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THE VEGETATION IN THE DOLINAS OF THE KARST REGION NEAR TRIESTE (ITALY)

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Keywords: Karst, dolinas, vegetation, geomorphology, Trieste (NE Italy).

Abstract: On the basis of an ecological model the relationships between the vegetation and geomorphology of the dolinas are described for the Karst region near Trieste.
Observations about presence thresholds of primary coenoses and the classification of dolinas, according to vegetation are made.

Introduction

For some time geobotanists have been studying dolinas (sink-holes) and hollows in general, because of the profound changes they bring about in the local climate. Mention should be made of the now classical studies published by Beck (1906) and Horvat (1953) and more recently, by Polli (1961) and by Poldini and Toselli (1982) The type of hollow known as the dolina was selected because it offers suitable data for the study of the relationship between vegetation and geomorphological features. In the fact the dolina, as a hollow, enriches and is a factor of diversification in the environment. Morphological discontinuity of an exclusively physical nature has a selective role in the organisation of flora into types of vegetation and their synthesis. The objective of this study is to investigate:

1. the ecology of the coenoses by the indirect method (Whittaker 1978)
2. the relationship between geomorphological discontinuity *(Dg)* * and vegetational diversity *(Dv)* and thus the role of dolinas in increasing the landscape diversity;
3. the classification of dolinas according to vegetation.

1. Data and methods

A strip of the Karst region near Trieste with a particularly high concentration of dolinas was chosen for this study. 63 dolinas were considered to constitute a sample which would adequately represent their variability. The local conditions (geomorphological features) taken into consideration were the following: depth,

* The term "discontinuity" is used here to refer to the sharp variations produced by dolinas on abiotic variables, which are used in this study to identify the geomorphology of the area under investigation (ecotone variations).

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rockness, volume, form, orientation, eccentricity and potential as agricultural land or pasture.

Pedological features and height above sea level were not taken into consideration as both are constant in the area under examination.

To analyse the relationship between coenoses and geomorphological features a representative model of the dolina was created taking into account the total vegetation inside, represented by a presence/absence table of individual coenoses and the seven geomorphological features mentioned above.

The coenoses found in the dolinas must be divided into two groups:

A : *Secondary coenoses,* listed below in descending order of intensity of use:

Intensity of use	Culture and Pastures	Post-Culture Vegetation	Hedges
I High	- Robinia woods	10 - Groupings of *Lamium orvala* and *Sambucus nigra*	—
II Medium	11 - *Arrhenatheretum brometosum erecti.* 12 - *Arrhenatheretum holcetosum lanatis* (MEADOWS)	6 - *Brachypodio - Agropyretum intermedii*	—
III Weak	4 - *Danthonio - Scorzonertum cirsietosum pannonici*	3 - *Prunus spinosa* shrubs	—
IV Low	5 - *Chrysopogono - Centaureetum cristatae.* (PASTURES)	—	8 - *Corno-Ligustretum illyricum* (*)

Table 1 — Secondary coenoses, listed in descending order of intensity of use.

B: *Primary coenoses:*

1. *Galantho-Coryletum*
2. *Ostryo-Quercetum pubescentis*
7. *Seslerio-Quercetum petraeae*
9. *Asaro-Carpinetum*

Description of geomorphological features

1. Depth P - the difference between the height of the highest contour line (outer rim) and the height of the floor, in metres.
2. Rockiness R - conventional measurement on a scale from 0 (absence) to 4 (vertical walls). In the area under examination the dolinas are rocky only on north-facing slopes.
3. Volume V - given by the product of $A \times a \times P$, where A is the major axis and "a" the minor axis, of the figure formed by the highest contour line circumscribing the dolina. Measured in cubic metres.

