = \frac{(t^2 \times v^2)}{p^2}$$

where:
n – the minimum number of sample plots of a given size;
t – the coefficient in the tables of normal distribution for the assumed confidence level of 0.95;
v – variability coefficient (%) for the volume of the analyzed feature on sample plots of a given size;
p – the assumed error.

The results of calculations were used to make tables and a series of graphs. The graphs allowed for the extension of the data received in the course of research. Additionally, they made it possible to find out, by way of extrapolation, the number of 1ha plots which should be set up in order to calculate the volume of whole trees or of timber classes and groups depending on the assumed error. The dependency between the size and number of plots was described by an expotential model with the function $y = a \times e^{(b \times x)}$, where y – the number of sample plots with the assumed error; a and b – coefficients describing the course of the curves; e – the basis of the natural logarithm; x – plot size. The model was adjusted on the basis of the determination coefficient R^2. In all stages of the analyses, timber of groups S1 and S4 was ignored due to its scarce occurrence. These groups were included in middle-sized wood considered as a whole.

The next stage was to determine the parameters of a series of equations allowing for the determination of the necessary number of sample plots, depending on their size and the assumed error, and taking into account timber classes and groups. These dependencies were also described by the expotential model because it provided the most precise reflection of the analysed dependencies. In these equations: y – symbolizes the number of plots; x – the assumed error. In the case of the volume of a whole tree and the volume of commercial boles, the dependencies were additionally shown on graphs.

RESULTS

In the analysed spruce timber the variability coefficients of the sums of volume of whole trees, of commercial boles and particular classes and groups of quality and size are very varied (Table 2). The highest values occur in the following classes: WA0, WB0, WB1, in grup S2 and also at some points which result from joining classes or groups of timber. Small variability is shown by the volume of large-sized timber treated jointly, by the volume of commercial boles and by the volume of a whole tree, while the values of these coefficients are close to each other. The conclusion is that an analysis of these features of spruce timber would require setting up only a small number of sample plots. In the area under present research, depending on the size of a plot, and assuming the 10% error (accepted in practice), the number of plots would range from three 1 ha plots to thirty-two 0.05 ha plots. Variability coefficients decrease steadily as the size of plots increases. As an exception, class WB1 does not show this dependency; the coefficients are generally very high and range from 63.30% to 69.93%. The explanation might be a sporadic occurrence of timber of this class (special, high quality timber), noted only at certain sample plots, and a great range of sizes and volume of trees whose butt logs were classified as timber WB1. As a result, high values of coefficients and large variability of fractions of timber were obtained by joining classes WB0 and WB1. For 1 ha plots, where the data was obtained by extrapolation, for analyses of volume of whole trees, commercial boles and large-sized timber it would be enough to set up, depending on the assumed error, only from 3 to 59 plots, though their number would increase considerably if timber classes and groups are considered. The greatest number of plots, as many as 2168, should be set up for the purposes of research on the volume of class WB1 with the error of 3%. The course of these dependencies is shown on the example of a whole tree and a commercial bole (Fig. 1 and 2). Determination coefficients for these curves ranged between 0.66 and 0.98.

Table 2. Minimum number of sample plots depending on their size and assumed error

Timber class or group	0.05 ha				0.1 ha				0.2 ha			
	Error	10 [%]	5 [%]	3 [%]	Error	10 [%]	5 [%]	3 [%]	Error	10 [%]	5 [%]	3 [%]
	Variability coefficient	Number of sample plots			Variability coefficient	Number of sample plots			Variability coefficient	Number of sample plots		
WA0	63.71	156	625	1736	49.56	95	378	1051	41.62	67	267	741
WB0	65.77	167	666	1850	63.83	157	627	1743	62.71	151	605	1682
WB1	67.04	173	692	1922	63.30	154	617	1714	69.43	186	742	2062
WB0+WB1	67.03	173	692	1922	59.60	137	547	1520	55.50	119	474	1318
WC	35.59	49	195	542	29.50	33	134	372	24.93	24	96	266
W jointly	28.85	32	128	356	23.51	21	85	236	20.01	15	62	171
S2	46.14	82	328	911	40.31	63	250	695	37.24	53	214	593
S jointly	44.31	76	302	840	37.38	54	215	598	33.75	44	175	487
Merchantable boles	28.7	32	127	352	23.41	21	84	234	19.92	15	61	170
Whole tree	28.57	31	126	349	23.22	21	83	231	20.17	16	63	174

