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VOLUME INCREMENT INDEXES AND THEIR VARIATION IN A 35-YEAR OLD PINE STAND

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Abstract. The study analysed four volume increment indexes in terms of basic statistical characteristics. Empirical material consisted of 314 pine trees, growing in a 35-year old pine stand. Stem analysis was conducted on cut trees and 4 volume increment indexes C_1, C_2, C_3 and C_4 were calculated in successive 5-year growing periods. The lowest variation was found for two increment indexes, C_2 and C_4. A slightly higher variation was observed for index C_3, while the highest for C_1. The highest coefficients of variation of indexes C_1, C_2 and C_3 were recorded in the growing period of 6-10 years, while the lowest for the period of 11-15 years. In case of index C_4 it was the period of 31-35 years and 16-20 years, respectively. No distinct trend or relationship was found between the arithmetic mean of increment index C_3 and the age of trees. The mean of index C_1 increased with the age of trees, similarly as it was the case with index C_2, with only one difference that in the last growing period this mean decreased. Index C_4 decreased with the age of trees. In most cases the highest variation of indexes was recorded for trees of Karft's classes IVb and Va. In those tree stands in which tending operations were conducted, the variation of all volume increment indexes should be lower.

Key words: volume increment, volume increment indexes, pine

INTRODUCTION

Current volume increment of a tree stand is considered one of the best symptoms of efficiency of silviculture. It is the volume of current volume increment which determines to the highest degree the scope of forest utilization and the planned management and silvicultural procedures. Current volume increment of a tree stand may be determined using two methods. The first consists in the calculation of differences between periodically measured volumes, while the other, applied more frequently, is based on a single backward measurement at the end of the growing period. A study by Borowski [1954] had a considerable impact on the investigations of accuracy and improvement of methods belonging to the latter group, as it introduced the concept of volume increment

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intensity (a quotient of the current periodical volume increment of a debarked stem and the breast height diameter area of a stem with bark measured at the end of the growing period). Studies by Borowski [1954, 1958, 1961 b, 1964, 1971] and Borowski and Rokosz [1974] on volume increment intensity, and especially the determination of variation and its dependency on different characters of trees, constituted the basis for the development of a method to determine current volume increment of a tree stand. Several studies concerning volume increment intensity in pine stands and to a limited extent spruce stands were carried out e.g. by Borowski [1954, 1961 a, b], Dudek [1965, 1969], Lemke [1971, 1984], and in an oak stand by Remi [1981]. Borowski [1961 a, 1964] showed a high variation in volume increment intensity (mean coefficient of variation in analysed tree stands was 30.5% for the 10-year growing period and 33.0% for the 5-year growing period). In the oak stand Remi [1981] recorded the variation of 33.0% (10-year period) and 35.4% (5-year period). The dependency between volume increment intensity and different characters of trees within a tree stand and the dependency between mean values of volume increment intensity of the tree stand and its characteristics constituted the basis for a set of pine volume increment tables by Dudek [1994].

Remi [1977] proposed the introduction of other volume increment indexes and comparing them with volume increment intensity. The introduction of new indexes was based on the assumption that b.h.d. form factor at the beginning and at the end of a short growing period is identical. If such an assumption is made, then volume increment is connected with the form factor and the sum of specific combinations of products of b.h.d. debarked cross-section area and height at the end of the period and their increments. Thus, it was suggested to use these products to generate volume increment indexes, similarly to the formula of form factor. Remi proposed the four following indexes, which are abstract numbers:

$$C_1 = \frac{Z_v}{Z_g \cdot Z_h},\ C_2 = \frac{Z_v}{Z_g \cdot h},\ C_3 = \frac{Z_v}{g \cdot Z_h},\ C_4 = \frac{Z_v}{g \cdot h}$$

where:

Z_v – volume increment,
Z_g – b.h.d. debarked cross-section area,
Z_h – increment in height,
g – b.h.d. debarked cross-section area,
h – height.

Studies on the above mentioned volume increment indexes and their change with age in an 86-year old pine stand were carried out by Turski [2005], while in a 50-year old stand by Turski and Andrzejewski [2005]. This study is a continuation of earlier studies, this time conducted in a 35-year old pine stand. Four volume increment indexes were analysed, taking into consideration basic statistical characteristics calculated in successive 5-year growing periods, starting from the 6-10 year period. The first 5-year growing period was neglected, as some trees did not yet reach the height of 1.3 m. Analysis was conducted both for the whole tree stand, dominant and secondary stands, as well as trees belonging to individual Kraft's classes. It was also verified whether populations of the analysed volume increment indexes exhibit normal distributions.