(*) The name suggested by Horvat (1956, 1974) has been provisionally adopted. The table for this coenose is in fact poorly identified in terms of characteristic or differential species. The samples taken on the Karst and in Friuli are well differentiated both from the central European *Viburno-Ligustretum* and from Horvat's *Corno-Ligustretum* by *Rubus ulmifolius* and by *Peucedanum venetum.*

4. Form F - this factor (F_{ok}), which represents the degree of geometrical "regularity" of the dolina, is quantified by four parameters:

A and a, as in point 3 above

P depth

D, the horizontal distance between the deepest point and the centre of the shape described by the highest contour line. The measurement is given by:

$$F_{ok} = \frac{\sqrt{2} - S_{ok}}{\sqrt{2}}$$

where S_{ok} is the normalised euclidean distance between point $B_k (A, a, D, P)$ representing a generic dolina $_{k}$, and point $B_o (A, A, O, A/2)$ representing a regular geometric form for reference. The result is therefore $0 \leq F_{ok} \leq 1$. High F values correspond to dolinas which are near to hemispherical in form.

5. Orientation S

$$S_k = 1 + \cos \alpha_k$$

where α_k is the angle formed by the major axis A_k of the highest contour line and an east-west line.

S provides a measurement of the solar energy entering the dolina. High S values correspond to dolinas, with a major axis close to an east-west direction, which receive the highest amount of solar heat.

6. Eccentricity E

$$E_k = 1 + \frac{2\,D_k}{A_k}$$

A, D have already been described

$$D_k\, max = \frac{A_k}{2} \qquad 1 \leq E \leq 2.$$

7. Potential U

$$U_k = \frac{G_k}{G_{max}} \text{ (relative value of potential)}$$

where $G_k = \dfrac{A^l_k}{L^m_k (R_k + 1)^n}$ (absolute value of potential)

and G_{max} is the maximum value of G_k therefore $0 \leq U \leq 1$.

A and R have already been described; L is the distance, by path or road, from dolina to the nearest location with agricultural activity or pasture. A, L and R are of different weight in the quantification of U.

$$l = 1{,}2 \quad ; \quad m = 0{,}4 \quad ; \quad n = 0{,}8$$

The geomorphological features quantified for the 63 dolinas, as described, are arranged in classes whose extreme values are shown in the table 2.

GEOMORPHOL. FEATURES	UNIT OF MEASUREMENT	VALUES MEASURED	
		MIN	MAX
P	metres	4	59
R	—	0	4
V	10^3 cubic metres	4	12.036
F	—	0.58	0.90*
S	—	1	2*
E	—	1.00	1.82*
U	—	0.02	1.00*

Table 2 — Extreme values of the geomorphological features.

The dolinas as physical entities may now be represented by a group of seven parameters with values comprised in the classes mentioned above. For reasons of uniformity, however, and because of the demands of successive elaborations, it was considered appropriate to use for each of the seven features, four classes of values, instead the numerical values obtained:

Classes

1 - low values	from MIN to Medium Low (Mb)
2 - medium low values	from Mb to Medium (M)
3 - medium high values	from M to Medium High (Ma)
4 - high values	from Ma to MAX

The numerical values of the levels which define each class, for each feature, are shown in the table 3.

LEVEL / FEATURE	MIN	Mb	M	Ma	MAX
P	4	9	13	22	59
R	0	0.5	1.2	2.4	4.0
V	4	93	476	3110	12.036
F	0.58	0.71	0.77	0.81	0.9
S	1.00	1.12	1.55	1.80	2.00
E	1.00	1.14	1.23	1.41	1.82
U	0.02	0.07	0.16	0.30	1.00

Table 3 — Values of the class levels.

The numbers of dolinas considered according to class of values and to feature is shown in the table 4.

(*) the values measured are found inside the fields of variability:

$$0 \leq F \leq 1; \quad 1 \leq S \leq 2; \quad 1 \leq E \leq 2; \quad 0 \leq U \leq 1$$

CLASS / FEATURE	1	2	3	4	TOTAL
P	20	22	14	7	63
R	19	22	15	7	63
V	35	20	5	3	63
F	13	12	23	15	63
S	14	10	18	21	63
E	15	28	14	6	63
U	22	17	17	7	63

Table 4

In order to be able to represent the dolina in the form of a model also from the point of view of geomorphological discontinuity, it should be pointed out that this discontinuity is proportional:

- directly to the depth P
- inversely to the surface B of the mouth, given by the product of the lengths of the two axes A x a
- directly to parameter C, which gives the measure of deviation of the mouth from a circular form, given by the proportion $\frac{A}{a}$.

