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Synanthropization indices of urban floras — an attempt at definition and assessment

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Abstract

The objective of this paper is to present the principle and results of selecting floristic parameters which best reflect the effects of different intensity and duration of anthropopressure within the borders of a large urban agglomeration (exemplified by Warsaw). Those parameters which in particular take into account such quantities as, for example, the percentage of kenophytes, therophytes-newcomers, permanently established synanthropes and so on, make it possible to assess the degree of advancement of flora synanthropization, including its temporal aspect. The results indicate that the selected parameters (especially their 3- or 6-component complexes) could also be of importance as indices of flora synanthropization in other cities, when floristic lists from different anthropopressure zones within each city are compared.

Key words: *flora synanthropization, anthropopressure zones, indices of flora synanthropization*

INTRODUCTION

It is obvious that the quantitative and qualitative composition of the flora of different areas within the borders of a town are variable in time and constitute, among others, the effect of local natural influences overlapped by the impact of man. This is, in turn, the result of the chances of migration and survival which, in a given area, man has created for specific plant species, eliminating at the same time other species more or less intentionally during the centuries of his activity.

Anthropopressure is defined by the author of this term (Olaczek 1972,

1974) as: "the complex of direct and indirect human impacts which cause changes in plant cover". A simplification of this is reducing anthropopressure to "a complex of anthropogenic factors". Anthropopressure as the cause of synanthropization process should be viewed in spatial and temporal aspects, both of which are equally important. The effect of the long-term activity of specific anthropogenic factors on flora is not the same as a single and short period of activity of the same factors with a comparable intensity. In the first of these cases the flora has time for a "response": a gradual decline of some species, introduction of others, their entrance to the existing plant communities and, therefore, the formation of new social connections, selection of new, more enduring ecotypes and so on. The rate of scale of flora synanthropization are, at least to some degree, a specific feature of a given area dependent on many historical and habitat factors. The properties of plants, their biology, ecology, dynamics of spreading are also very important.

The present paper deals with the degree of dependence between the selected quantities characterizing flora in Warsaw and the local intensity of anthropopressure. In other words, it is an attempt at characterizin the anthropopressure zones in the city by means of the mentioned quantities (further conventionally defined as floristic parameters). The value of the index would, therefore, incorporate only these parameters from among the proposed, which exhibit a distinct gradient when passing from a zone strongly transformed by man over many years, located in the centre of the city, towards the peripheries, where man's impact is in general limited or has occurred later.

The problem of floristic criteria, permitting the comparison of different areas is not new. Faliński (1966) introduced the concept of the index of natural object synanthropization. The same author (Faliński 1971) presented the following criteria for the distinctiveness of flora in different areas: the absolute number of species, the apophyte-anthropophyte ratio, the proportion of ephemerophytes, the geographical spectra of flora, the spectra of life forms. Kornaś (1977) proposed taking 3 indices into account when comparing specific floras: the index of modernization of the flora, the index of synanthropization of the flora and the index of instability of the flora. Pyšek (1989) compared ruderal floras of different areas in which the proportion of archaeophytes and kenophytes was considered. Sukopp (1972), Kunick (1974), Blume and Sukopp (1976) suggest taking into account the application of the following parameters when the flora of a compared areas is described: the number of plant species per 1 km^2, the percentage of anthropophytes, archaeophytes, kenophytes, therophytes and rare species in the flora. The critical examination of the usefulness of some indices as indicators of the current state of a habitat was introduced by Kowarik (1988).

It seems that particularly useful in comparing floras of specific areas, especially terrains of different intensity and variable duration of man's impact, would be those floristic parameters, which include the proportion of species particularly associated with man's activity, such as life forms (especially therophytes) and some groups also distinguished in the geographical-historical classification of synanthropic plants (Kornaś 1981, 1982). This application makes it possible to consider not only ecological, but also historical aspects of flora synanthropization process. The following should therefore be taken into account:

- the importance of permanently established alien species (the result of successful establishing of species, which has lasted under new conditions for a longer or shorter period);
- the importance of synanthropic newcomers (the effect of increased plant migration over a period of about 200 years);
- the importance of native and alien synanthropes (and therefore the result of changes in social connections);
- the consideration of annual species which are also synanthropic newcomers (associated in particular with unstable habitats, especially those created by man).

The aim of this paper is the selection of those quantities, among many theoretically possible, which characterize flora and adequately reflect the differentiation of anthropopressure zones. Each of the parameters so-chosen can be recognized in Warsaw as an index of the degree of advancement of flora synanthropization (index of flora synanthropization). It seems that most of them could have a more general meaning but this, however, would require verification in other cities. It may be assumed, when comparing floras, that greater credibility in assessing the degree of flora synanthropization can be achived when not only one of the above indices but several of them simultaneously are taken into account. This would be, therefore, a complex (compound) index of flora synanthropization.

MATERIAL AND METHODS

Subjected to analysis were over 50,000 items of floristic data (computer data base) collected from the Warsaw area over the last ten years (floristic lists in each of 225 square blocks with app. 1.5 km side each).

Each square in the Warsaw area was assigned to one of four anthropopressure zones distinguished within the city (Sudnik-Wójcikowska 1986, 1987). These zones were distinguished on the basis of following criteria: type of vegetation cover and form of land use dominating in each of the squares (including the history of man's impact).

- Zone A is characterized by the strongest and the longest lasting anthropopressure (compact settlement, ruined soils, permanent contamination of the area for a long time, dominance of ruderal communities).

- Zone B is characterized by a weaker anthropopressure (loose settlement, less contamination, segetal communities occurring alongside ruderal ones).
- Zone C – human influence is weaker or, when its influence is somewhat more marked, it has existed for a short time; seminatural communities dominate.
- In zone D a great proportion of the communities close to natural ones, although undoubtedly they remain within the range of big town influence.

The first attempt at determining the flora synanthropization index for the Warsaw area (using less data) has been presented in an earlier publication (Sudnik-Wójcikowska 1988). In this paper 28 floristic parameters assembled into 3 groups will be introduced. Some of these parameters correspond to the various indices of synanthropization proposed by other authors. The majority, however, are parameters that are, theoretically, possible to accept or parameters whose unsuitability will be indicated and these should be rejected. A similar principle of assessing the usefulness of a parameter as a possible index of flora synanthropization has been applied as in the previously cited paper. The total number of squares in each of the anthropopressure zones is considered to be a statistical sample (of size: $n_A = 62$, $n_B = 90$, $n_C = 55$, $n_D = 18$). Each square is characterized by a definite value of each of the 28 floristic parameters.

The statistical significance of differences between parameters in neighbouring anthropopressure zones was determined. A parameter was considered to be a potential index of synanthropization and was used further on when differences were statistically significant and a gradient of its values was found when passing from stronger to weaker anthropopressure zones.

The analyzed parameters can be divided into 3 groups. The abbreviations and designations used throughout this paper are as follows:
S – the total number of species; *Ns* – the number of nonsynanthropic species; *Ap* – the number of proper apophytes (euapophytes); *Ae* – the number of apophytes not established permanently in anthropogenic habitats; *Ar* – the number of archaeophytes; *Ep* – the number of epoecophytes; *Ag* – the number of agriophytes; *Ef* – the number of ephemerophytes; *Eg* – the number of ergasiophygophytes; *T* – the number of therophytes; *Ta* – the number of alien therophytes, otherwise therophytes-anthropophytes; *Tn* – the number of therophytes-newcomers, othervise therophytes which are epoecophytes, agriophytes, ephemerophytes or ergasiophygophytes as well.

