THE DEGREE OF SIMILARITY OF DENDROCHRONOLOGICAL CURVES AS AN INDICATOR OF SITE CONDITIONS

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ABSTRACT

The paper presents an investigation of the possibility of using dendrochronological methods in determining the degree of the adaptation of spruce stands to the given site conditions. The results of the investigation were statistically evaluated. The results obtained may be of use for the problem of the selection of trees species suitable for specific ecological conditions.

L'article présente une recherche portant sur la possibilité d'utiliser les méthodes dendrochronologiques pour déterminer le degré d'adaptation de peuplements d'épicéas à des conditions stationnelles déterminées. Les résultats obtenus peuvent être utilisés pour aborder le probléme de la sélection des espèces arboréennes adaptées à des milieux écologiques déterminés.

Es wurde die Möglichkeit untersucht, die Anpassung von Fichtenbeständen an vorliegende Standortsbedingungen dendrochronologisch zu ermitteln. Die Ergebnisse wurden statistisch geprüft und können dazu beitragen, Baumarten für bestimmte ökologische Bedingungen auszuwählen.

INTRODUCTION

On the basis of dendroclimatological studies on spruce (*Picea excelsa* L.) in the Tatra Mountains, Ermich (1963, 1955) reported that the dendrochronological curves of separate groups of trees growing under various site conditions showed various degrees of similarity. The tree-ring curves of spruce growing on proper sites showed much greater similarity than these plotted for trees growing under conditions removed from the optimal ones. Similar conclusions may be drawn on the basis of the investigations carried out by Huber and Holdheide (1942), Feliksik (1972) and Fritts (1971).

These observations may suggest a hypothesis that spruce growing under conditions which meet their requirements show much greater uniformity in the leading tendencies of the dendrochronological curves than the trees grown under unfavourable conditions. In the former case the trees are better adapted to the site conditions than in the latter.

From the biological point of view this opinion may be substantiated as follows. In general, the trees growing on proper sites are healthy and resistant to the unfavourable climatic and biotic factors. Therefore, the process of their annual growth is not seriously disturbed and the course of their dendrochronological curves is usually similar, since it is chiefly influenced by climatic variations which affect individual specimens in a similar

*After an illustrious career in dendrochronology, Professor Ermich passed away in Krakow on 18 June 1976.

way. On the other hand, trees growing on sites which do not meet their requirements develop poorly, are less resistant to unfavourable environmental events, and are not healthy. The disturbances in the growth are much more conspicuous and not uniformly distributed in separate trees, this being visible in the much poorer similarity of growth rings of these trees.

The above suggestions may be also presented in the following way. If the trees of a given group of specimens show a consistent rhythm of variation in the width of annual rings, thus their satisfactory adaptability to the site conditions is thereby shown while poorer similarity of the curves suggests a lower degree of this adaptability.

This opinion may find a practical application in forestry, particularly in sylviculture and forest management, since it would be possible to predict on this basis whether a given stand grows under proper ecological conditions or not.

The aim of the present work was to verify this idea with regard to the spruce and to determine the practical value of the method discussed.

MATERIAL

Thirteen stations (Table 1) representing three categories of stands were used in the study: 1) Natural spruce stands of the upper mountain zone on the Babia Góra Mt and in the "Romanka" and "Pod Rysianką" nature reserves, representing patches of the Piceetum excelsae (tatricum) community characterized by pronounced ecological adaptabilities to limiting soil and climate conditions of montane sites (Celiński and Wojterski 1963; Kawecki 1939). These spruce trees show great resistance to the noxious action of biotic and physical factors. 2) "Butorza" and "Bukowiec" nature reserves including artificial but highly productive and hard fir-spruce stands formed on natural habitats of the forest communities of the primary lower mountain zone, chiefly the Carpathian beech forest (Fagetum carpaticum) and the spruce-fir forest (Abieti-Piceetum montanum). They are characterized with high quality class and biological expansiveness of the spruce and its marked hardiness to the noxious influences of insects and fungi (Alexandrowicz 1963; Myczkowski 1968; Rieger 1968). 3) The third category of spruce stands includes negative post beech plantations of foreign spruce in the Beskid Żywiecki chain (Forest division Węgierska Górka, forest district Zielone and Cięcinki) and in the Beskid Nowosądecki chain (Forest division Krynica, forest district Tylicz and Kopciowa). Unlike the well developed and highly productive stands in the "Butorza" and "Bukowiec" nature reserves, they are usually thinned, damaged, and frequently affected by various calamities (Chodzicki 1966; Gądek 1967; Mańka 1953; Myczkowski 1958).

METHODS

Preliminary

The investigation was carried out on the samples taken with Pressler increment borer from 13 stations. Seven stations (Table 1, nos. 1-7) were represented by 70 trees growing under the site conditions favourable for the spruce, while 49 trees from six stations (Table 1, nos. 8-13) were from negative spruce stands of artificial origin. On all stations dominant or semi-dominent trees (I and II Krafft class) without any symptoms of damages were selected. In separate groups the distance between trees did not exceed 100 meters.