Therefore, taking account of the preponderant weight of P compared to the other factors, we may write:

$$Dg = P^2 \frac{C}{B}$$

$$\text{where } C = \frac{A}{a} \quad \text{and} \quad B = A \cdot a$$

the result is:

$$Dg = \left(\frac{P}{a}\right)^2$$

The function Dg will be used later in the analysis of his connections with the vegetational diversity.

The calculations of the clustering are described by Feoli E., Lagonegro M. and Zampar A. (1982).

2. Results

Before the correlations between vegetation and morphology are examined, some statistical data expressing the average characteristics of the sample are presented below. The relative frequency of dolinas in terms of classes of values of geomorphological features, derived from table 4 is represented in the table 5.

FEATURE \ CLASS	1	2	3	4
P	31	36 *	22	11
R	30	35 *	24	11
V	57 *	33	6	4
F	22	19	37 *	22
S	22	16	28	34 *
E	23	46 *	22	9
U	35 *	27	27	11

Table 5

* Maximum frequency

The arrangement of dolinas in classes of geomorphological features shows that in the sample the most frequent dolinas are small (max in *V1*), of low potential (max in *U1*), with a high *S* (max in *S4*), but with *P, R, F* and *E* in the medium low and medium high classes.

The most likely dolina from a geomorphological point of view is therefore:

GEOMORPH. FEATURES	CLASS
P	2
R	2
V	1
F	2
S	4
E	2
U	1

The relative frequency distribution of dolinas, in terms of the number of coenoses they contain, is represented in the following graph (Fig. 1).

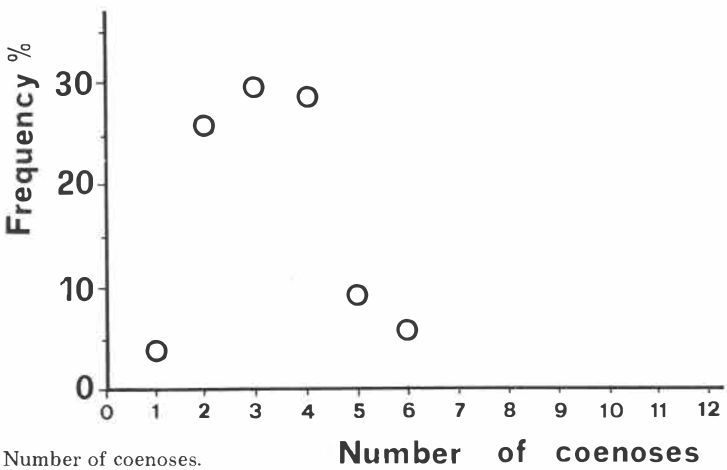


Fig. 1 — Number of coenoses.

The maximum frequency (29%) was of dolinas with 3 coenoses. No dolina was found to have more than 6 coenoses.

Finally, table 6 presents the maximum frequencies of coenoses according to geomorphological features represented in the matrix of the most favourable ecological conditions.

This table, was obtained from seven matrices, (one for each geomorphological feature, which, for the purposes of simplicity, do not appear in the text) each having 12 rows (coenoses) and 4 columns (classes of values of the geomorph. features) whose elements represent the relative frequency of the dolinas. By selecting the maximum values of the elements in these matrices, we obtain a synthetic representation of the most favourable ecological conditions for the 12 coenoses.

	GEOMOPHOLOGICAL FEATURES						
COE-NOSES	*P*	*R*	*V*	*F*	*S*	*E*	*U*
1 □	4	4	4	4	1	1	1
2 □	4	1	4	2	1	3	2
3	4	1	4	3	3	3	4
4	1	1	4	1	2	3	2
5	4	3	4	4	2	3	4
6	4	2	2	2	3	1	4
7 □	4	2	4	2	2	2	4
8	2	2	3	1	1	2	4
9 □	3	3	4	4	2	1	1
10	1	4	2	3	1	4	2
11	2	1	3	1	1	2	3
12	2	1	2	3	1	2	3

□ Primary coenoses.

