ANALYSIS OF DIVERSITY INDICES USED IN THE STUDY OF HERBAL PHYTOCENOSES

PĂTRUȚ D., ANGHEL C., BOLDEA M.

This paper presents the analysis of indices applied when studying the phytocenoses. The main indices that measure the diversity of a phytocenoses formed by S species and N individuals ($1 \leq S \leq N$) are represented in the paper by the formulae (1)–(5). In order to reduce these indices to the same variation range (0;1) one has to calculate the relative or equitability indices by dividing them by the maximum index (corresponding to the maximum diversity). Each maximum index can be calculated either by reducing N to the S value, or by increasing S up to the N value. We consider that it is important to calculate the maximum indices by keeping S and N constant and by achieving the uniform distribution of species individuals (relation 6). In the paper, we have calculated these absolute and relative indices both for more typical theoretical variants and for three practical situations achieving thus the present conclusions.

Key words: diversity indices, phytocenoses diversity.

INTRODUCTION

Theoretical analysis. The most evident feature of the vegetal association diversity is the specific richness (abundance), represented by the totality of species, that make it up (Frontier S., Pichod-Viale D., 1993). Thus, the given vegetal association presents a large diversity, if its phytocenoses are composed of a large number of species, and a low diversity, when the number of species is low. The specific richness is an insufficient parameter for the ecosystem diversity determination (Barboult R., 1992), as two vegetal associations can have the same degree of diversity if their number of species is equal, although some of the species can be represented by a small number of individuals. Therefore the determination of some quantitative species parameters as abundance, frequency, biomass, is necessary.

The study of vegetal associations diversity rises serious problems, when determining the populations (number of individuals) of the composing species, mostly when the herbal cover is dense. Besides, some annual or perennial species include bushes, so that it is almost impossible to determine if they are made up of one or more individuals. The most exact method to determine the number of individuals / species is their counting over an area corresponding to the minimal one. But as this method is a very difficult one, we used more efficient methods, as for instance those offered by the scale ecology (Pichett S.T.A., Rogers K.H., 1997, cited by Soran V. *et al.*, 1999), or the point area sampling procedure described by Gounot M. (1969) irrespective of the method used the collected data can be used for the diversity indices calculation.

In the literature (Hajdu L., 1976, Nosek J.N., 1976, Botnariuc N., Vădineanu A., 1982, Maarel van der E., 1988, Barboult R., 1992, Boşcaiu Monica, 1993, Frontier S., Pichod-Viale D., 1993, Stugren B., 1994, Hawsworth D.L., 1998, Krebs Ch.J., 1999, Soran V. *et al.*, 1999 etc.) we can find many diversity indices.

One category of diversity indices takes into account the total number of species (S) and a total number of individuals (N) presents on the sampling surface. From this category the following indices are most frequently mentioned:

– the Monk index: $d = \frac{S}{N}$

– the Gleason index: $d = \frac{S}{\log N}$

– the Margalef index: $d = \frac{S-1}{\ln N}$

– the Menhinic index: $d = \frac{\log S}{\log N}$

– the Willis index: $d = \frac{S^2}{N}$

More important are the indices that take into account the concentration of each species (n_I):

– the Gini mutability : $$D_G = 1 - \sum_{i-1}^{S} \left(\frac{n_i}{N} \right)^2 \quad (1)$$

– the McIntosh index: $$D_M = \frac{N - \sqrt{\sum_{i=1}^{S} n_i^2}}{N - \sqrt{N}} \quad (2)$$

– the Simpson index: $$D_S = 1 - \frac{\sum_{i=1}^{S} n_i (n_i - 1)}{N(N-1)} \quad (3)$$

The diversity indices derived from the information theory that have been used most widely are:

– the Shannon-Weaver index: $H^{/} = -\sum_{i=1}^{S} \frac{n_i}{N} \log_2 \frac{n_i}{N}$ (4)

– the Brillouin index: $H = \frac{1}{N} \log_2 \frac{N!}{n_i! n_2! ... n_s!}$ (5)

The diversity indices can be applied perfectly on vegetal communities of similar size or yield capacity (productivity). On the contrary, each species "i" is given a new magnitude as compared with standard species (of the size one).