MATERIAL AND METHODS

This study is based on the material collected from the experimental clear cutting area, established in a 35-year old pine stand in the Murowana Goślina Experimental Forest Station. Mean stand height was 13.53 m, mean breast height diameter was 11.5 cm, while site index was I. The forest site type was fresh coniferous forest, with the degree of stocking of 1.16. A total of 314 trees were included in the study. The conducted complete stem analysis on cut trees made it possible to determine the following values for successive 5-year growing periods: volume increment Z_v, b.h.d. debarked cross-section Z_g, increment in height Z_h, as well as height h and b.h.d. debarked cross-section g. These parameters were used to calculate four volume increment indexes, for which basic statistical characteristics were next calculated: arithmetic mean, standard deviation and the coefficient of variation. These characteristics were calculated jointly for all trees constituting the tree stand and for both the dominant and secondary stand, as well as trees included in individual Kraft's classes. Moreover, the normality of distributions was assessed for volume increment indexes in successive 5-year growing periods.

RESULTS

Volume increment indexes in the entire tree stand, in the dominant and secondary stands, and in Kraft's classes were characterized using arithmetic means (Table 1). Arithmetic mean of index C_1 in the entire tree stand, as well as individual Kraft's classes increases with age (except for Kraft's class Va). Apart from the 11-15 year growing period, the arithmetic mean of the analysed index is higher in the secondary stand than in the dominant stand (Fig. 1). In Kraft's classes the lowest arithmetic mean in each of the analysed growing periods, apart from that of 31-35 years, was recorded in Kraft's class I. The arithmetic mean of increment index C_2 for the entire tree stand was lowest in the first analysed growing period (6-10 years), increasing in successive periods, reaching the highest value (0.989) in the period of 26-30 years, and then decreasing in the last period to 0.905 (the period of 31-35 years). In each growing period the mean of this index was higher in the secondary stand (Fig. 2). The arithmetic mean of index C_3 for all trees of the tree stand had the highest value in the first growing period – 1.202 (6-10 years), decreased in the successive growing period and then increased continuously until the period of 26-30 years (1.208), to again decrease in the last period to the value of 1.067. Apart from the first growing period means of this index were higher in the dominant stand (Fig. 3).

The arithmetic mean of the fourth of the investigated indexes, i.e. C_4, for the entire stand decreased in successive growing periods from 0.631 (period of 6-10 years) to 0.111 (period of 31-35 years). In the first two growing periods the mean for the secondary stand was higher (in Kraft's class Va the mean of this index was highest) than for the dominant stand, while in successive periods the trend was the opposite (the mean of the index was highest in Kraft's class I; Fig. 4).

Calculated coefficients of variation for the four analysed volume increment indexes are given in Table 2, while values of this character for the entire stand in successive growing periods are presented graphically (Fig. 5). The highest coefficients of variation were found for index C_1. In the first growing period it had the highest value (53.72%),

Table 1. Arithmetic means of volume increment indexes in successive 5-year growing periods
Tabela 1. Średnie arytmetyczne wskaźników przyrostu miąższości w kolejnych 5-letnich okresach przyrostowych