Timber class or group	0.3 ha				0.5 ha				1 ha*			
	Error	10 [%]	5 [%]	3 [%]	Error	10 [%]	5 [%]	3 [%]	10 [%]	5 [%]	3 [%]	
	Variability coefficient	Number of sample plots			Variability coefficient	Number of sample plots			Number of sample plots			
WA0	36.73	52	208	577	31.79	39	156	432	8	76	140	
WB0	61.96	148	591	1642	58.84	133	533	1481	107	428	1195	
WB1	64.08	158	632	1756	68.98	183	733	2035	194	780	2168	
WB0+WB1	54.63	115	459	1276	54.39	114	455	1265	72	360	1008	
WC	21.90	18	74	205	21.38	18	70	196	5	20	120	
W jointly	17.79	12	49	135	16.66	11	43	119	3	18	59	
S2	35.25	48	191	531	35.26	48	191	532	26	133	372	
S jointly	32.15	40	159	442	31.78	39	156	432	18	103	283	
Merchantable boles	17.76	12	49	135	16.75	11	43	120	3	18	50	
Whole tree	18.08	13	50	140	16.96	11	44	123	3	14	54	

Explanations:
Symbols of timber classes and groups according to the quality and size classification (6, 10, 11)
* - values read from diagrams

Fig. 1. Dependency between size and number of sample plots in analysis of volume of a whole tree

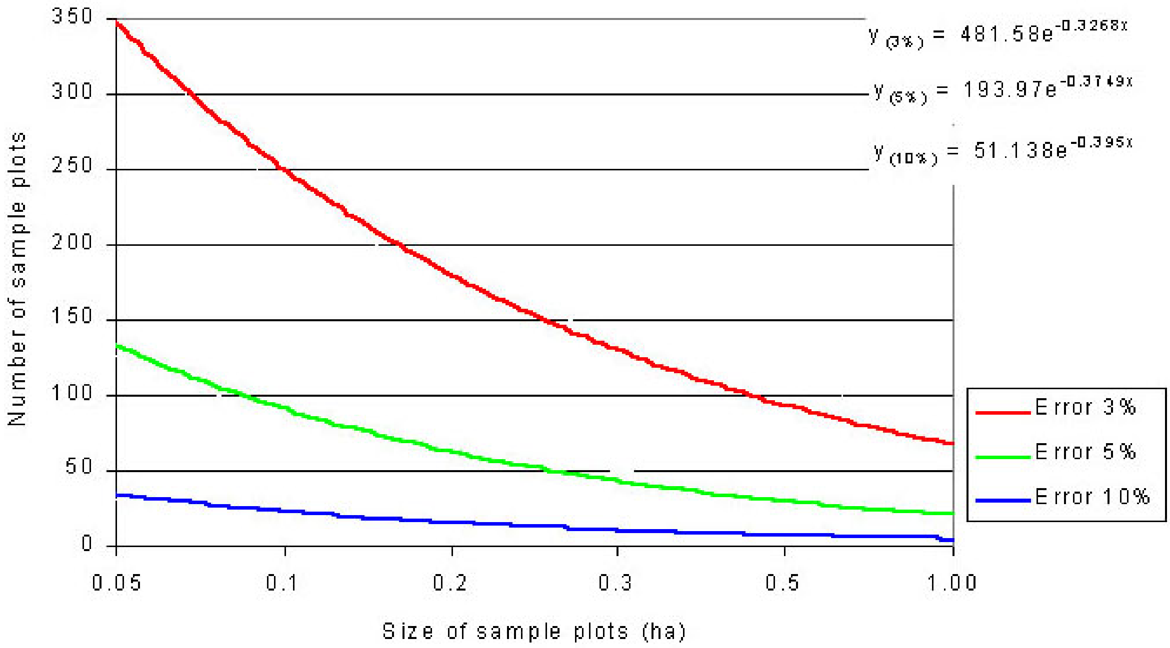
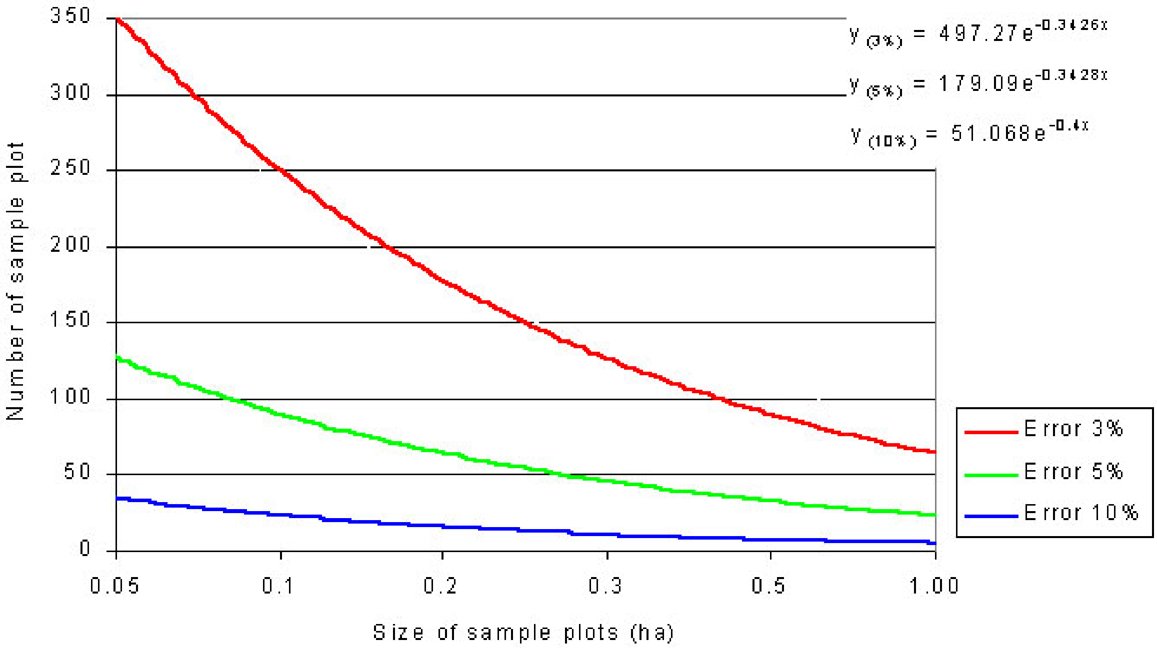