If we calculate the value of an index by using one of the (1)–(5) functions, we cannot be sure that the value of this index is great or small, if we do not know how near or far that value is to the maximum or minimum index. Therefore we must calculate for every index the maximum and minimum value that is the definition or variation range. For doing this it is necessary to define the terms minimum and maximum diversity. Nosek J.N. (1976) does it in one of his papers in the following way:

– diversity is maximum if: S = N and N > 1.

Under these conditions $n_I = N$ and all indices (1)–(5) are zero. If the association is made up of the same species, then no diversity exists. A more rigorous analysis is necessary when the maximum diversity is calculated as for some indices the maximum depends either on the number of species (S) or on the total number of individuals (N).

– diversity is maximum when:

a) S = N if S > 1 and N > 1

In such conditions $n_i = 1$ (i = 0, 1, 2, ..., S = N). Diversity is maximum when each individual belongs to another species. That means that the number of species is equal to the number of individuals (S = N). When calculating the maximum indices values we obtain:

$$D_{G\max} = 1 - \frac{1}{N},\ D_{S\max} = 1,\ D_{M\max} = 1,\ H^{/}_{\max} = \log_2 N,\quad H_{\max} = \frac{1}{N}\log_2 N!$$

b) maximum diversity if:

1 < S < N and $n_1 = n_2 = \ldots n_s = N/S$, i.e. a uniform distribution of individuals among the species.

When calculating the maximum indices values we obtain:

$$D_{G\max} = 1 - \frac{1}{S}$$

$$D_{S\max} = 1 - \frac{N-S}{S(N-1)}$$

$$D_{M\max} = \frac{1-\frac{1}{\sqrt{S}}}{1-\frac{1}{\sqrt{N}}} \tag{6}$$

$$H'_{\max} = \log_2 S$$

$$H_{\max} = \frac{1}{N}\left[\log_2 N! - S\log_2\left(\frac{N}{S}\right)!\right]$$

If N/S is not a round number we calculate with round n_i, nearest to the fraction N/S. If N is too big and it surpases the capacity of a calculator, the following formula can be used:

$$\ln N! = \ln\sqrt{2\pi} + \ln\sqrt{N} + N\ln N - N.$$

The change for the logarithmic relation is carried out with the formula:

$$\log_2 A = \frac{\ln A}{\ln 2}$$

After having calculated the maximum indices, we can calculate the relative indices or the equitability indices by means of the Hubert formula:

$$H_r = \frac{H}{H_{\max}}$$

Thus all relative indices have their variation range (0; 1) and the maximum value is chosen. We appreciate that the maximum values must be calculated by means of relation (6) as a calculated index for the experimental data with the given S and N must be compared with the calculated maximum index that keeps S and N.

Table 1

Theoretical examples of variants for biodiversity

Variant	1	2	3	4	5	6	7	8	9	10	N
A	10	10	10	10	10	10	10	10	10	10	100
B	1	11	11	11	11	11	11	11	11	11	100
C	1	1	13	13	12	12	12	12	12	12	100
D	1	1	1	13	14	14	14	14	14	14	100
E	1	1	1	1	16	16	16	16	16	16	100
F	1	1	1	1	1	19	19	19	19	19	100
G	1	1	1	1	1	1	23	23	24	24	100
H	1	1	1	1	1	1	1	31	31	31	100
I	1	1	1	1	1	1	1	1	46	46	100
J	1	1	1	1	1	1	1	1	1	91	100
L	5	5	5	5	5	5	5	5	5	55	100

Table 2

The biodiversity indices for different variants (S, N constant)

Variant	D_G	$H^{/}$	H	D_S	D_M	D_{Gr}	$H^{/}_{r}$	H_r	D_{Sr}	D_{Mr}
A	0.900	3.322	3.069	0.909	0.760	1	1	1	1	1
B	0.891	3.219	2.975	0.900	0.744	0.990	0.969	0.970	0.990	0.979
C	0.880	3.101	2.867	0.888	0.726	0.978	0.933	0.934	0.977	0.955
D	0.866	2.965	2.742	0.874	0.703	0.962	0.893	0.894	0.961	0.925
E	0.846	2.804	2.593	0.855	0.675	0.940	0.844	0.845	0.941	0.888
F	0.819	2.608	2.410	0.827	0.638	0.910	0.785	0.785	0.910	0.839
G	0.778	2.362	2.178	0.786	0.588	0.864	0.711	0.710	0.865	0.774
H	0.711	2.036	1.868	0.718	0.514	0.790	0.613	0.609	0.790	0.676
I	0.576	1.562	1.411	0.582	0.388	0.640	0.470	0.460	0.640	0.511
J	0.171	0.722	0.593	0.173	0.099	0.190	0.217	0.193	0.190	0.130
L	0.675	2.419	2.231	0.682	0.478	0.750	0.728	0.727	0.750	0.629
Maxima l values	0.900	3.322	3.069	0.909	0.760	–	–	–	–	–