Growing period Okres przyrostowy	Increment index Wskaźnik przyrostu	Entire stand Cały drzewostan	Dominant stand Drzewostan główny	Secondary stand Drzewostan podrzędny	Kraft's class – Klasa Krafta					
					I	II	III	IVa	IVb	Va
31-35 years 31-35 lat	C_1	9.325	7.580	11.769	7.392	7.251	7.902	8.683	13.829	12.930
	C_2	0.905	0.846	0.986	0.828	0.827	0.869	0.919	1.052	0.991
	C_3	1.067	1.195	0.887	1.306	1.215	1.138	0.903	0.981	0.784
	C_4	0.111	0.134	0.076	0.147	0.139	0.126	0.094	0.075	0.060
26-30 years 26-30 lat	C_1	7.871	6.483	9.786	6.214	6.285	6.737	8.370	9.732	11.190
	C_2	0.989	0.899	1.113	0.849	0.868	0.942	1.034	1.108	1.194
	C_3	1.208	1.302	1.076	1.450	1.323	1.229	1.117	1.141	0.978
	C_4	0.159	0.183	0.126	0.200	0.185	0.175	0.142	0.132	0.105
21-25 years 21-25 lat	C_1	5.781	5.716	5.871	4.980	5.330	6.293	5.549	6.023	6.043
	C_2	0.976	0.926	1.045	0.879	0.898	0.966	0.982	1.047	1.103
	C_3	1.096	1.162	1.003	1.153	1.167	1.162	1.018	1.010	0.983
	C_4	0.190	0.197	0.180	0.206	0.197	0.193	0.181	0.178	0.182
16-20 years 16-20 lat	C_1	3.257	3.256	3.258	2.928	3.172	3.446	3.369	3.233	3.175
	C_2	0.866	0.842	0.899	0.789	0.828	0.873	0.903	0.894	0.901
	C_3	1.035	1.073	0.982	1.054	1.048	1.098	1.013	0.963	0.970
	C_4	0.277	0.279	0.274	0.285	0.275	0.279	0.181	0.268	0.279
11-15 years 11-15 lat	C_1	1.905	1.911	1.898	1.830	1.914	1.939	2.007	1.943	1.755
	C_2	0.686	0.673	0.704	0.651	0.675	0.681	0.719	0.718	0.677
	C_3	1.013	1.017	1.006	1.009	1.020	1.019	1.023	0.994	1.001
	C_4	0.371	0.361	0.384	0.361	0.363	0.36	0.273	0.375	0.402
6-10 years 6-10 lat	C_1	1.251	1.091	1.486	1.025	1.062	1.138	1.141	1.344	1.997
	C_2	0.652	0.601	0.726	0.577	0.595	0.616	0.632	0.705	0.854
	C_3	1.202	1.033	1.445	0.983	1.015	1.066	1.101	1.308	1.948
	C_4	0.631	0.579	0.707	0.554	0.569	0.596	0.373	0.685	0.833

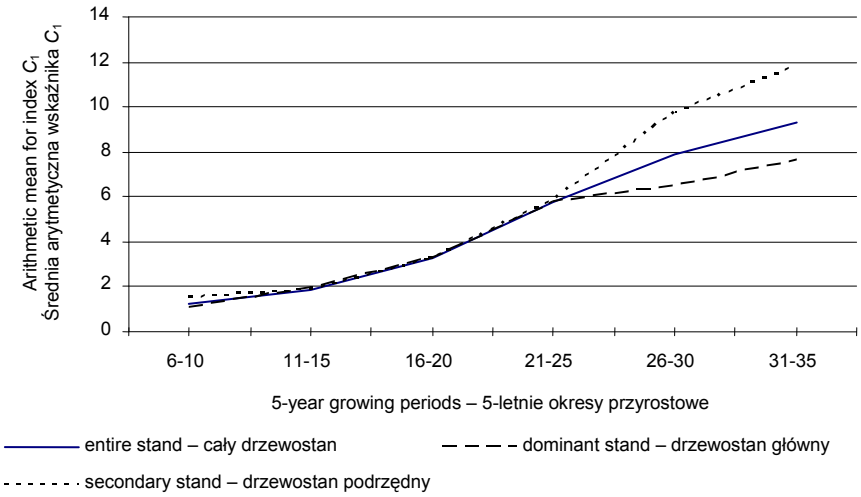

Fig. 1. Arithmetic mean for index C_1 in successive 5-year growing periods for the entire, dominant and secondary stands
Rys. 1. Średnia arytmetyczna wskaźnika C_1 w kolejnych 5-letnich okresach przyrostowych dla całego drzewostanu oraz drzewostanu głównego i podrzędnego