Group I – parameters expressed in absolute values as the number of one or several groups of synanthropes per square:

P_1 – the total species numbers: $S = Ns + Ap + Ae + Ar + Ep + Ag + Ef + Eg$,
P_2 – the total anthropophyte number: $Ar + Ep + Ag + Ef + Eg$,
P_3 – the total number of permanently established anthropophytes: $Ar + Ep + Ag$,

P_4 – the total number of anthropophytes not permanently established: $Ef+Eg$,

P_5 – the total number of anthropophytes – synanthropic newcomers: $Ep+Ag+Ef+Eg$,

P_6 – the number of archaeophytes: Ar,

P_7 – the total kenophyte number: $Ep+Ag$,

P_8 – the number of alien therophytes: Ta.

Group II – parameters expressed (per square) as a reciprocal ratio of specific groups of synanthropers; these are mutually exclusive groups, they do not have any species in common:

P_9 – the ratio of the total number of anthropophytes to the total number of native species: $\frac{Ar+Ep+Ag+Ef+Eg}{Ns+Ap+Ae}$,

P_{10} – the ratio of the total number of anthropophytes to the total number of apophytes: $\frac{Ar+Ep+Ag+Ef+Eg}{Ap+Ae}$,

P_{11} – the ratio of the total number of permanently established anthropophytes to the number of proper apophytes (euapophytes): $\frac{Ar+Ep+Ag}{Ap}$,

P_{12} – the ratio of the number of kenophytes to the number of archaeophytes: $\frac{Ep+Ag}{Ar}$,

Group III – parameters expressed (per square) as the percentage of a specific group or groups of species within a larger whole (for example: the percentage in the flora, the percentage among the total number of therophytes and so on):

P_{13} – the percentage of synanthropic species in the flora: $\frac{Ap+Ae+Ar+Ep+Ag+Ef+Eg}{S} \times 100\%$,

P_{14} – the percentage (in the flora) of permanently established synanthropes: $\frac{Ap+Ar+Ep+Ag}{S} \times 100\%$,

P_{15} – the percentage of proper apophytes in the flora: $\frac{Ap}{S} \times 100\%$,

P_{16} – the percentage (in the flora) of non-synanthropes and native species not established permanently in anthropogenic habitats: $\frac{Ns+Ae}{S} \times 100\%$,

P_{17} – the percentage of anthropophytes in the flora: $\frac{Ar+Ep+Ag+Ef+Eg}{S} \times 100\%$,

P_{18} – the percentage of recent anthropophytes in the flora: $\frac{Ep+Ag+Ef+Eg}{S} \times 100\%$,

P_{19} – the percentage (in the flora) of permanently established anthropophytes: $\frac{Ar+Ep+Ag}{S} \times 100\%$,

P_{20} – the percentage (in the flora) of anthropophytes not established permanently: $\frac{Ef+Eg}{S} \times 100\%$,

P_{21} – the percentage of kenophytes in the flora: $\frac{Ep+Ag}{S} \times 100\%$,

P_{22} – the percentage of kenophytes among the total number of anthropophytes: $\frac{Ep+Ag}{Ar+Ep+Ag+Ef+Eg} \times 100\%$,

P_{23} – the percentage of recent anthropophytes (permanently or not permanently established) among the total number of anthropophytes: $\frac{Ep+Ag+Ef+Eg}{Ar+Ep+Ag+Ef+Eg} \times 100\%$,

P_{24} – the percentage of therophytes in the flora: $\frac{T}{S} \times 100\%$,

P_{25} – the percentage of therophytes-newcomers in the flora: $\frac{Tn}{S} \times 100\%$,

P_{26} – the percentage of alien therophytes in the flora: $\frac{Ta}{S} \times 100\%$,

P_{27} – the percentage of alien therophytes among the total number of therophytes: $\frac{Ta}{T} \times 100\%$,

P_{28} – the percentage of therophytes-newcomers among the total number of therophytes: $\frac{Tn}{T} \times 100\%$,

In order to assess the possible usefulness of the above 28 floristic parameters as indices of the degree of advancement of synanthropization a multi-staged selection process was carried out, successively eliminating those parameters which did not correspond to the criteria discussed below. The following detailed procedure was performed:

1. The frequency distributions of the successive parameters in each of the anthropopressure zones are presented in the form of frequency polygons. Analysis of graphs has enabled rough assessment of the possible usefulness of parameters (it required, however, confirmation using statistical methods) and has allowed the conclusion that the distributions do not have to be normal. This has determined the selection of nonparametric tests in the further procedure.

2. The nonparametric rank sum test (Greń 1984, Zar 1984) was applied to prove if significant differences between zones in respect to a given parameter value exist.

3. Afterwards, the method of nonparametric multiple comparisons with unequal sample sizes (Zar 1984) was applied for parameters for which

differences were found to be significant. This method made it possible to determine which pairs of zones exhibit statistically significant differences.

4a. On the above grounds, floristic parameters which best differentiate zones of various anthropopressure intensity were selected, namely those for which the differences between neighbouring zones: *A-B*, *B-C*, *C-D* were significant.

4b. The parameters for which significant differences had been shown between zones: *A-B*, *B-C*, *C-D* were considered additionally. There were no significant differences between zones of smaller anthropopressure intensity, that is C-D. Instead, this significance was maintained between zones B-(C+D).

5. Parameters selected in such a way (4a, 4b) can have certain indicatory value. It is conceivable that some of them indicate a high degree of reciprocal correlation. In order to eliminate such "similar" parameters cluster analysis was carried out. The results were presented in the form of a dendrogram obtained by Ward's method. The matrix of linear correlation coefficient (Kucharczyk 1982, Anderberg 1973) served to construct the dendrogram. Other methods of grouping of objects were applied giving similar results and have been omitted here; for example: the nearest neighbour method, the furthest neighbour method, the unweighed pair group method, the flexible sorting method (Moraczewski, unpublished materials).

Analysis of the dendrogram has shown groups of parameters (point 4a, 4b), which differentiate zones in a similar way. One parameter was chosen from each of the obtained clusters. The assemblage of these parameters, considered together, could represent the complex index of flora synanthropization.

6. The number of parameters in the complex can possibly be limited in favour of their quality, choosing only those for which the differences between all neighbouring zones: *A-B*, *B-C*, *C-D* has been found to be significant (point 4a).

RESULTS

1. The detailed data concerning specific values of each of the 28 floristic parameters in individual (225) squares are obtainable in the Department of Phytogeography of the Warsaw University. Presentation of the parameters' frequency distributions in each of the anthropopressure zones in the form of frequency polygons (Figs. 1-5) is intentional and useful for characterizing parameters. The following quantities are particularly important when the degree of flora synanthropization is involved:

a. The parameter ranges are not too wide in each of the zones.

b. The shifting of parameters from lower to higher values (or inversely) is marked when passing to successive zones ($A \rightarrow B \rightarrow C \rightarrow D$). Similarly, the