Table 6 — Matrix of the most favourable ecological conditions. It may be deduced from this table that, for example, coenose 1 is most frequent in dolinas, if they exist, with values of class 4 for features *P, R, V* and *F* and of class 1 for features *S, E* and *U.*

We can now analyze the relationship between coenoses and morphology which are derived from the seven matrices above mentioned.

Secondary coenoses

The presence of this group depends exlusively on intentional human intervention, which means that the search for a possible causal ralationship with geomorphological features would not produce results of any significance. Some of the more important features of these coenoses, however, are pointed out below, in descending order of intensity of use (see Tab. 1).

It may be seen first that both primary and secondary coenoses are most frequent in large dolinas. This is because large dolinas are suitable for various types of agricultural use, and at the same time may posses several pedoclimatic environments.

I - Coenoses at a high intensity of use:

- Groupings of *Lamium orvala, Sambucus nigra* (10) and robinia woods.

These groupings, which derive from hoed cultures, are absent in dolinas of high potential, but present in those of low and medium potential; they are most frequent in the last of these categories. This may be explained by the supposition that dolinas of medium-low potential were the first to be abandoned and that in some cases this type of tree culture (robinia) which requires little maintenance and is used only occasionally, was chosen by man for dolinas of the most marginal agricultural utility.

II - Coenoses at a medium intensity of use:

- *Arrhenatheretum brometosum erecti* (11)
- *Arrhenatheretum holcetosum lanati* (12).

These are most frequent in small depressions, which are the most suitable for the maintenance of meadows. While on one hand a slight depression is suitable for mesophilous species, which have greater requirements than karstic pasture, a moderate difference in height does not impede fertilisation and collection of forage. These two coenoses are most frequent in dolinas of medium high potential *U3*. They are totally absent in dolinas of maximum depth, rockiness and volume.

- *Brachypodio - Agropyretum intermedii* (6)

This is a coenose deriving from previous hoed cultures. As was to be expected, its maximum frequency is in dolinas of high potential.

III - Coenoses at a weak intensity of use:

- *Danthonio - Scorzoneretum cirsietosum pannonici* (4)

This is represented by meadows and pasture; therefore observations made about coenoses 11 and 12 (meadows) partially apply. It is absent in dolinas of maximum rockiness, but present with a moderate maximum frequency in large dolinas (*P4* and *V4*) and in those of maximum potential (*U2, U3*).

- *Prunus spinosa* shrubs (3)

As a result of its particular needs this species is found in cool and damp locations, with high maximums of frequency in dolinas of high potential, depth and volume. It is typical of postculture.

IV - Coenoses at a low intensity of use:

- *Chrysopogono - Centaureetum cristatae* (5)

This has a clear maximum frequency in dolinas of large dimensions (*P4, V4*) and of low rockiness (*R1, R2*). This may be explained by the fact that large dolinas have large slopes with a southern exposure, which man has turned into pasture. The concomitant maximum frequency of seminatural vegetation (2 and 7) may be understood in the light of the consideration that the north-facing slopes of these dolinas are just as extensive and rocky where man has kept woodland.

The dolinas most frequently used for pasture, as was to be expected, are those of the highest potential (*U4*).

- *Corno-Ligustretum coryletosum* (see note pag. 3)

The presence of this coenose is the result of stone clearance and the construction of cairns and perimeter walls in the dolinas. This environment is ideal for the formation of hedges. Its maximum frequency is consequently in dolinas of the highest potential (*U4*). Its total absence in dolinas of maximum rockiness does not stem from any ecological incompatibility - this coenose is in fact markedly lythophilous - but from the fact that a high degree of rockiness has prevented any agricultural use.

Primary coenoses

From the analysis of the data on semi-natural coenoses it may be observed that:

1 - *Galantho-Coryletum* (G-C)

Table 6, showing the most favourable ecological conditions, makes clear the preference of this coenose for large dolinas (*P4, V4*) of high rockiness (*R4*), regular form *(F4)* and low eccentricity *(E1)*. Its frequency is not affected by the feature of orientation and potential. The maximum frequency of G-C in dolinas where coenose 3 is close to its maximum values may be explained by the fact that the pedoclimatic conditions which favour this coenose - cool and damp areas - are also ideal for G-C.