Table 3

The experimental data and correspondent indices
for Hordeetum hystricis (Soo, 1933) Wedelberg. 1943 association

Locality	N	S	D_G	$H^{/}$	H	D_S	D_M	D_{Gr}	$H^{/}_{r}$	H_r	D_{Sr}
Timişoara	459	22	0.752	2.824	2.500	0.754	0.527	0.788	0.633	0.585	0.639
Saravale	470	8	0.232	0.861	0.899	0.233	0.130	0.265	0.287	0.308	0.192
Diniaş	481	15	0.687	2.520	2.640	0.688	0.461	0.736	0.645	0.693	0.593

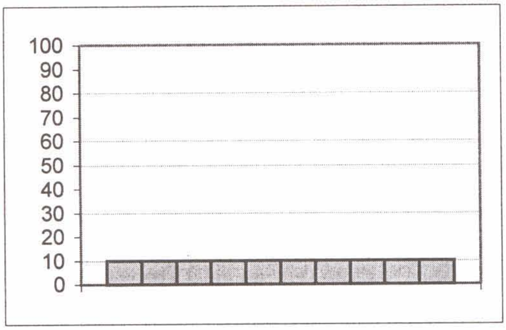

Fig. 1 – Distribution of individuals – variant.

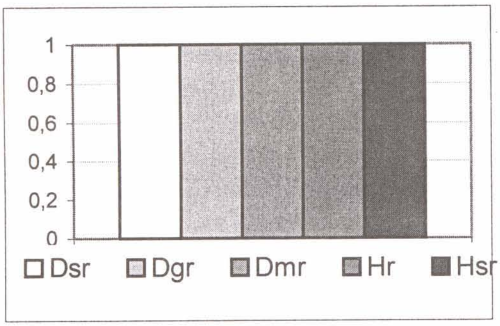

Fig. 1.1 – The relative indices variant A.

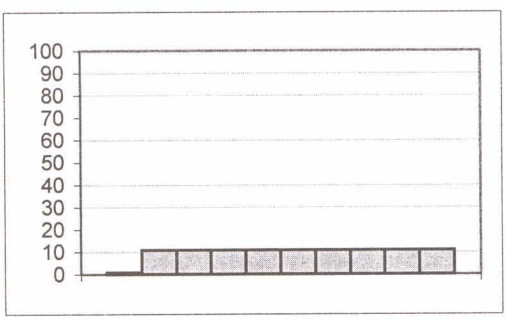

Fig. 2 – Distribution of individuals – variant B.

Fig. 2.1 – The relative indices for variant B.

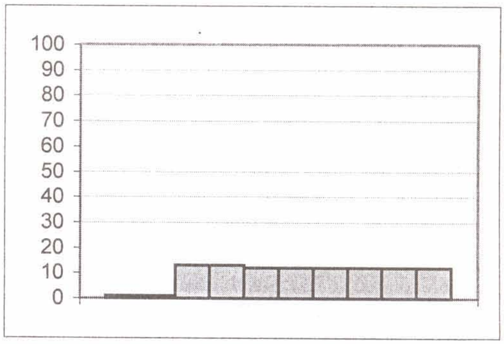

Fig. 3 – Distribution of individuals – variant C.

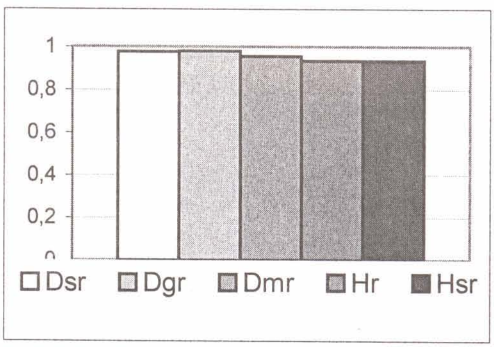

Fig. 3.1 – The relative indices for variant C.