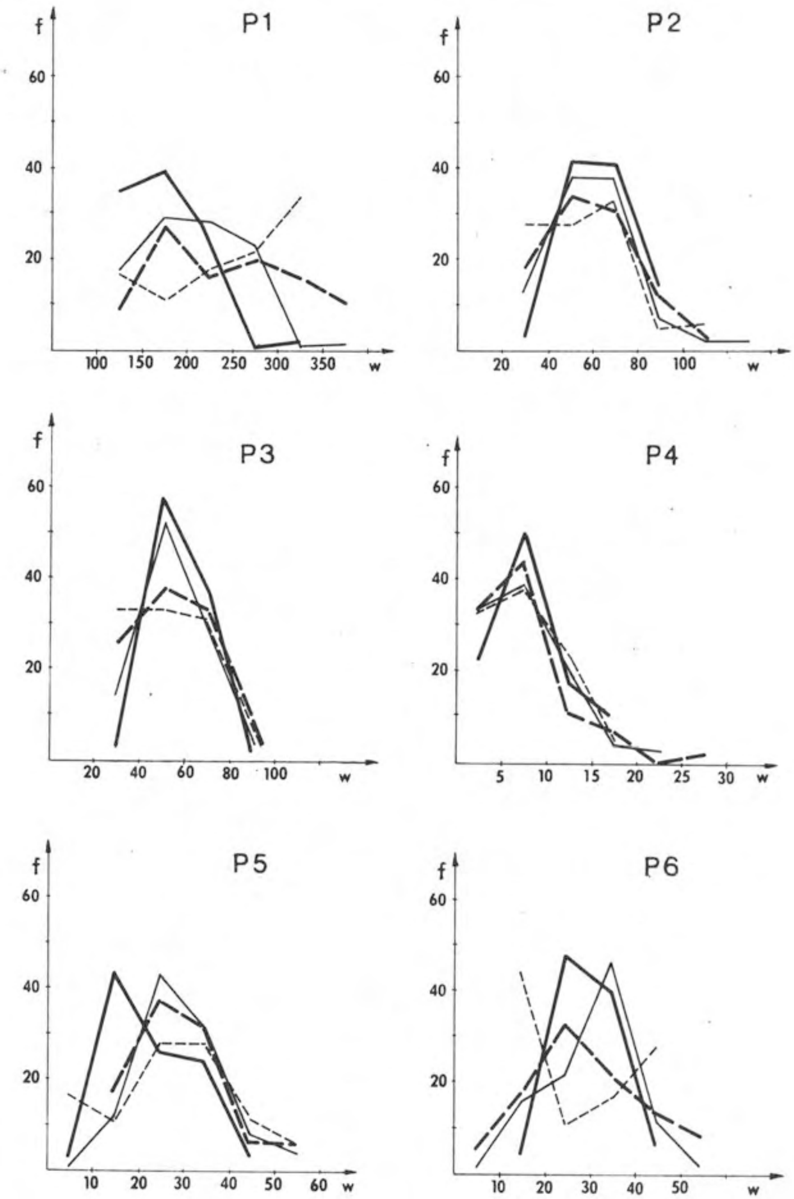

Fig. 1 Frequency polygons for the successive floristic parameters: P_1 - P_{28} (f — frequency, P — parameters values)