The maximum presence of G-C and 5 in large dolinas (*V4*) may be explained by the fact that, as happens in mountain areas, their south-facing slopes have been turned into pasture and the north-facing slopes have been kept wooded.

2 - *Ostryo-Quercetum pubescentis* (O-Q)

This is part of the zonal vegetation (climax) of the supramediterranean Karst. Its presence has nothing to do with any geomorphological features. It is limited to south-facing upper rims and is nothing more than part of the dominant vegetation penetrating in from the outside. In small dolinas this in fact is the only forest vegetation.

It should be pointed out that in this case, as in the case of G-C its preference for large dolinas, which are also where secondary coenoses are most frequent, may be explained by considering that they are the most suited to cultivation on south-facing slopes and on the floor, while on north-facing slopes conditions favour the conservation of nearly-natural vegetation.

7 - *Seslerio-Quercetum petraeae* (S-Q)

It must also be supposed in the case of S-Q that its maximum frequency in dolinas where secondary coenoses are also found is due to the suitability (mentioned above) of large dolinas for different types of cultivation on their south-facing slopes and floors and for the maintenance of trees on the opposite slopes.

As this is a semi-natural coenose its maximum frequency in dolinas of the highest level of potential may appear contradictory. This may be explained by considering that the pedoclimatic conditions (cool environment and deep soil) which encourage the establishment of S-Q are also ideal for agriculture.

The fact that S-Q is found less frequently with the other two primary coenoses than it is with the secondary types means that S-Q is the first of the extra-zonal types to establish itself in dolinas which retain conditions favourable for agriculture.

9 - *Asaro-Carpinetum* (A-C)

The maximum frequency of this coenose is in dolinas of depth *P3* rather than in those of *P4*, as might have been expected. The dolinas of depth *P4* in the sample under examination have very wide mouths, encouraging the movement of air from outside into the dolinas, impeding the establishment of A-C. In dolinas of depth *P3* the relationship between mouth size and depth gives rise to the so-called "cold trap" in their deepest parts.

The geometrical relationships underlying this mechanism may be understood by reference to function *Dg*, geomorphological discontinuity, described above.

Once *Dg* has been calculated for each dolina in the sample, the distribution on the surface formed by axis *Dg* and axis *P*, as shown on the Figure 2 makes the following considerations possible:

- narrow and deep dolinas, suitable for A-C, are situated in the central part of the interval of variability of *P* and not at its highest point;
- the distribution of the dolinas containing A-C shows a precise threshold line for the values of *Dg*, below which are found only dolinas not containing A-C; the minimum