From each tree three cores were taken at the height of 1.3 m and the annual rings of the period 1919-1969 were measured. For each tree the mean value of the annual

Table 1. List of the investigation areas with average percentages of dissimilarity.

No of the station	Forest division Forest district	Altitude above sea level (m)	Average percentage of dissimilarity	Community
		Specific habitats		
1.	Istebna Reserve "Bukowiec"	550	27.8	Artificial but of excellent quality, highly productive fir-spruce stands on natural habitats of forest communities of the primary lower mountain zone, chiefly the Fagetum carpaticum and Abieti-Piceetum montanum.
2.	Rycerka Reserve "Butorza"	650	26.6	
3.	Rycerka Reserve "Butorza"	650	27.0	
4.	Jeleśnia Reserve "Pod Rysianką"	1150	23.0	Natural spruce forests of the upper mountain zone (Piceetum tatricum)
5.	Jeleśnia Reserve "Romanka"	1350	25.5	
6.	Babia Góra National Park	1200	27.2	
7.	Babia Góra National Park	1200	27.2	
		Unspecific habitats		
8.	Węgierska Górka Ciecinki	700	34.1	Decisively negative, artificial fir-spruce stands on the habitat of the Carpathian beech forests (Fagetum carpaticum)
9.	Węgierska Górka Zielona	650	33.3	
10.	Krynica Kopciowa	700	40.6	
11.	Krynica Tylicz Huzary Mountain	800	36.9	
12.	Krynica Parkowa Mountain	700	40.7	
13.	Krynica Tylicz Szalone Mountain	750	42.9	

growth was computed and on this basis the dendrochronological curves of the investigated trees were plotted. The curves of separate trees were compared in pairs within separate groups, the number of counter-sectors of the curves compared being computed. The obtained value is used in the Huber formula (Bednarz 1973; Feliksik 1972)

$$R_o = \frac{n^- \times 100}{n - 1}$$

where R_o is the similarity coefficient of the curves, expressed in percent,
n^- is the number of inconsistent sectors of the curves compared,
n is the number of all compared sectors of the curves.

The R_0 percentage shows the degree of similarity of the curves of the two trees compared. The coefficients calculated in this way were then used in computing the arithmetic mean of similarity of the dendrochronological curves of spruce groups representing separate stations. Table 1 presents the preliminary results of the investigation only. It supports the opinion stated earlier that higher percentage of dissimilarity suggest poorer adaptability of trees to the site conditions, while lower percentages indicate better adaptation. The whole material was evaluated statistically in order to eliminate random errors from the results of the investigation.

Statistical analysis

In the next stage of the investigation the degree of similarity of the growth curves plotted separately for each group of spruce was estimated, the number of the counter-sectors being directly used, while their percentage in relation to all sectors was not computed.

The number of counter-sectors was computed for each pair of two curves of each group of trees separately. In the case of 10 trees measured, there were 45 such pairs, in the case of eight trees 28 pairs, and in the case of six and seven trees 21 and 15 pairs respectively. In general, $\frac{1}{2}n(n-1)$ pairs in the case of the *n* trees measured. The number of counter-sectors is a discrete random variate varying from pair to pair and from station to station. It was assumed that on one investigation area the distribution of this random variate is binominal. The variate was designated as *k*. Thus the figure

$$k_{ij}$$

expresses the quantity of counter-sectors of the pair number *i* and on the investigation area number *j*. With k_{ij} figures corresponding to one site a square matrix of *n* lines and *n* columns may be formed. Thus 13 matrices were set for further investigations.

On the basis of figures set together in the matrices for each site of a *j* number, the average quantity of $\bar{k}_{ij}$ counter-sectors was calculated using the formula

$$\bar{k}_j = \frac{1}{\frac{1}{2}n(n-1)} \sum_i k_{ij} \qquad (1)$$

and a hypothesis was made that the computed average $\bar{k}_j$ is an estimate of the expected number of counter-sectors in the 50-year period (1919-1969) for a random pair of trees from a *j* station. The value

$$p_j = \frac{\bar{k}_j}{50} \qquad (2)$$

was also computed and a hypothesis of a broader sense was made that in the case of each site of the *j* number, the p_j value[1] determined with the (2) formula, constitutes the estimate of the probability of the occurrence of counter-sectors on this station; this probability is constant in a pair of growth curves of two random trees at one station and equals p_j while the observed variability in the number of counter-sectors is of random character only. The hypothesis thus framed was verified using the Chi square test at the significance level = 0.05, the number of the degrees of freedom being $\frac{1}{2}n(n-1)$.

1) this value corresponds with the dissimilarity percentage in Table 1.

Therefore, for the k_{ij} variates a transformation was applied

$$Y_{ij} = 2 \text{ arc sin} \sqrt{\frac{k_{ij}}{50}} \tag{3}$$

then the statistic was calculated for each investigation area separately

$$_j^{(emp)} = 50 \cdot \sum_i \left(Y_{ij} - \bar{Y}_j\right)^2 \tag{4}$$

The statistic (4) was compared with a corresponding theoretical value χ^2 [0.05; ½ n(n − 1) − 1]. Moreover, the total average quantity of counter-sectors

$$\bar{k} = \frac{1}{119} \sum_j \sum_i k_{ij} \tag{5}$$

and corresponding probability

$$p = \frac{\bar{k}}{50}$$

were also computed.