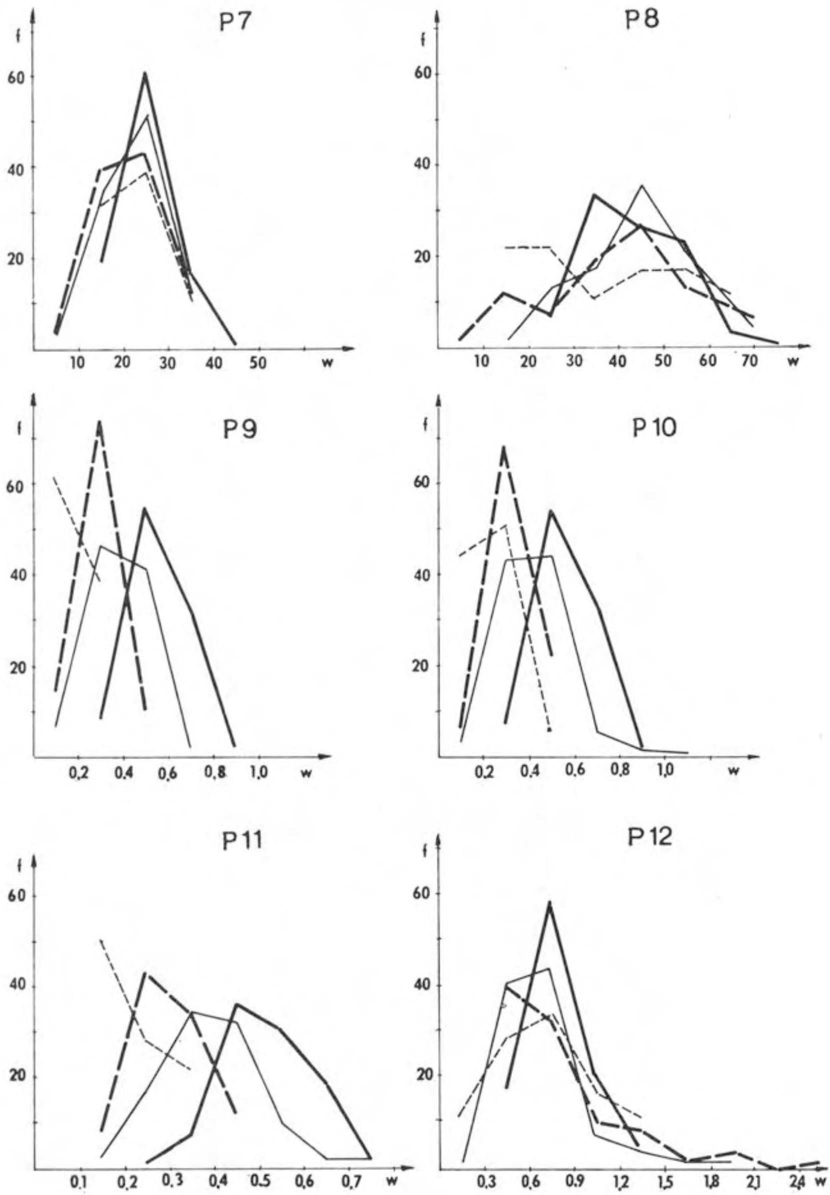

Fig. 2. Description as at Fig. 1

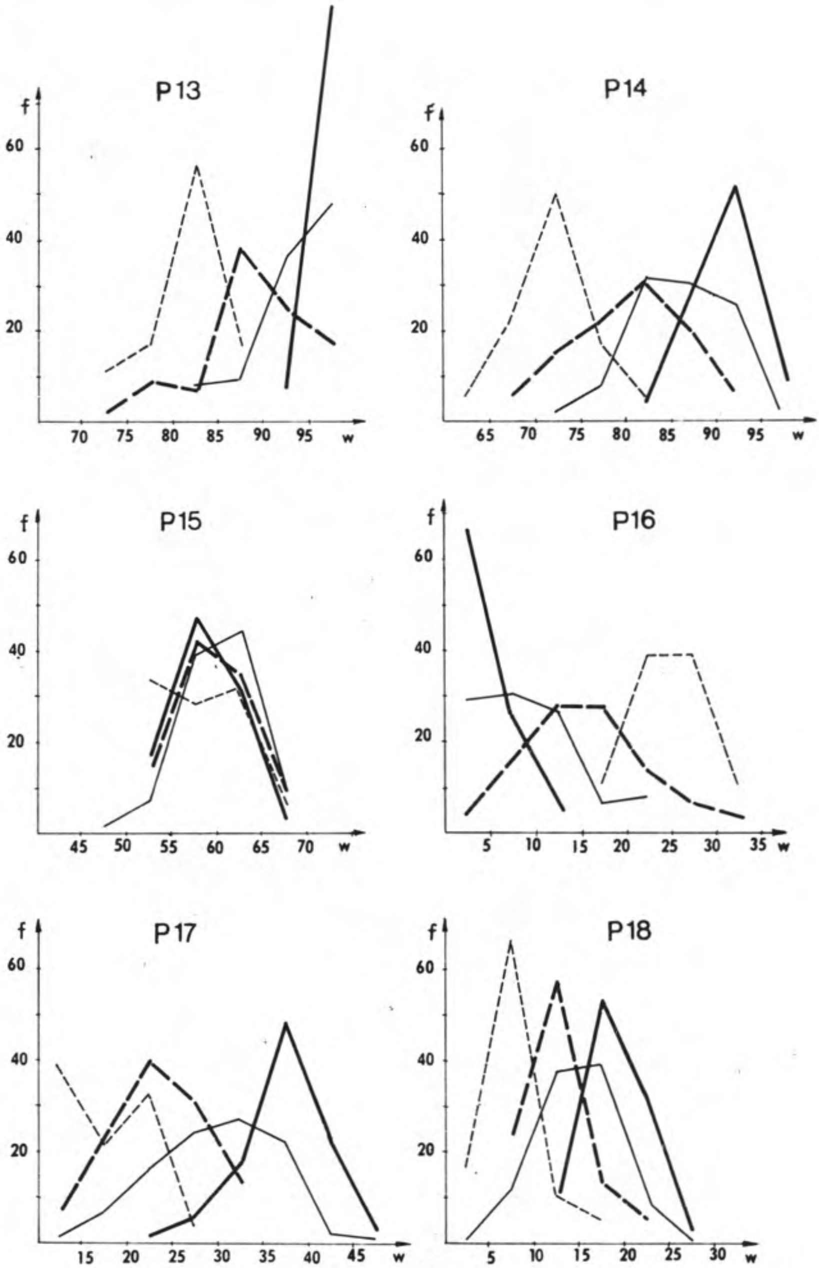

Fig. 3. Description as at Fig. 1

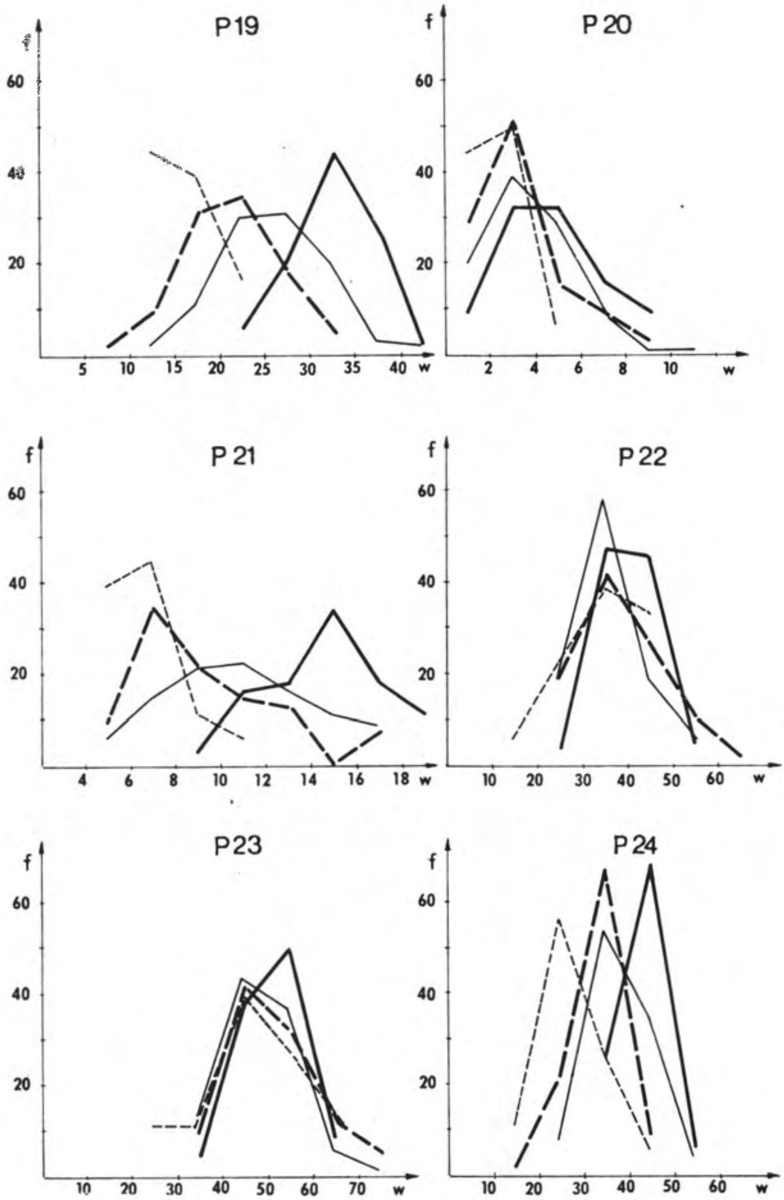

Fig. 4. Description as at Fig. 1

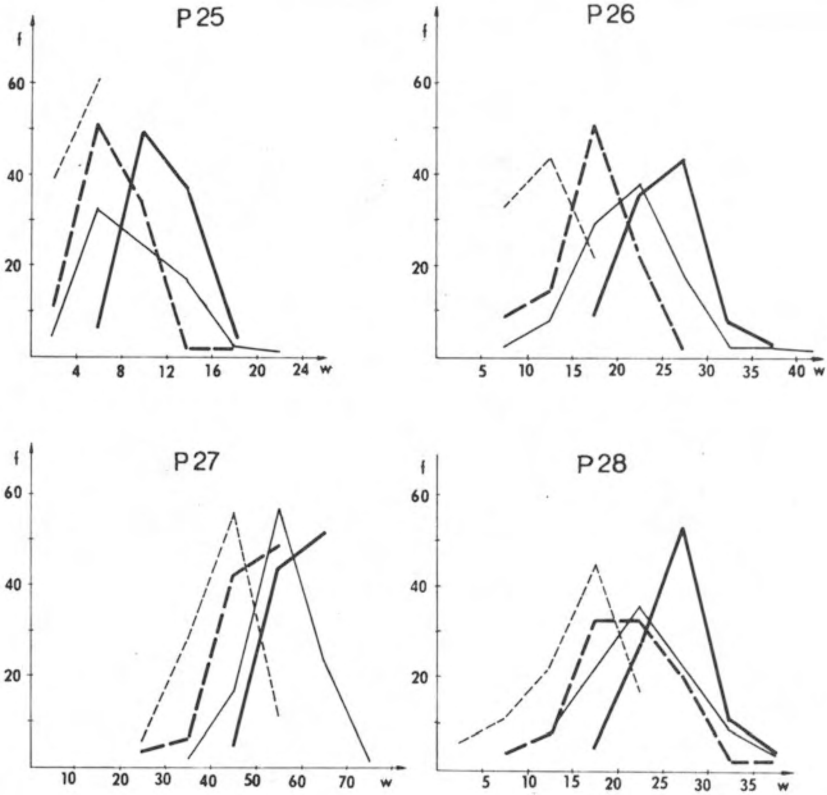

Fig. 5. Description as at Fig. 1

"peak" (therefore, the range of the most frequent values) is also displaced.

Analysis of frequency polygons, after considering the above annotations, enabled determination of the parameters having indicatory significance: P_9, P_{10}, P_{11}, P_{13}, P_{14}, P_{16}, P_{18}, P_{19}, P_{21}, P_{24}, P_{25}, P_{26}, P_{28} and probably P_{17}, P_{27}. This is a result of visual assessment, perhaps not deprived of certain subjectivism. It should be confirmed by indicating the statistical significance of differences between zones.