Fig. 2. Dependency between size and number of sample plots in analysis of volume of commercial boles



The next stage of research was drawing the curves which showed the dependency between the value of error from 1% to 10% and the number of sample plots (Fig. 3 and 4). The diagrams concern only the volume of a whole tree and of a commercial bole. For the remaining classes and groups of quality and size a table was created which contains parameters of equations describing the course of the curves (Table 3). Determination coefficients for this series of curves remained within the range of 0.55 to 0.81. Using the general formula provided in Methods as well as the parameters contained in the table, it is possible to calculate the number of plots depending on their size and on the error assumed to be any value within the range of 1 to 10%. The situation of the curves clearly depends on the size of a plot. The highest curve corresponds to 0.05 ha plots, while the lowest curve corresponds to 1 ha plots. The course of the curves shows that, up to the values of error amounting to 4 – 5%, the curves presenting the volume of a whole tree and the volume of a commercial bole go down rapidly, especially in the case of small plots. Further on the curves approach each other and, starting from the 7 – 8% error, are arranged almost parallel to the horizontal axis. This indicates the necessity of setting up a large number of sample plots for a high required precision of results. Their number increases dynamically with a decreasing size of plots.

Fig. 3. Number of sample plots depending on the assumed error for the calculation of the volume of a whole tree