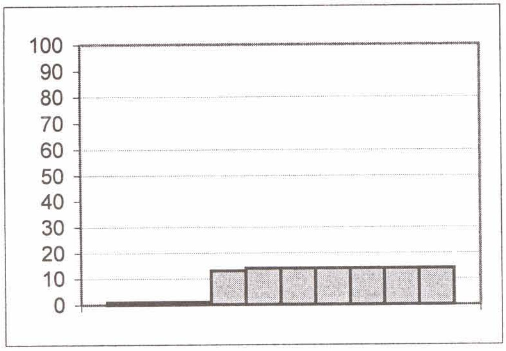

Fig. 4 – Distribution of individuals – variant D.

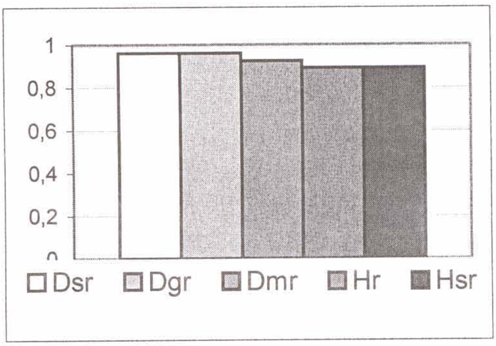

Fig. 4.1 – The relative indices for variant D.

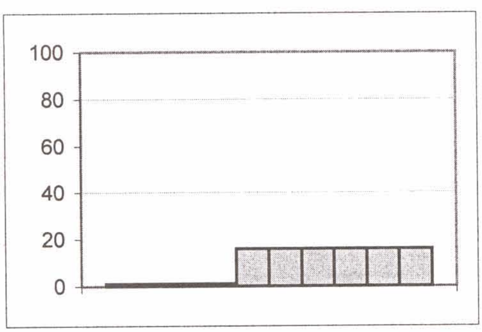

Fig. 5 – Distribution of individuals – variant E.

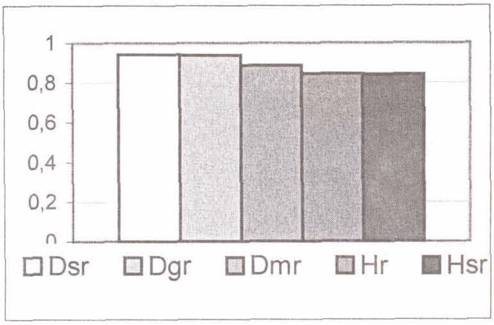

Fig. 5.1 – The relative indices for variant E.

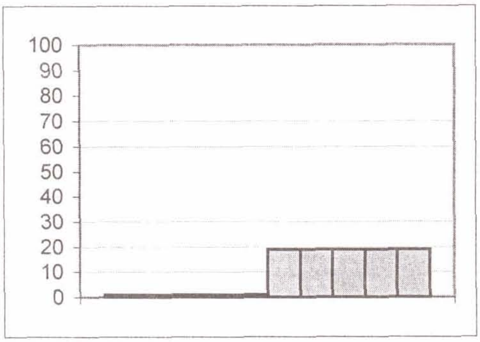

Fig. 6 – Distribution of individuals – variant F.

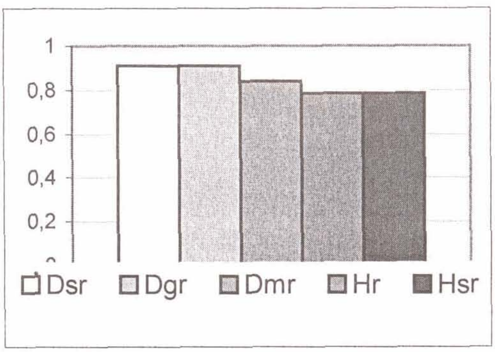

Fig. 6.1 – The relative indices for variant F.

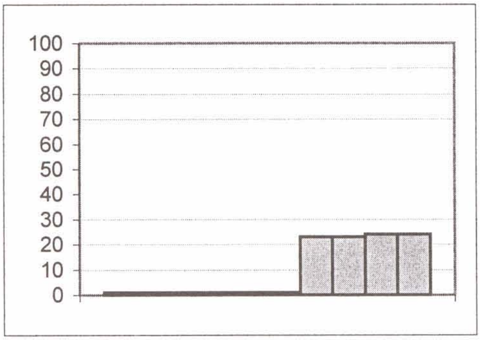

Fig. 7 – Distribution of individuals – variant G.