The results of the nonparametric rank sum test application with reference to the 28 floristic parameters are presented in the Table 1. Analysis of the obtained results does not show significant differences (at the level of odds $\alpha = 0.05$) between any zones in pairs for the following 6 parameters (calculated χ^2 values are distincly smaller than the limit value $\chi^2_{0.05'4} = 7.82$): P_2, P_3, P_4, P_5, P_6, P_8. Therefore, they do not have any indicatory significance.

3. The method of nonparametric multiple comparisons (at the level of odd $\alpha = 0.05$) was applied for the remaining 22 floristic parameters (Table 2). This

Table 1

Results of the nonparametric rank sum test applied to determine if anthropopressure zones differ significantly in respect to the values of each floristic parameter

Floristic parameters	Rank sum values for every anthropopressure zone				Calculated Chi-square value	Results of comparison with limit value ($\chi^2 = 7.82$)
	A	B	C	D		
1	2	3	4	5	6	7
P_1	4446.5	10027.5	7733.5	3217.5	53.25	+
P_2	7528.0	10290.0	5829.5	1777.5	2.58	–
P_3	7676.5	10313.5	5884.5	1750.5	2.42	–
P_4	7400.0	10108.5	6010.5	1906.0	1.00	–
P_5	8041.5	9771.0	5863.5	1749.0	6.09	–
P_6	6858.0	10885.5	5830.0	1851.5	2.50	–
P_7	8282.5	9763.5	5765.5	1613.5	9.82	+
P_8	7136.0	10715.5	5908.0	1665.5	3.03	–
P_9	10814.5	10410.0	3746.0	454.5	114.22	+
P_{10}	10699.5	10330.5	3847.0	548.0	105.00	+
P_{11}	10736.0	10254.0	3848.5	586.0	104.49	+
P_{12}	8304.5	8954.5	6377.5	1788.5	11.20	+
P_{13}	10748.0	10520.0	3794.0	363.0	115.38	+
P_{14}	10394.5	10804.0	3849.5	377.0	104.76	+
P_{15}	6090.0	11560.5	6311.5	1463.0	12.58	+
P_{16}	3253.5	9726.5	8722.0	3723.0	118.48	+
P_{17}	10814.5	10409.5	3746.5	454.5	114.21	+
P_{18}	10565.0	9982.5	4342.5	535.0	92.81	+
P_{19}	10855.5	10435.0	3704.0	430.5	117.35	+
P_{20}	8833.5	10351.0	5137.5	1103.0	29.14	+
P_{21}	10544.0	9975.5	4373.5	532.0	91.87	+
P_{22}	8254.0	9010.0	6291.0	1870.0	9.83	+
P_{23}	8027.0	9075.0	6661.5	1661.5	9.79	+
P_{24}	10139.5	10721.5	4049.0	515.0	88.55	+
P_{25}	10313.5	10318.5	4327.0	466.0	89.22	+
P_{26}	10374.5	10881.5	3710.0	459.0	103.96	+
P_{27}	10004.5	10965.0	3852.5	603.0	86.67	+
P_{28}	9882.5	9949.5	4952.0	641.0	63.91	+

+ – significant differences; – – no significant differences.

method enables the comparison of all four zones with each other: *A-B*, *B-C*, *A-C*, B-D, *A-D*, *C-D*.

4a. The significance of the differences between the neighbouring zones: *A-B*, *B-C*, *C-D* is very important for further considerations. This is shown for the following 5 parameters: P_{13}, P_{14}, P_{18}, P_{21}, P_{25}, and all four zones differ significantly in respect to the values of these parameters.

4b. On the other hand the differences in the successive 9 parameters were not found to be significant between the zones with the smallest anthropopres-

Table 2

Results of the applied method of nonparametric multiple comparisons

Floristic parameters	Calculated Q value for the successive pairs of anthropopressure zones and conclusions from its comparison with the limit value $Q_{0.05,4} = 2.639$											
	A-B		*B-C*		*A-C*		*B-D*		*A-D*		*C-D*	
	Q	Results	Q	Results	Q	Results	Q	Results	Q	Results	Q	Results
P_1	3.65	+	2.48	–	5.55	+	3.54	+	5.70	+	1.78	–
P_7	2.23	–	0.39	–	2.35	–	1.34	–	2.69	+	1.03	–
P_9	5.27	+	4.22	+	8.61	+	5.41	+	8.52	+	2.44	–
P_{10}	5.19	+	3.98	+	8.31	+	5.07	+	8.13	+	2.27	–
P_{11}	5.32	+	3.91	+	8.36	+	4.90	+	8.05	+	2.15	–
P_{12}	3.08	+	1.38	–	1.47	–	0.26	–	2.17	–	1.12	–
P_{13}	5.07	+	4.26	+	8.46	+	5.78	+	8.74	+	2.77	+
P_{14}	4.26	+	4.44	+	7.91	+	5.92	+	8.37	+	2.78	+
P_{15}	2.80	+	1.27	–	1.32	–	2.99	+	1.13	–	2.03	–
P_{16}	5.09	+	4.34	+	8.56	+	5.33	+	8.32	+	2.29	–
P_{17}	5.27	+	4.22	+	8.61	+	5.41	+	8.52	+	2.44	–
P_{18}	5.34	+	2.86	+	7.41	+	4.88	+	8.05	+	2.81	+
P_{19}	5.31	+	4.31	+	8.73	+	5.51	+	8.63	+	2.47	–
P_{20}	2.44	–	1.96	–	3.89	+	3.33	+	8.21	+	2.28	–
P_{21}	5.32	+	2.80	+	7.34	+	4.88	+	8.04	+	2.85	+
P_{22}	2.95	+	1.18	–	1.54	–	0.04	–	1.88	–	0.79	–
P_{23}	2.55	–	1.71	–	0.70	–	0.73	–	2.31	–	1.79	–
P_{24}	3.97	+	4.05	+	7.29	+	5.43	+	7.72	+	2.57	–
P_{25}	4.63	+	3.21	+	7.10	+	5.32	+	8.03	+	3.00	+
P_{26}	4.15	+	4.74	+	8.09	+	5.71	+	8.10	+	2.39	–
P_{27}	3.53	+	4.59	+	7.40	+	5.31	+	7.33	+	2.11	–
P_{28}	4.38	+	1.86	–	5.62	+	4.52	+	7.10	+	3.11	+

+ – significant differences; – – no significant differences.

sure: *C-D*. However, significant differences were found between: *A-B*, *B-C* (and *B-D*). Therefore, the differences exist among three zones: *A*, *B*, and $(C+D)$ and they are significant for: $P_9, P_{10}, P_{11}, P_{16}, P_{17}, P_{19}, P_{24}, P_{26}, P_{27}$. In the case of parameter P_{28} the differences between zones: *A-B*, *C-D* are significant but not so between *B-C*.

The applied statistical methods, therefore, confirm the conclusions which are drawn from rough analysis of frequency polygons. They make it possible to reduce the number of parameters to 15 which differentiate zones relatively well. These parameters will be taken into account in further considerations.