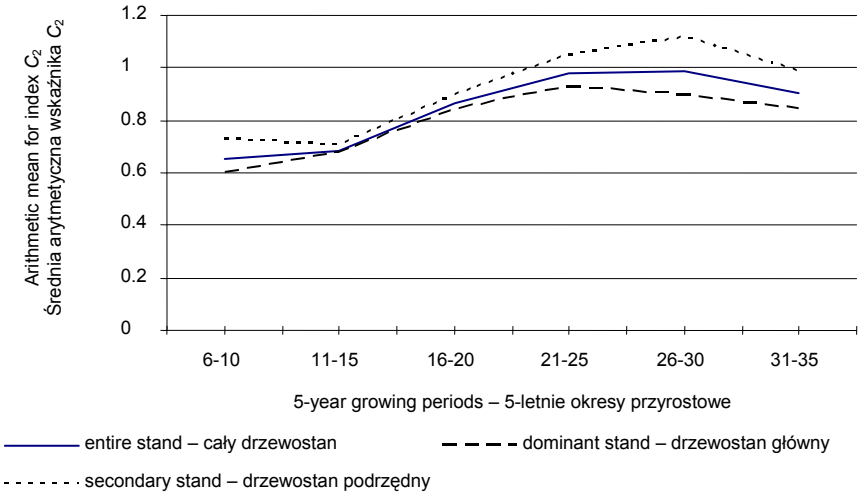

Fig. 2. Arithmetic mean for index C_2 in successive 5-year growing periods for the entire, dominant and secondary stands
Rys. 2. Średnia arytmetyczna wskaźnika C_2 w kolejnych 5-letnich okresach przyrostowych dla całego drzewostanu oraz drzewostanu głównego i podrzędnego

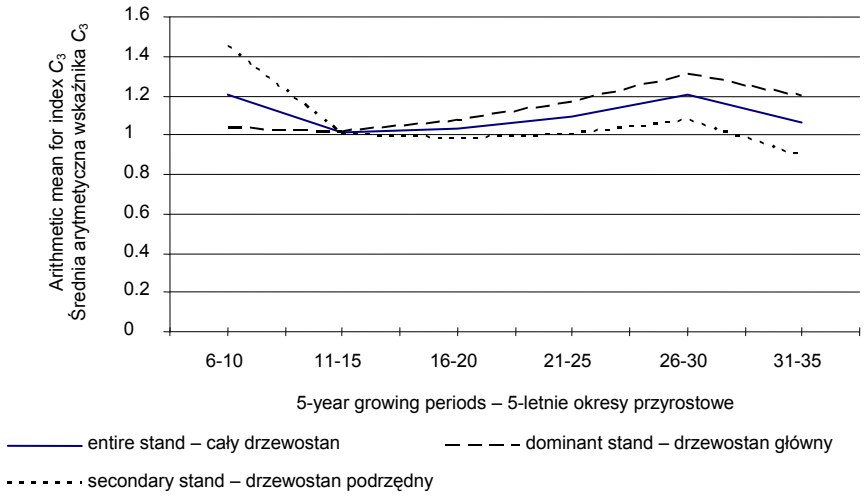

Fig. 3. Arithmetic mean for index C_3 in successive 5-year growing periods for the entire, dominant and secondary stands
Rys. 3. Średnia arytmetyczna wskaźnika C_3 w kolejnych 5-letnich okresach przyrostowych dla całego drzewostanu oraz drzewostanu głównego i podrzędnego

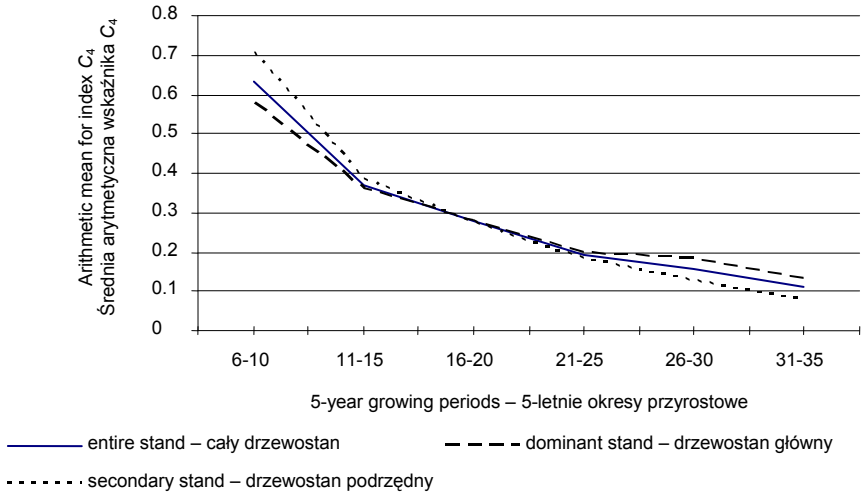

Fig. 4. Arithmetic mean for index C_4 in successive 5-year growing periods for the entire, dominant and secondary stands
Rys. 4. Średnia arytmetyczna wskaźnika C_4 w kolejnych 5-letnich okresach przyrostowych dla całego drzewostanu oraz drzewostanu głównego i podrzędnego