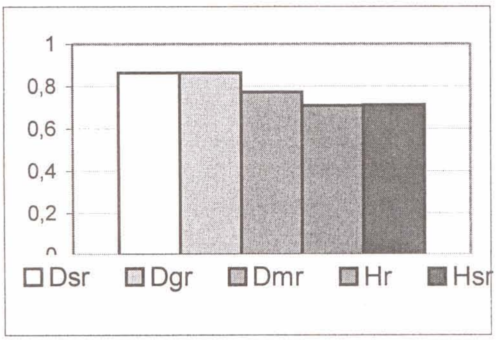

Fig. 7.1 – The relative indices for variant G.

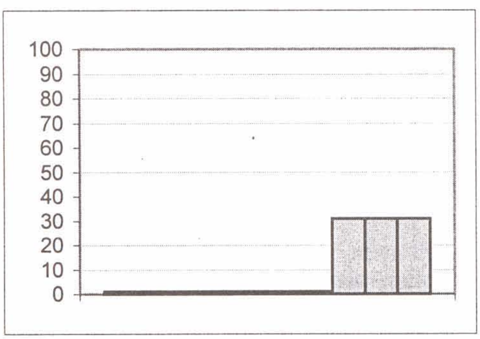

Fig. 8 – Distribution of individuals – variant H.

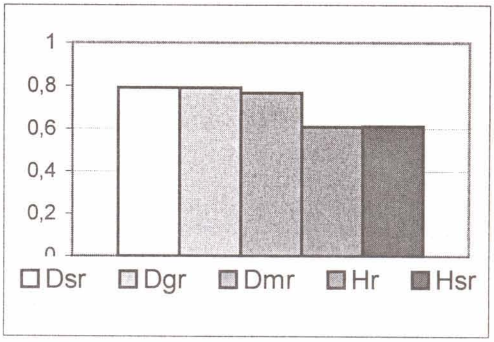

Fig. 8.1 – The relative indices for variant H.

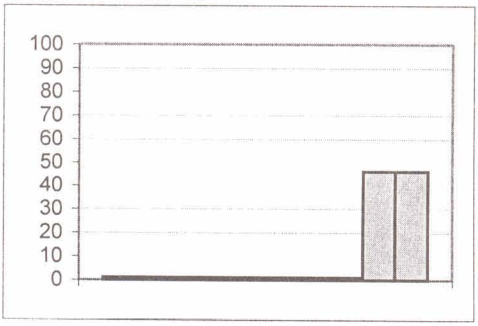

Fig. 9 – Distribution of individuals – variant I.

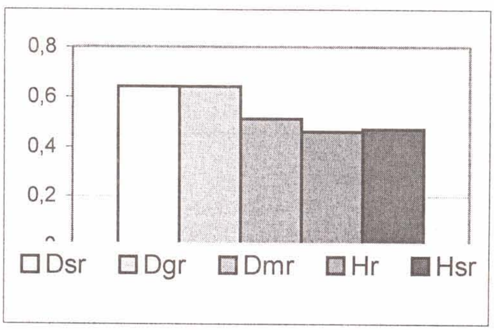

Fig. 9.1 – The relative indices for variant I.

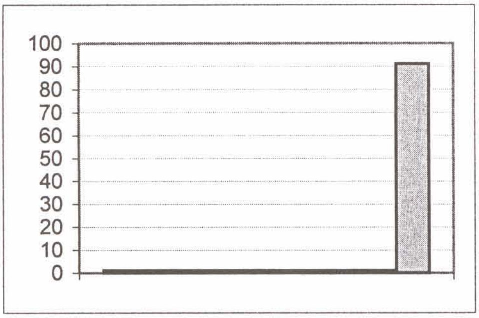

Fig. 10 – Distribution of individuals – variant J.

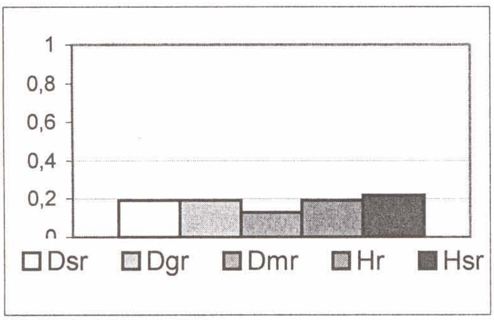

Fig. 10.1 – The relative indices for variant J.