5. Analysis of the dendrogram structure obtained by Ward's method shows the occurrence of three basic groups of parameter (Fig. 6):

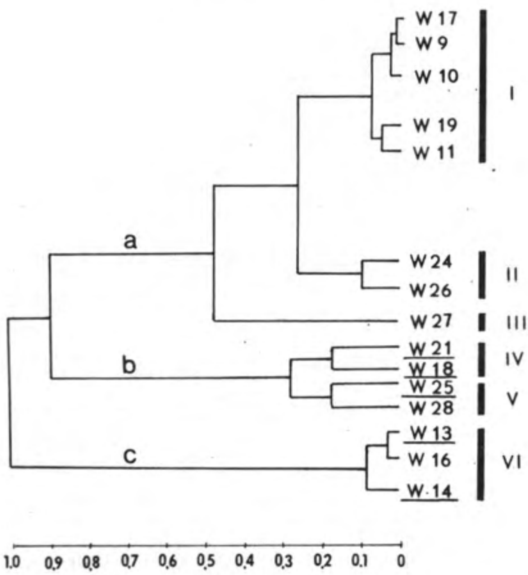

Fig. 6. Dendrograms of the value series of 15 floristic parameters (denoted W) obtained by Ward's method (relative scale, explanation in the text)

a. Parameters in which the percentage (or the number) of anthropophytes or therophytes is considered.

b. Parameters in which the percentage of synanthropic newcomers is considered.

c. Parameters in which the percentage of synanthropes (non-synanthropes) is considered.

Further disaggregation makes it possible to distinguish six clusters which can be treated as typological classes (Fig. 6):

Class I – parameters in which the number (or percentage) of anthropophytes (or anthropophytes permanently established) is considered: P_9, P_{10}, P_{11}, P_{17}, P_{19}.

Class II – parameters in which the percentage of therophytes (or alien therophytes) in the flora is considered: P_{24}, P_{26}.

Class III – a parameter in which the percentage of alien therophytes among therophytes is considered: P_{27}.

Class IV – parameters in which the percentage of recent anthropophytes (or kenophytes) in the flora is considered: P_{18}, P_{21}.

Class V – parameters in which the percentage of therophytes-newcomers in the flora (or in flora of therophytes) is considered: P_{25}, P_{28}.

Class VI – parameters in which the percentage of synanthropes (non-synanthropes) is considered: P_{13}, P_{14}, P_{16}.

Six-component complexes can be obtained by selecting one parameter from each of the six classes. There are many possible variants, for example:

P_{11} – the ratio of the total number of anthropophytes permanently established to the number of proper apophytes,
P_{26} – the percentage of alien therophytes in the flora,
P_{27} – the percentage of alien therophytes among therophytes,
P_{18} – the percentage of recent anthropophytes in the flora,
P_{25} – the percentage of therophyte-newcomers in the flora,
P_{14} – the percentage (in the flora) of synanthropes established permanently;

P_{10} – the ratio of the total number of anthropophytes to the total number of apophytes,
P_{24} – the percentage of therophytes in the flora,
P_{27} – the percentage of alien therophytes among therophytes,
P_{21} – the percentage of kenophytes in the flora,
P_{28} – the percentage of therophyte-newcomers among therophytes,
P_{13} – the percentage of synanthropes in the flora;

P_{9} – the ratio of the total number of anthropophytes to the total number of native species,
P_{24} – the percentage of therophytes in the flora,
P_{27} – the percentage of alien therophytes among therophytes,
P_{21} – the percentage of kenophytes in the flora,
P_{25} – the percentage of therophyte-newcomers in the flora,
P_{13} – the percentage of synanthropes in the flora;

P_{19} – the percentage (in the flora) of anthropophytes established permanently,
P_{26} – the percentage of alien therophytes in the flora,
P_{27} – the percentage of alien therophytes among therophytes,
P_{18} – the percentage of recent anthropophytes in the flora,
P_{25} – the percentage of therophyte-newcomers in the flora,
P_{14} – the percentage (in the flora) of synanthropes established permanently.

6. The "best" parameters showing significant differences within all neighbouring pairs of zones can be concentrated on by limiting even more the number of parameters in the complex. These are parameters from the following classes (underlined in Fig. 6): from class IV – P_{18}, P_{21}; from class V – P_{25}; from class VI – P_{13}, P_{14}. Therefore, four 3-component complexes of parameters are only possible, for example:

P_{21} – the percentage of kenophytes in the flora,
P_{25} – the percentage of therophyte-newcomers in the flora,
P_{14} – the percentage (in the flora) of synanthropes established permanently;

P_{18} – the percentage of recent anthropophytes in the flora,
P_{25} – the percentage of therophyte-newcomers in the flora,
P_{13} – the percentage of synanthropes in the flora.

Each of the proposed 6- or 3-component complexes of floristic parameters can play, at least in Warsaw, the role of a compound index of the advancement of flora synanthropization. It seems that such compound index could have a more general meaning. The value of the parameters in the complex should be taken into account when comparing floristic lists from two different areas within a given urban agglomeration, or the same area, but from two different periods. Larger values (smaller only in case of parameter P_{16}) could indicate a higher degree of flora synanthropization.

DISCUSSION

THE ASSESSMENT OF THE USEFULNESS OF THE PROPOSED FLORISTIC PARAMETERS FOR THE ESTIMATION OF FLORA SYNANTHROIPIZATION (EXEMPLIFIED BY WARSAW)

Many of the 28 parameters presented for verification should be rejected. Both the rough analysis of frequency polygons, as well as the results of the statistical methods applied indicate the unfitness of all of the parameters expressed in absolute numbers of specific synanthrope groups (P_1-P_8).

Zone *A* clearly differs from all the remaining ones in respect to the number of species per square (P_1), therefore, the differences: *A-B*, *A-C*, *A-D* are significant (Table 2). This is easy to justify due to the striking poorness of the flora in zone *A*, which is evidently associated with great uniformity of habitats and specific history of the areas in the centre of the city. However, neighbouring zones B-C and C-D do not have to differ significantly in respect to the species number, because of the variety of habitats possible in these zones: the greater richness of native flora is marked, at the same time they are still within the range of a big city's impact.

In the case of parameter P_7 (the number of kenophytes per square) the significance of differences is pronounced only between the most distant zones: *A-D* (Table 2).

Completely unsuitable are those parameters expressed as the percentage of recent anthropophytes (or kenophytes) among the total anthropophytes (P_{23}, P_{22}) and P_{15} – percentage of proper apophytes in the flora.

Parameter P_4 (the total number of anthropophytes not permanently established) constitutes the index of instability of the flora proposed by Kornaś (1977). It seems that the application of this index should possibly be limited only to sufficiently large areas and those where floristic observations are conducted for a similar time and sufficient duration. It appears that parameter P_{20} (the percentage of this group of species in the flora) also does not have, at least in Warsaw, greater indicatory value.

Analogically as in the case of parameter P_{12} (the kenophyte-archaeophyte ratio) – the index of modernization of flora (Kornaś 1977) significant differences were found only for stronger anthropopressure zones: *A-B*. It is somewhat suprising that, at least in Warsaw, the zones of the remaining pairs (even *A-D*) do not differ significantly. In zone *D* communities close to natural ones dominate, so the number of archaeophytes is smaller; the number of kenophytes is also limited (mainly hemi- or holoagriophytes). Hence the quotient value does not have to differ greatly from quotient for zone *A*, where both of these numbers are respectively larger.

The next group of parameters shows smaller limitations of their indicatory role: they differentiate the neighbouring zones in pairs with the exception of the least disturbed: C-D. Therefore, differences are found to be significant between zones: *A-B*, *B-C*, *B-D*. Parameters P_9, P_{10}, P_{11} expressed as the ratio of aliens (the total number of anthropophytes, anthropophytes permanently established) to the number of native species (apophytes, proper apophytes) belong here. The lack of significant differences between weaker anthropopressure zones can be explained by $\pm$ simultaneous decline in the number of native, as well as alien synanthropes in zone *D*, in comparison with zone *C* (the quotient value does not have to change significantly).