Table 2. Coefficients of variation of volume increment indexes in successive 5-year growing periods
Tabela 2. Współczynniki zmienności wskaźników przyrostu miąższości w kolejnych 5-letnich okresach przyrostowych

Growing period Okres przyrostowy	Increment index Wskaźnik przyrostu	Entire stand Cały drzewostan	Dominant stand Drzewostan główny	Secondary stand Drzewostan podrzędny	Kraft's class – Klasa Krafta					
					I	II	III	IVa	IVb	Va
31-35 years 31-35 lat	C_1	46.21	23.73	46.47	27.23	24.09	21.69	24.05	47.48	41.86
	C_2	21.98	15.72	24.75	8.09	16.69	16.80	17.85	24.24	28.76
	C_3	36.46	24.52	49.04	23.81	21.89	25.92	39.76	50.05	55.74
	C_4	36.04	20.15	36.84	12.24	17.99	23.81	26.60	33.33	38.33
26-30 years 26-30 lat	C_1	48.63	29.34	49.69	29.59	31.60	27.45	41.94	50.54	49.79
	C_2	26.49	17.46	28.84	16.02	12.10	19.75	23.89	30.14	29.90
	C_3	30.46	22.43	38.94	20.41	22.98	21.07	24.80	40.58	48.77
	C_4	27.04	16.94	27.78	12.50	13.51	19.43	19.72	25.00	31.43
21-25 years 21-25 lat	C_1	40.49	48.85	25.84	23.47	21.24	60.92	19.07	25.20	30.38
	C_2	18.75	15.44	20.00	13.54	15.37	15.22	14.87	16.91	24.03
	C_3	22.08	19.79	22.73	17.00	17.40	22.55	20.83	23.86	23.91
	C_4	17.89	14.72	20.00	13.59	13.20	16.06	17.68	21.35	20.88
16-20 years 16-20 lat	C_1	30.43	34.18	24.40	15.85	34.33	36.85	22.14	20.57	29.54
	C_2	18.71	19.36	17.35	10.39	26.33	14.78	15.95	15.55	20.42
	C_3	25.80	28.98	18.43	14.90	15.84	38.25	17.08	14.02	22.68
	C_4	14.44	13.26	15.33	12.28	13.09	14.34	17.68	13.06	17.92
11-15 years 11-15 lat	C_1	23.83	21.09	27.29	18.31	20.59	22.33	25.01	23.42	32.02
	C_2	14.58	12.93	16.05	13.36	12.74	13.07	14.46	14.76	18.46
	C_3	17.37	18.39	15.81	14.17	14.71	22.08	13.10	12.47	20.48
	C_4	15.90	13.30	18.23	14.13	11.57	14.17	14.29	12.80	24.13
6-10 years 6-10 lat	C_1	53.72	30.06	62.65	14.34	25.71	35.50	21.21	38.91	69.90
	C_2	30.82	15.97	38.29	12.65	18.32	14.94	19.62	27.38	47.42
	C_3	54.57	22.65	64.78	14.24	26.40	21.86	22.16	40.44	71.97
	C_4	32.96	18.65	39.75	14.08	19.51	19.13	12.33	27.88	49.34

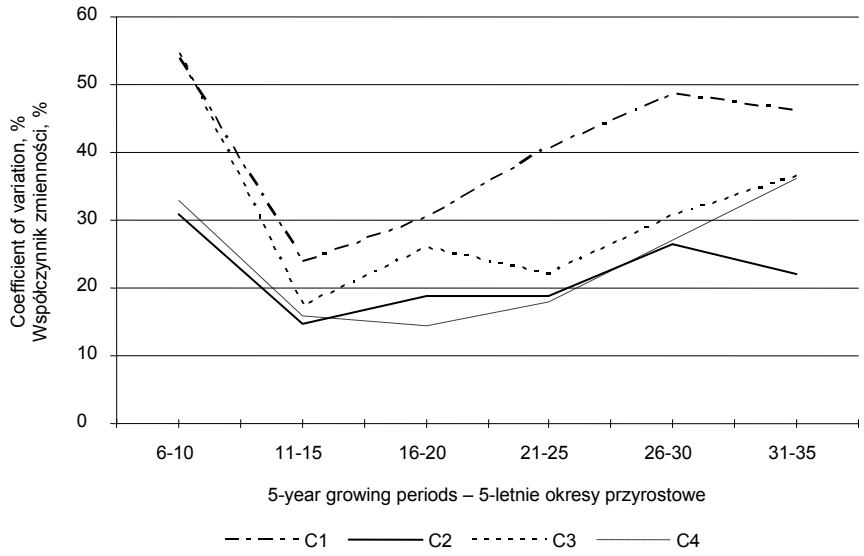

Fig. 5. Changes in coefficients of variation for volume increment indexes in 5-year growing periods
Rys. 5. Zmiana współczynników zmienności wskaźników przyrostu miąższości w 5--letnich okresach przyrostowych