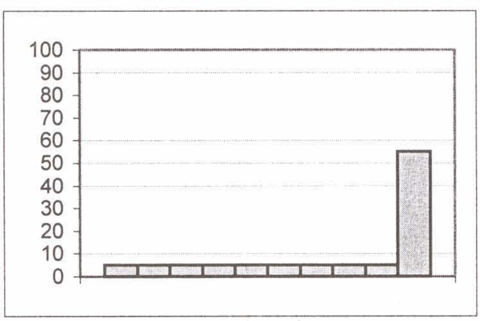

Fig. 11 – Distribution of individuals – variant L.

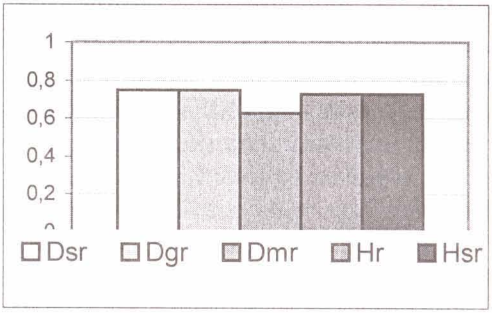

Fig. 11.1 – The relative indices for variant L.

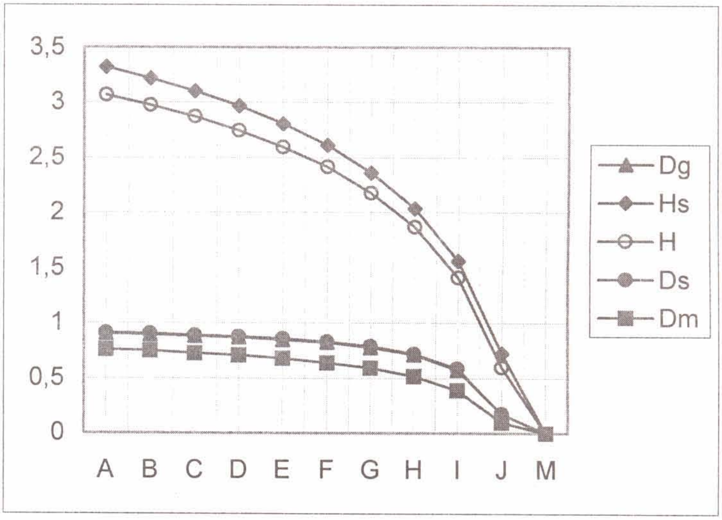

Fig. 12 – The diminution curves of absolute indices.

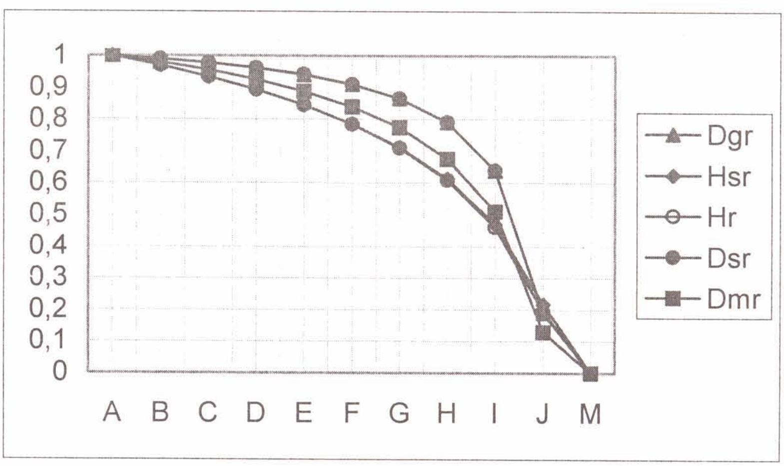

Fig. 13 – The diminution curves of relative indices.

In order to follow the evolution of the analyzed indices, we must think of 10 ideal theoretical variants comprising S = 10 and N = 100 individuals as in Table 1 and the n_1 with its values taken from the table for each variant.

We start with variant A with a uniform distribution and go gradually up to variant J which has a maximum distribution (keeping S = 10 and N = 100). Variant M with S = 1 and N = 100 is not to be found in the table. Table 1 also comprises variant L in order to compare 2 variants with different distributions and the same value of the diversity indices.