The lack of significant differences between zones *C-D* in the case of parameters P_{16}, P_{17}, P_{19} is striking. P_{16} is expressed as the percentage in the flora of non-synanthropes and native species not established permanently in anthropogenic habitats; perhaps at least some portion of the species which are not synanthropes in zone *D* can appear temporarily in zone *C*, in habitats somewhat transformed by man. The total percentage of both species group in the flora can be rather similar. It is difficult to explain the limitation of the application of parameters P_{17}, P_{19} in which the percentage of anthropophytes and permanently established anthropophytes is considered. However, attention should be paid to the results of the sum rank test: Q values (correspondingly 2.47 and 2.44) are in both cases comparatively approximate to the limit value $Q_{0.05,4} = 2.639$ (Table 2).

Parameters from P_{24} to P_{28} take into consideration the number of therophytes. The differences are markedly significant within all neighbouring zones in pairs, even between *C-D*, for parameter P_{25} (the percentage of therophyte-newcomers in the flora). Perhaps this is associated with a limited entrance of annual newcomers to the close to natural communities dominating in zone *D* (many agriophytes are perennial plants).

However, the significance of the differences between zone *C-D* disappears when P_{24} – the percentage of the total number of therophytes in the flora – is considered (and therefore, one must also deal with the ancient aliens and annual species which are not synanthropes, and associated in Warsaw, for example, with swards on sands, riverside alluvia and the like). Similar test results are obtained with reference to parameters in which the percentage of alien therophytes in flora (P_{26}) and among the total therophytes (P_{27}) is taken into account.

The most sensitive and best differentiating neighbouring zones are parameters (besides P_{25} mentioned above) not expressed in absolute numbers and in which such values as: synanthrope number, the number of synanthropes already established permanently, the number of recent anthropophytes or kenophytes – are attributed to the local richness of flora (P_{13}, P_{14}, P_{18}, P_{21}). Therefore, it should be emphasized that most of the parameters that are considered to be best include the proportion of those synanthropes whose numbers are associated with the duration of man's impact.

It is worth noting that the results of the nonparametric multiple comparisons method will change somewhat when the level of odds $a = 0.1$ instead of $a = 0.05$ (then the limit value $Q_{0.1 \cdot 4} = 2.394$). In this case the following parameters differentiating all zones in pairs (besides those mentioned above) should be considered: P_9, P_{17}, P_{19}, P_{24}.

GENERAL REMARKS CONCERNING ANTHROPOPRESSURE AND INDICES OF FLORA SYNANTHROPIZATION PROCESS

Both the intensity of anthropopressure and the synanthropization process can not be measured directly. Indirect assessment unfortunately requires a series of generalizations and approximations.

Undoubtedly, the establishment of a four degree anthropopressure scale is quite a gross simplification. The basic unit in each of the anthropopressure zones, a square c. 1.5 km side each, is large enough to constitute a mosaic of vegetation, habitat types, forms of land-use, areas of different history. Squares were assigned to an appropriate zone on the grounds of surface domination of specific vegetation type, form and history of land-use. Meanwhile, the changing intensity of man's impact should be treated as a time-space continuum. The necessity of assigning each square to a definite zone, sometimes required an arbitrary approach. If "typical", selected squares are compared (and their number is adequately large) then sharper differences of definite floristic parameters might be expected between zones.

The search for indices of flora synanthropization is, therefore, an attempt at determining general tendencies, which because of a certain heterogenity of objects (squares) appear only when their number is adequately large.

The expectation of simple relationships between anthropopressure and indices of synanthropization seems to be a misunderstanding. Indices are created when a species group distinguished in the classification of Kornaś (1981, 1982) is taken into account. This is a geographical-historical classification and has constituted a valuable supplement for the division of synanthropes proposed since the beginning of XX century (Rikli 1903, Naegeli and Thellung 1905). However, it is an artificial, conventional division, not free of certain simplifications, as are many other divisions in sciences.

It is obvious that man's impact, above all, determines the nature of the flora in areas of various degrees of urbanization. The properties of plants also have some significance: the ability to survive, the biology of reproduction and dispersal, the capability of occupying new terrains and permanent establishment in others. Hence the significance which the proportion of permanently established species, especially synanthropic newcomers, has for the assessment of the state of flora. However, floristic parameters which consider the discussed "geographical-historical" species groups can not possibly be applied directly and only as indicators of the existing habitat conditions (compare also Kowarik 1988 and his actualistic conception of hemeroby). Instead, the idea of indicator value of vascular plants (Ellenberg 1979) is useful for the assessment of the habitat state. Many authors have applied it with success (for example: Witting and Durwen 1982, Klotz 1987, Gödde and Wittig 1983, Durwen et al. 1984, Janssen and Brandes 1984, Pyšek and Pyšek 1988).

GENERAL REMARKS CONCERNING THE POSSIBILITY OF APPLYING INDICES OF THE FLORA SYNANTHROPIZATION PROCESS

It might be expected that the role of an index showing the degree of advancement of flora synanthropization would be better played by an entire complex of indices, then any of the chosen floristic parameters individually. Therefore, it is possible to limit the role of chance in the assessment of flora synanthropization of different areas within a given urban agglomeration.

Each of the proposed 6- and especially 3-component complexes of the selected floristic parameters could have such a significance. It has been proved that they well differentiate anthropopressure zones – on the one hand, and do not show greater reciprocal correlation – on the other.

It seems that a general tendency should become marked when comparing floristic lists from zones of different anthropopressure intensity: a gradual change of the value of floristic parameters belonging to the complex, as human impact intensifies (the increase of all parameters' values with the exception of

P_{16}). This also concerns the comparison of floristic lists from the same area but derived from different periods: earlier, when anthropopressure was in general smaller, and current.

The acceptance of equal criteria of classifying species to definite groups in the geographical-historical classification of synanthropic plant is essential in any comparison. The species status is not a constant feature, but has a local meaning and can change in time (for example: in a given town, species can attain the first stages in the establishing process, in another, however, it may have been a permanent element of synanthropic flora for a long time; in a given terrain the species is a native element of the synanthropic flora, in another it should be classified as alien). In this paper a somewhat simplified assumption has been accepted, that in a stated time in a given town the status of synanthropes is more or less constant. This means that under the existing geographical conditions the potential possibilities of establishment of species, as well as their time of arrival can be determined unequivocally.

The possibility of comparing value ranges of indices not only within different zones of one town, but in analogical anthropopressure zones of different towns is a separate problem. Perhaps these towns should not be located far from each other. However, it is conceivable that the characteristic features of individual towns: their history, function, degree and period of industrialization will make these comparisons impossible.

The following problems, which are beyond the framework of this paper, therefore, still remain to be solved:

1. The more or less universal significance of complex indices, and therefore, the possibility of their application with reference to the urbanized areas of lowland Poland, entire Poland, or Central Europe.
2. The surface of compared areas – the appropriate number of basic units (squares) and their size.

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REFERENCES

Anderberg M. R., 1973. Cluster analysis for applications. Academic Press, New York, 360 pp.

Blume H. P., Sukopp H., 1976. Ökologische Bedeutung anthropogener Bodenveranderungen. Schr. R. Vegetationskde 10: 75-91.

Durwen K. J., Berkhoff F. W., Wittig R., 1984. Zur Auswertung der floristischen Kartierung der Bundesrepublik Deutschland mit Hilfe von Zeigerwerten. Verhandl. Ges. für Ökologie 12: 289-294.

Ellenberg H., 1979. Zeigerwerte der Gefässpflanzen Mitteleuropas. Scripta Geobotanica 9: 5-122.

Faliński J. B., 1966. Antropogeniczna roślinność Puszczy Białowieskiej jako wynik synantropizacji naturalnego kompleksu leśnego. Rozprawy Uniw. Warszawskiego 13: 1-256.