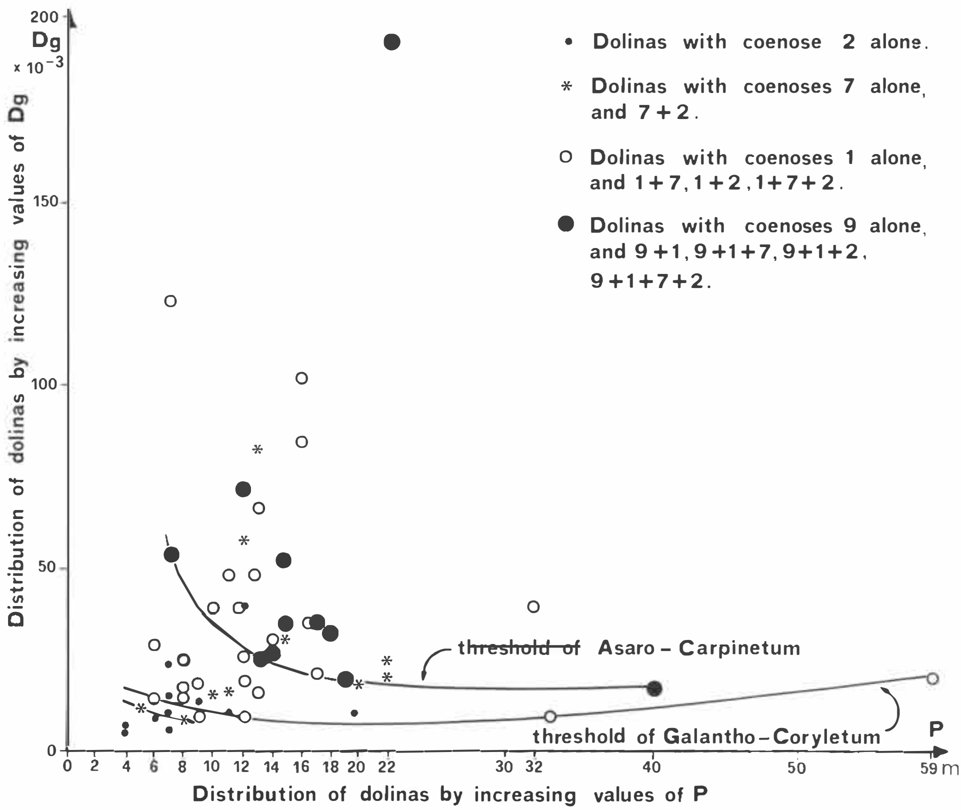


Fig. 2 — Threshold of presence of primary coenoses in dolinas.

corresponds to depth class *P3*.

An important ecological deduction may be made about the A-C from the above observations: the presence of this coenose in the dolinas studied is not determined by their depth alone, but by the relationship between their depth and width of mouth.

It should also be noted that this coenose is of maximum frequency in the class of minimum potential *U1*. It may be presumed that pedological factors and other conditions favourable to this coenose have also discouraged the exploitation of this environment.

While the A-C has a precise threshold line, that of G-C is not clearly discernable, and the threshold of S-Q is practically non-existent. The A-C dolinas have the role of working against anthropization and floristic alteration. The connection between European, Euro-Asiatic and Euro-Siberian geophytes, typical of coenoses A-C, and its low level of anthropization has been demonstrated (Poldini and Vidali, in press); this in turn is connected to the minimum level of potential of these dolinas.

Bearing in mind that geomorphological discontinuity (function *Dg*) has a selective function as far as external primary coenoses are concerned, and that O-Q is present in the dolinas as a result of penetration from the outside, increasing levels of vegetational diversity (*Dv*) may be identified by means of an analysis of the presence of primary coenoses in the dolinas.

The ascending order of vegetational diversity, divided into four levels, is given by:

- Low *Dv* in dolinas with O-Q alone
- Medium-low *Dv* in dolinas with O-Q and S-Q
- Medium-high *Dv* in dolinas with O-Q, S-Q and G-C
- High *Dv* with O-Q, S-Q, G-C and A-C