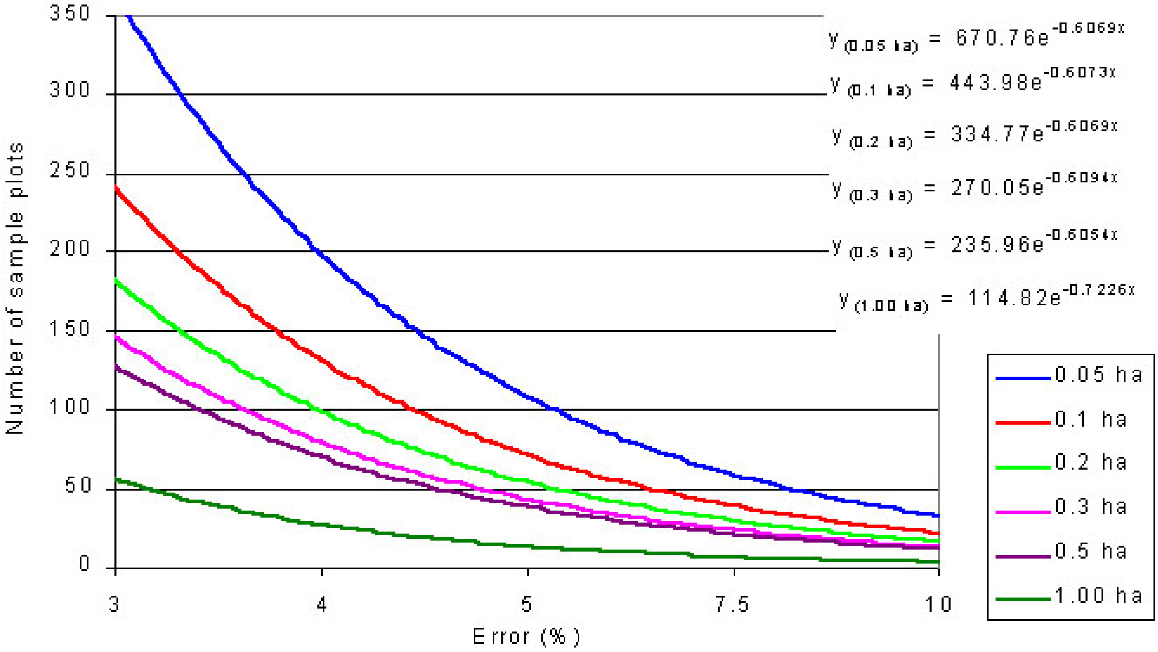


Fig. 4. Number of sample plots depending on the assumed error for the calculation of the volume of commercial boles

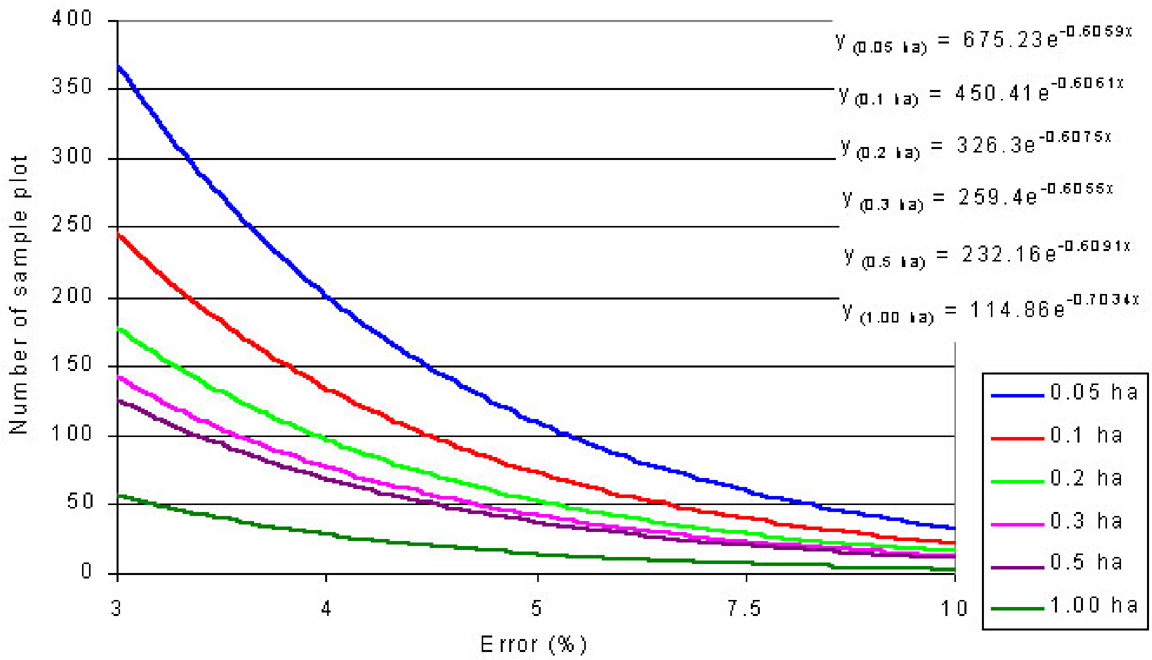


Table 3. Parameters of expotential equations for particular classes and groups of timber depending on size of sample plots