Faliński J. B., 1971. Flora i roślinność synantropijna wsi i miast – próba analizy porównawczej. Mater. Zakł. Fitosoc. Stos. UW 27: 15-37.

Gödde M., Wittig R., 1983. A preliminary attempt at a termal division of the town of Münster (North Rhine-Westphalia, West Germany) on a floral and vegetational basis. Urban Ecology 7: 255-262.

Greń J., 1984. Statystyka matematyczna. Modele i zadania. PWN, Warszawa, 363 pp.

Janssen Ch., Brandes D., 1984. Struktur und Artenvielfalt von Randzonen der Grossstädte dargestellt am Beispiel von Braunschweig. Braunschw. Naturk. Schr. 2.1: 57-97.

Klotz S., 1987. Floristische und vegetationskundliche Untersuchungen in Städten der DDR. Düsseldorfer Geobot. Kolloq. 4: 61-69.

Kornaś J., 1977. Analiza flor synantropijnych. Wiad. Bot. 21: 85-91.

Kornaś J., 1981. Oddziaływania człowieka na florę: mechanizmy i konsekwencje. Wiad. Bot. 25: 165-182.

Kornaś J., 1982. Man's impact upon the flora: processes and effects. Memorabilia Zool. 37: 11-30.

Kowarik I., 1988. Zum menschlichen Einfluss auf Flora und Vegetation. Theoretische Konzepte und ein Quantifizierungsansatz am Beispiel von Berlin (West). Landschaftsentwicklung u. Umweltforschung 56, Tech. Univ., Berlin, 280 pp.

Kucharczyk J., 1982. Algorytmy analizy skupień w języku ALGOL 60. PWN, Warszawa, 275 pp.

Kunick W., 1974. Veränderungen von Flora und Vegetation einer Grossstadt dargestellt am Beispiel von Berlin (West). Diss. Tech. Univ. Berlin, Berlin (West), 453 pp.

Naegeli D., Thellung A., 1905. Die Flora des Kantons Zürich. I. Teil. Die Ruderal- und Adventivflora des Kantons Zürich. Viertelj. Schr. naturf. Ges., Zürich 50: 225-305.

Olaczek R., 1972. Formy antropogenicznej degeneracji leśnych zbiorowisk roślinnych w krajobrazie rolniczym Polski niżowej. Wyd. Uniw. Łódzkiego, Łódź, pp. 170.

Olaczek R., 1974. Etapy pinetyzacji grądu. Phytocoenosis 3. 3-4: 201-213.

Pyšek A., Pyšek P. 1988. Standörtliche Differenzierung der Flora der westböhmischen Dörfer. Fol. Mus. Rer. Natur. Bohem. Occid., ser. Bot. 28: 1-52.

Pyšek P., 1989. Archeofyty a neofyty v ruderální flóře některých sidlišt v Čechách. Preslia 61: 209-226.

Rikli M., 1903. Die Anthropochoren und der Formenkreis des *Nasturtium palustre* DC. Ber. zürich. bot. Ges. 13: 71-82.

Sudnik-Wójcikowska B. 1986. Distribution of some vascular plants and anthropopressure zones in Warsaw. Acta Soc. Bot. Pol. 55: 481-496.

Sudnik-Wójcikowska B., 1987. Flora miasta Warszawy i jej przemiany w ciągu XIX i XX w. Vol. 1 i 2. Wyd. Uniw. Warszawskiego, Warszawa, 242+435 pp.

Sudnik-Wójcikowska B., 1988. Flora synanthropization and anthropopressure zones in a large urban agglomeration (exemplified by Warsaw). Flora 180: 259-265.

Sukopp H., 1972. Wandel von Flora und Vegetation in Mitteleuropa unter dem Einfluss des Menschen. Ber. Landwirsch. 50: 112-130.

Witting R., Durwen J. K., 1982. Ecological indicator-value spectra of spontaneous urban floras. In: R. Bornkamm, J. A. Lee, M. R. D. Seaward, Urban Ecology. Symp. Bln. 1980. Oxford-London-Edinburgh-Boston-Melbourne: 23-31.

Zar J. H., 1984. Biostatistical analysis. Prentice Hall., Englewood Cliffs, 718 pp.

Wskaźniki procesu synantropizacji flor miejskich — próba zdefiniowania i oceny

Streszczenie

W pracy zostały wykorzystane wyniki 10-letnich badań florystycznych prowadzonych na terenie Warszawy. Materiał stanowiły spisy florystyczne z 225 kwadratów zaliczonych do określonych stref antropopresji.

Proces synantropizacji flory jest przejawem jej reakcji na nasilenie antropopresji, która definiowana jako "całokształt bezpośrednich i pośrednich oddziaływań człowieka, wywołujących zmiany w szacie roślinnej" i będąca sprawcą procesu synantropizacji, powinna być rozpatrywana zarówno w aspekcie przestrzennym, jak i czasowym.

Celem pracy było znalezienie wskaźników procesu synantropizacji flory, a więc wybór spośród teoretycznie możliwych wielkości charakteryzujących florę (określanych umownie jako parametry florystyczne) tych, które w sposób najbardziej adekwatny odzwierciedlają zróżnicowanie antropopresji. Są to zatem parametry uwzględniające liczebność grup gatunków szczególnie związanych z działalnością człowieka (niektóre grupy wyróżnione w geograficzno-historycznej klasyfikacji roślin synantropijnych Kornasia (1981), niektóre terofity) oraz wykazujące określony gradient przy przejściu od stref silniejszej do słabszej antropopresji.

Ocenę przydatności parametrów przeprowadzono traktując ogół kwadratów w każdej ze stref jako próbę statystyczną i stosując określone metody statystyczne (test sumy rang, metodę nieparametrycznych porównań wielokrotnych dla prób o nierównej liczebności, metodę analizy skupień). W rezultacie kilkustopniowej selekcji parametrów florystycznych uzyskano 6-, a przy ostrzejszych kryteriach 3-składnikowe kompleksy. Kompleks parametrów florystycznych może pełnić rolę zbiorowego wskaźnika zaawansowania procesu synantropizacji flory (zbiorowego wskaźnika stopnia synantropizacji flory). Przykłady takich kompleksów przedstawiono w rozdziale "Wyniki".

Większe wartości parametrów w kompleksie (mniejsze tylko w przypadku jednego parametru) wskazywałyby na większe zaawansowanie procesu synantropizacji flory danego terenu, w porównaniu z innym, w obrębie tej samej aglomeracji miejskiej. Wydaje się, że jest to pewna ogólna tendencja, która powinna być zachowana przy porównywaniu ze sobą stref o różnym nasileniu antropopresji także w obrębie innych miast. Odnosi się to również do list florystycznych z tego samego obszaru, lecz z różnych okresów (zmieniające się w czasie nasilenie antropopresji). Warunkiem porównań jest przyjęcie jednakowych kryteriów zaliczania gatunków do grup w geograficzno-historycznej klasyfikacji roślin synantropijnych. Status gatunków powinien być określony zgodnie z aktualnym dla danego miasta i danego okresu stanem flory (etap zadomawiania się gatunku, jego indygenat).

Sprawą otwartą pozostaje natomiast mniej lub bardziej uniwersalny charakter zbiorowego wskaźnika stopnia synantropizacji flory. Należałoby stwierdzić, czy i na ile istnieje możliwość porównania zakresów wartości parametrów nie tylko w obrębie jednego miasta, lecz w analogicznych strefach różnych, zwłaszcza odległych miast. Odrębnym zagadnieniem jest minimalna powierzchnia porównywanych obszarów.