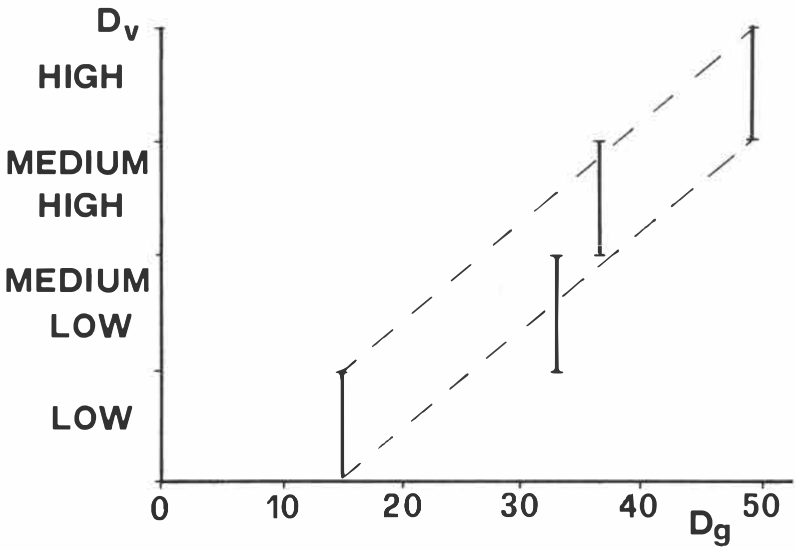


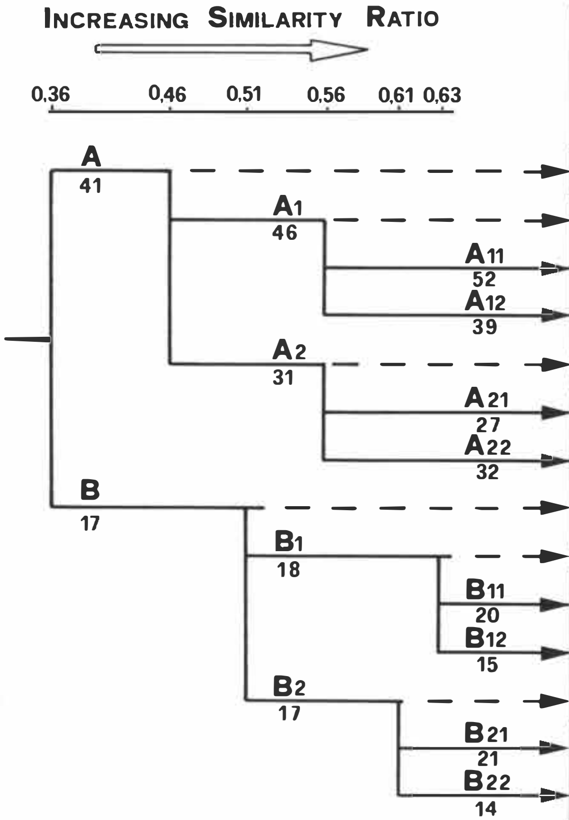
Fig. 3

The dependence of the vegetational diversity *Dv* upon geomorphological discontinuity *Dg* may thus be expressed in the Figure 3.

The *Dg* axis shows the average *Dg* values for the groups of dolinas belonging to the four *Dv* levels. The dependence of *Dv* on *Dg* is almost linear - the vegetational diversity increases in a linear way with the growth of geomorphological discontinuity.

3. Conclusions

The study of the similarity between dolinas, based on primary coenoses and geomorphological features, has produced the results shown in the table 7, the interpretation of which, presented in graph form, is confined to the first three levels.



PRIMARY COENOSES			
2	7	1	9
O-Q	S-Q	G-C	A-C
50	48	74	91
31	39	58	64
19	26	35	46
12	13	23	18
19	9	16	27
4	0	6	18
15	9	10	9
50	52	26	9
27	23	13	0
9	7	6	0
18	16	7	0
23	29	13	9
10	16	6	9
13	13	7	0

Tab. 7

The table 7 shows, for example, that dolinas containing G-C are shifted by 74% on cluster A with an average *Dg* of 41 (26% on B, average *Dg* 17) which is subsequently shifted to 58% and 16% in A1 and A2 respectively.

The shift of the dolinas on clusters A and B is particularly significant. A contains dolinas of a high level of geomorphological discontinuity (41) with maximum frequency of G-C and A-C (74% and 91% respectively). The presence of oak coenoses is less marked. This group of dolinas, which may be globally defined as the "*Asaro-Carpinetum*" type, represents the continental extreme of the ecological spectrum of the Karst region near Trieste.

This characteristic becomes progressively more accentuated in the subsequent shifts on clusters A1 and A11, with an even higher *Dg* (56 and 52 respectively), medium high rockiness and medium low potential.

Symmetrically, B, B2 and B22 contain a concentration of dolinas of low *Dg*, with minimum values for A-C and G-C and with a presence of oak dolinas equal to that of line A, A1 and A11. The morphological characteristics of these groups are low rockiness and medium high potential. It may therefore be concluded that, above a common base presence of oak dolinas in clusters A and B, the continental component A-C and G-C is added to cluster A alone.

The above considerations lead to the following classification:

I O-Q dolinas

II S-Q dolinas

III A-C dolinas

It should be pointed out that this classification is not "exlusive" but "cumulative" in that the group of "A-C dolinas" includes the sub-group of "S-Q dolinas" which includes "O-Q dolinas".

Riassunto.

Le relazioni tra vegetazione e geomorfologia delle doline nel Carso triestino sono descritte sulle basi di un modello ecologico. Vengono riportate osservazioni sulla classificazione delle doline in base alla loro vegetazione.

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