Timber class or group	Parameter	0.05 ha	0.1 ha	0.2 ha	0.3 ha	0.5 ha	1 ha
WA0	a	3903.134	2361.764	1665.105	1298.435	971.461	536.46
	b	-0.335	-0.335	-0.335	-0.335	-0.335	-0.417
WB0	a	4159.24	3916.457	3780.345	3691.2	3328.61	2778.835
	b	-0.335	-0.335	-0.335	-0.335	-0.335	-0.332
WB1	a	4319.39	3852.1	4634.326	3947.61	4574.383	5056.16
	b	-0.335	-0.335	-0.335	-0.335	-0.335	-0.332
WB0+WB1	a	4320.045	3416.175	2960.88	2869.37	2845.235	2673.863
	b	-0.335	-0.335	-0.335	-0.335	-0.335	-0.365
WC	a	1217.726	835.372	603.425	466.17	434.334	284.574
	b	-0.335	-0.335	-0.337	-0.338	-0.333	-0.42
W jointly	a	799.772	539.236	395.292	315.138	264.113	174.977
	b	-0.335	-0.339	-0.342	-0.343	-0.332	-0.413
S2	a	2046.347	1555.94	1340.007	1190.92	1192.56	468.689
	b	-0.335	-0.334	-0.336	-0.335	-0.335	-0.172
S jointly	a	1881.115	1339.786	1091.606	997.618	970.612	302.738
	b	-0.335	-0.334	-0.335	-0.337	-0.335	-0.127

Explanations:
Symbols of timber classes and groups according to the quality and size classification [6, 10, 11]

DISCUSSION

The problem of determination of an optimum amount of material necessary to determine quality features of timber was discussed previously in a large number of studies. The paper by Barszcz and Rutkowska [1], discussed only parameters of wood defects occurring on standing trees in mature spruce stands of the Beskidy Mts. The variability of these features and the assumed level of error allowed for the determination of the minimum number of trees to be considered in order to characterize their timber with relation to defects occurring in it. The values of variability coefficients of timber defects were very varied in the research mentioned above. They often exceeded the level of 100%. Depending on the assumed error (3 or 5%) and the kind of defect, the minimum number of model trees required to analyse timber defects ranged from 17 to 938.

Research on the optimalization of the number and size of sample plots in spruce stands, which was similar to the present research, was carried out by Leśniak [3]. Its scope was, however, much smaller (one sample plot of 1ha) so the computed coefficients of variability of volume of timber classes and groups were, as a result, much lower. Moreover, in Leśniak's research, the variability of class WA0 was higher in comparison with WB0 and WB1 – as opposed to the present study.

Unique research, due to special features of the area, was conducted by Zygmunt [12] in the Olkusz Industrial District. Assuming a constant size of sample plots (0.05 ha), which were also used for the purposes of inventory of stand, he only optimalized their number. His analysis concerned volume of trees and value of timber, based on the classification of quality and size. Calculations allowed for correction of the assumed variability coefficients as well as for determination, depending on the required precision of results, of the number of sample plots necessary for analysis of volume and value of timber in industrial districts. It is worth emphasizing here that the coefficient of variability of volume of whole trees calculated by Zygmunt for mature stands of Olkusz Industrial District amounted to 33%, which was very close to the value obtained in the present research (28.57% for a 0.05 ha sample plot).

CONCLUSIONS

1. Due to a large and usually unknown variability of quality of timber, any research carried out with the use of sample plots requires the determination of their optimum size and number, necessary to obtain results on the required level of precision.
2. An analysis of variability coefficients of timber quality conducted in the mature spruce stands of the Beskid Żywiecki Mts showed that the minimum number of sample plots clearly increases with the increasing required precision of calculations. This tendency is present in most classes or groups distinguished according to quality and size of timber, independently of the size of sample plots. As an exception, this dependency was not confirmed for the timber of class WB1.
3. The largest number of sample plots was calculated for high quality timber of class WB1, which may be explained by a sporadic occurrence and a wide range of sizes of the trees belonging to this class in the stands under research. The smallest number of sample plots (3 every time) can be assumed, with the error of 10% and plot size of 1 ha, for an analysis of volume of: large-sized wood of all quality classes jointly, commercial boles and a whole tree.
4. Dependencies between the size and the required number of sample plots were described (assuming the error of 3, 5 and 10%) by equations of regression, assuming the expotential model as the best adjusted one. The expotential model was also used to construct equations which allowed for the calculation of the minimum number of sample plots (sized from 0.05 to 1 ha), depending on the assumed error. The course of these curves indicates a dynamically increasing number of plots, especially the small ones, when the error was lower than 4-5%.
5. Due to the lack of more precise data concerning the variability of quality of Norway spruce timber, the obtained results may be used as approximations in research on the quality of this species in its southern natural range in Poland. The results may also constitute the basis for similar approximations in preliminary stages of research on the quality and size structure of this timber in other parts of the country, including the northern range of spruce.

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