to reach the maximum in the successive period (23.83%). In the next periods the coefficient of variation increased, to decrease again in the last. In case of index C_2 markedly lower values were found (for some periods over two-fold) for the coefficient of variation in comparison to C_1. Also in this case the highest variation was recorded in the first analysed period (30.82%), which decreased in the next period to 14.58%. Successive periods were characterized by increasing variation until the last but one, to decrease again in the last period. The next index, i.e. C_3, in the first growing period had the highest coefficient of variation among all indexes (54.57%). The next growing period brought a rapid drop in variation to 17.37%, followed by a single decrease in the period of 21-25 years. Coefficients of variation for index C_4 were slightly different than the three previous ones. Starting from the first growing period variation decreased, taking the lowest value in the period of 16-20 years (14.44%), to increase continuously in the successive periods until the highest value was reached in the last period of 31-35 years (36.04%). For the last two growing periods and for the first one coefficients of variation for four volume increment indexes were higher in the secondary stand. The situation was identical in the period of 11-15 years (except for C_3) and 21-25 years (except for C_1). In the period of 16-20 years, apart from index C_4, the other three indexes exhibited higher variation in the dominant stand. Generally, the lowest variation was found for indexes C_2 and C_4, while the highest for C_1. This confirms previously studies conducted in two other pine stands [Turski and Andrzejewski 2005, Turski 2005]. Coefficients of variation in case of volume increment intensity, calculated unconventionally as the quotient of volume increment for the debarked stem and breast height diameter debarked cross-section [Lemke 1984] in the same stand, were higher than coefficients

calculated for C_2, C_3 and C_4 in the last two periods. We face the same situation also in the period of 21-25 years in case of C_2 and C_4 and in the period of 16-25 years for C_4. In the other cases variation in volume increment intensity was lower than that for the four indexes analysed in this study.

A large number of measurements are required when selecting trees from the stand in order to determine the mean values of indexes with the assumed standard error for the arithmetic mean and at the specific level of significance. For the general population in the 5-year growing period (31-35 years), at the assumed standard error of ±5% and the level of significance of 0.32 a total of 85 measurements are needed to calculate index C_1, 19 for C_2, 53 for C_3 and 52 for C_4. For the growing period of 11-15 years the figures would be as follows: C_1 – 23, C_2 – 8, C_3 – 12 and C_4 – 10 measurements, respectively. However, the above numbers would be appropriate under the condition that populations of individual volume increment indexes are consistent or similar to the normal distribution. In order to assess whether populations of increment indexes exhibit normal distributions the W Shapiro-Wilk test was performed. The Shapiro-Wilk test, based on positional statistics, is one of the most powerful for a wide range of alternative distributions. Moreover, it may be applied for samples with sizes $n \leq 50$ and it uses complete information from the sample [Krysicki et al. 2002]. Low values of statistics W indicate a deviation from normality. Table 3 contains values of statistics W for individual volume increment indexes. For indexes C_1 and C_3 it is stated that in all the growing periods their distributions differ from the normal distribution. In case of index C_2 its distribution does not differ from the normal distribution for one growing period (11-15 years), while for C_4 three growing periods (16-20, 21-25 and 26-30 years). Possibly one of the reasons for such a situation is the fact that at the calculation of increment indexes C_1, C_2, and C_3 increment in height and increment in b.h.d. increment are taken into consideration. For some trees increment in height and increment in b.h.d. cross-section could have been distinctly lower, which resulted in a situation when increment in height and in breast height diameter differed from mean values of this characteristic, causing excessive increase of these three increment indexes.