In Table 2 all absolute and relative indices are calculated, using the formulae (6) for comparison. In the figures from 1 to 10 we have the graphs for Tables 1 and 2, *i.e.* the distribution of individuals per variant and the corresponding relative indices.

In Figs. 12–13 we find the diminution curves of the absolute and relative indices depending of the variant. The values are taken from Table 2.

RESULTS AND DISCUSSION

Experimental analysis. To exemplify the way the diversity indices are calculated by our method, we have analyzed 3 phytocenoses of the association *Hordeetum hystricis (Soo, 1933) Wendelberg 1943* from Saravale, Timişoara and Diniaş. We have chosen this association deliberately as the composing species are almost of the same height and are equally distributed within the biotope. We determined the number of individuals/species with the method described by Guonot M. (1969). The specifically richness of the 3 phytocenoses is different: 8 species in Saravale, 15 species in Diniaş and 22 species in Timişoara. The distribution of individuals/species is also different (Table 3). In Table 4 we can find the synthetically experimental data and the corresponding absolute and relative indices for the phytocenoses we have analyzed (on the spot). The dominant species – Hordeum hystrix has the largest number of individuals within the 3 analyzed phytocenoses. The association has a weak regularity. According to the diversity indices values (Table 4) we found that the Timişoara phytocenoses is the most divers been followed by the Diniaş and Saravale ones. The relative indices values rise directly proportional to the number of species.

CONCLUSIONS

All diversity indices have maximum values when the number of species is minimal and the species distribution of the individuals is uniform. The existence of the dominant species in number diminishes the indices. The same value of an index can be given at different distributions of the individuals per species; H_r^* for the G and L variants, are practically equal although the 2 variants have different distributions. The diminution curve of the indices has the same aspect.

The equitability or the relative indices characterize in the best manner the diversity. Out of all analyzed indices the logarithmic functions are mostly used.

Although they have quite different formulae (4) and (5) respectively, the values of the relative logarithmic indices are almost identical at all variants of Table 1. The relative indices based on the calculation of the maximum with constant S and N, are very near in all variants of Table 1.

From a practical point of view, the natural pastures from the localities analyzed by us, have quite different diversity indices. The main explanation for the fact that all indices (absolute and relative) for Saravale are smaller than for Timişoara and Diniaş is that the number of species (S) is smaller in Saravale, while (N) are near to each other.

BIBLIOGRAPHY

1. Boşcaiu Monica, 1993, La signification des indices de diversite pour la paysage vegetal du parc National de Retezat (Roumanie), Colloques phytosociologiques, XXI, Camerino, 241–258.
2. Botnariuc N., Vădineanu A., 1982, Ecologie, Ed. Did şi Ped., Bucureşti, 378–382.
3. Daget Ph., Poissonet J., 1971, Une methode d'analyse phytologique des prairies, Criteres d'application, Ann. Agron., **22**(I), Paris, 5–41.
4. Frontiers S., Pichod-Viale D., 1993, Ecosistems, structure, fonctionement, evolution, 2e ed., Masson, Paris-Milan-Barcelone, 287–296.
5. Gounot M., 1969, Methodes d' etudes quantitative de la vegetation, Masson et Cie, Paris.
6. Hajdu L., 1976, Algal species diversity in two eutrophic fishponds, Part.I Species – individual level, Acta Bot. Sci. Hungaricae, **23**(1–2), 77–90.
7. Hawkswort D.L. (ed.), 1998, Biodiversity. Measurement and estimation, Chapman & Hall, The Royal Society.
8. Krebs Ch.J., 1999, Ecological Methodology, Addison Wesley Longman, Inc., 410–454.
9. Maarel van der E., 1988, Species diversity in plant communities in relation to structure and dynamics, SPB Academic Publishing, Hague, 1–14.
10. Nosek J.N., 1976, Comparative analysis of some diversity functions under different condition of sampling in sandy meadow, Acta Bot. Sci. Hungaricae, **22**, 415–435.
11. Soran V., Ardelean A., Maior C., Don I., 1999, Metode statistico-matematice de studiu a biodiversităţii fitocenozelor din ecosistemele naturale I., Studia Universitaris "V. Goldiş" Arad, Seria B, IX, 5–12.
12. Stugren B., 1994, Ecologie teoretică, Casa de Editura Sarmis, Cluj-Napoca, 112–116.

Received February 2003.

University of Agronomic Sciences, Timişoara