In order to check the degree of variability among the stations a hypothesis is made that the expected number (determined with the formula 5), of $\bar{k}$ counter-sectors and the corresponding *p* probability are the same on all investigated areas, thus they do not depend on site conditions understood as a complex of factors. This hypothesis was varified using the Snedecor test at the significance level = 0.05 and the transformation (3) as before.

The evaluation proposed by natural scientists with regard to the relation between the habitats of the station and the ecological requirements of spruce was additionally checked with the use of the runs test.

Mathematical tables were used in transforming the variates and in verifying the hypotheses.

THE RESULTS OF THE STATISTICAL ANALYSES AND INTERPRETATION

The results of the investigation are presented in Tables 2 and 3. It was found that in 12 stations, with the exception of the station No. 9, the results of applying a test at the 0.05 level did not contradict the hypothesis made above, that the expected probability of the occurrence of counter-sectors was uniform, constant with each pair of growth curves for random two trees on one investigation area (Table 2). In the case of the station No. 9 the hypothesis may not be verified but at the 0.01 level. Nevertheless, separate stations considerably differ with regard to the value of this probability, the differences being significant. It is substantiated by the analysis of variance (Table 3). One should reject the hypothesis that the expected quantity of sectors amounts to 15.2 and is common, the same at all investigated stations, since the empirical F value of the statistic is much greater than the corresponding theoretical critical value.

Thus the statistical analysis shows that it is not by chance that in a number of the investigated areas there occur sites with a high degree of similarity of growth curves, with a small number of counter-sectors and low probability of their appearance and, at the same time, sites where among the growth curves no similarity occurs or is only poor.

Table 2. Results of the application of the test in verifying the hypothesis about the constancy of p_j probabilities.

Station number	Degrees of freedom $\frac{n(n-1)}{2} - 1$	Statistics Empirical (formula No 4)	Theoretical $0{,}05; \frac{n(n-1)}{2} - 1$
1	44	30.21	60.481
2	44	39.17	60.481
3	44	44.81	60.481
4	44	41.36	60.481
5	44	36.80	60.481
6	44	33.75	60.481
7	44	43.38	60.481
8	44	31.77	60.481
9	44	51.70	60.481
10	27	45.50	40.113
11	27	24.43	40.113
12	24	16.38	23.685
13	20	20.84	31.410

Table 3. Results of the application of the analysis of variance in verifying the hypothesis about the constancy of the *k* average.

Reasons of the variability	degrees of freedom	Sum of squares	Mean of squares	Statistic F
Differences among the sites	12	6.9563	0.5797	empirical $\frac{0.5797}{0.0189} = 30.67$
Differences between the pairs	484	9.1279	0.0189	theoretical F(0.05; 12; 484) =
Total	496	16.0842	–	1.77

Now, both important theses set at the beginning of the work and statistically verified should be repeated: (1) the probability of the occurrence of the counter-sectors of two random spruce vary on stations of a different geographical situation and of a different complex of site conditions, and (2) the probability of the occurrence of the counter-sectors in a pair of growth curves of two random spruce is the same with the trees of one station under determined equal conditions of the site and of the type of habitat.

What are the reasons of this phenomenon? Most probably they may be found in the relations which occur between the ecological requirements of trees and the habitat conditions of a given site.

In a series of stations two types of such conditions appear. The arrangement of separate stations according to the increasing average number of counter-sectors permits the use of the runs test. From the point of view of the type of the habitat two runs may be only differentiated in this series; one includes the first seven stations and the other the remaining six. As compared with the theoretical values of the corresponding 0.05 significance levels (this being the 3.11 interval), this small number of two runs in the investigated series suggests that the arrangement of the series is not fortuitous but determined by important significant reasons. Since in this case the limiting factor is the situation and the ecological conditions of the investigated areas, one may reasonably claim that these reasons are connected with the habitat conditions.

Nevertheless, this opinion should be further supported by extended dendrochronological investigations on more numerous material and on other important species of forest trees.

SUMMARY

On 13 stations the dendrochronological investigation was carried out on spruce trees, the annual growth rings for the period of 1919-1969 being determined. The dendrochronological curves were plotted and compared in pairs within separate stations, Huber dissimilarity percentage being calculated as illustrating the degree of similarity of the dendrochronological curves. It was found that the mean dissimilarity percentages of separate stations distinctly differed and depended on the site conditions.

The obtained results were verified using the Chi square test, the number of counter-sectors in each pair of the dendrochronological curves being transformed into continuous random variables. It was found that the probability of the occurrence of the counter-sectors (1) was different on sites differing by the complex of habitat conditions but (2) was identical with trees from one site and approximate on sites characterized by similar habitat conditions.

The results of the investigation permit reasonable solution of the problem of the selection of forest trees adapted to a given type of habitat, since the degree of the similarity of the dendrochronological curves expressed by the probability of the occurrence of the counter-sectors may be used as an indicator of the adaptation of trees to the habitat.

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