Table 3. Assessment of normality of distributions for volume increment indexes using the W Shapiro-Wilk test in successive 5-year growing periods
Tabela 3. Ocena normalności rozkładów wskaźników przyrostu miąższości testem W Shapiro-Wilka w kolejnych 5-letnich okresach przyrostowych

Index Wskaźnik	Shapiro-Wilk W-test in the consecutive 5-year incremental periods Wartość statystyki W w kolejnych 5-letnich okresach przyrostowych					
	6-10 years 6-10 lat	11-15 years 11-15 lat	16-20 years 16-20 lat	21-25 years 21-25 lat	26-30 years 26-30 lat	31-35 years 31-35 lat
C_1	0.5209*	0.9779*	0.6993*	0.5287*	0.7342*	0.7647*
C_2	0.6568*	0.9853	0.8058*	0.9204*	0.8222*	0.9062*
C_3	0.5167*	0.8671*	0.5938*	0.9426*	0.9521*	0.9544*
C_4	0.6681*	0.9326*	0.9958	0.9925	0.9899	0.9705*

* Distribution differing from the normal distribution.
* Rozkład różniący się od rozkładu normalnego.

CONCLUSIONS

1. The lowest variation in the 35-year old pine stand in successive 5-year growing periods was found for two increment indexes, C_2, and C_4. A slightly higher variation was shown for index C_3, while the highest for C_1.

2. No distinct relationship was found between values of coefficients of variation of all analysed volume increment indexes and the age of trees in 5-year growing periods. However, it was found that the highest values of coefficients of variation for indexes C_1, C_2, and C_3 were recorded in the first growing period (6-10 years), while the lowest in the period of 11-15 years. In case of index C_4 they were periods of 31-35 years and 16-20 years, respectively.

3. No distinct trend or relationship was found between the arithmetic mean, calculated for the entire stand, for volume increment index C_3 and the age of trees. Arithmetic mean of index C_1 increased with the age of trees, similarly as in case of index C_2, with such a difference that in the last growing period this mean decreased. The mean for index C_4 decreased continuously with the age of trees.

4. Only for increment index C_2 its arithmetic means were always higher in the dominant stand than in the secondary stand. With one exception (period of 11-15 years) a similar situation occurred for index C_2. In case of the other two indexes such a regularity was not recorded.

5. In most cases the highest variation of indexes was found for trees of Kraft's class IVb and Va. In those stands, in which tending measures were taken (especially very intensive), variation in all volume increment indexes should be lower.

6. Results of this study are consistent with the analysis conducted by the author in two other pine stands. Low suitability for practice was found for indexes C_1 and C_3, primarily due to their high variation. A disadvantage of these two indexes was also the fact that they require the information on increment in height. Possible further studies should focus on the other two indexes, C_2 and C_4, and especially their relationship with primary taxonomic characters of trees.

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WSKAŹNIKI PRZYROSTU MIĄŻSZOŚCI I ICH ZMIENNOŚĆ W 35-LETNIM DRZEWOSTANIE SOSNOWYM

Streszczenie. W pracy poddano analizie cztery wskaźniki przyrostu miąższości pod względem podstawowych charakterystyk statystycznych. Materiałem empirycznym było 314 sosen, rosnących w 35-letnim drzewostanie sosnowym. Na ściętych drzewach wykonano analizę pniową i obliczono w kolejnych 5-letnich okresach przyrostowych cztery wskaźniki przyrostu miąższości C_1, C_2, C_3 i C_4. Najmniejszą zmiennością charakteryzują się dwa wskaźniki przyrostowe C_2 i C_4. Nieco większą zmienność wykazuje wskaźnik C_3, a największą C_1. Największe współczynniki zmienności wskaźnika C_1, C_2 i C_3 odnotowa-

no w okresie przyrostowym (6-10 lat), a najmniejsze dla okresu 11-15 lat. W wypadku wskaźnika C_4 był to odpowiednio okres 31-35 lat i 16-20 lat. Stwierdzono brak wyraźnej prawidłowości i związku pomiędzy średnią arytmetyczną wskaźnika przyrostu C_3 a wiekiem drzew. Średnia wskaźnika C_1 rośnie z wiekiem drzew podobnie jak wskaźnika C_2, z tą jednak różnicą, że średnia ta zmniejsza się w ostatnim okresie przyrostowym. Wskaźnik C_4 zmniejsza się wraz z wiekiem drzew. W większości przypadków odnotowano największą zmienność wskaźników dla drzew IVb i Va klasy Krafta. W drzewostanach, w których przeprowadzono zabiegi pielęgnacyjne, powinna być mniejsza zmienność wszystkich wskaźników przyrostu miąższości.

Słowa kluczowe: przyrost miąższości, wskaźniki przyrostu miąższości, sosna

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