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Ecological conditions, flora and vegetation of a large doline in the Mecsek Mountains (South Hungary)

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Abstract – Vegetation-environment relationships were investigated in a large doline of the Mecsek Mts (South Hungary). To reveal the vegetation pattern, we collected vegetation data and environmental variables along a 243 m long transect. A total of 144 vascular plant species and 4 vegetation types were identified in the doline. We found that both the species composition and the vegetation pattern are significantly influenced by air temperature, air humidity, soil moisture and altitude. Our results confirm the putative temperature and vegetation inversion in the doline.

Keywords: direct gradient analysis, doline, flora, vegetation types, vegetation inversion, redundancy analysis, species composition, Mecsek Mountains, Hungary

Introduction

Karst surfaces and environments are extremely vulnerable to degradation and pollution (CALÓ and PARISE 2006, BREG 2007), thus they are currently in the focus of research and conservation efforts. Dolines are funnel- and bowl-shaped closed depressions formed by water infiltration, which range from a few meters to a few hundred meters in diameter and depth (VERESS 2004).

At night, cold-air lakes develop in the depressions (BÁRÁNY-KEVEI 1999), resulting in low air temperatures and high air humidities, which in turn strongly influences the composition of local flora and vegetation (BECK-MANNAGETTA 1906, MORTON 1936, ÖZKAN et al. 2010). Many karst depressions around the world have developed into excellent refuge areas for relict, mountain (HORVAT 1953) and endemic species (EGLI et al. 1990, BRULLO and GIUSSO DEL GALDO 2001), which play a central role in the knowledge about vegetation history.

The study was carried out in the karst area of 30 km^2 in the Mecsek Mountains (South Hungary), near the city of Pécs. Sub-Mediterranean type, middle-aged oak-hornbeam (*Asperulo taurinae-Carpinetum* Soó et Borhidi in Soó 1962) and beech forests (*Helleboro odori-Fagetum* Soó et Borhidi in Soó 1960) dominate the present vegetation of the plateaus

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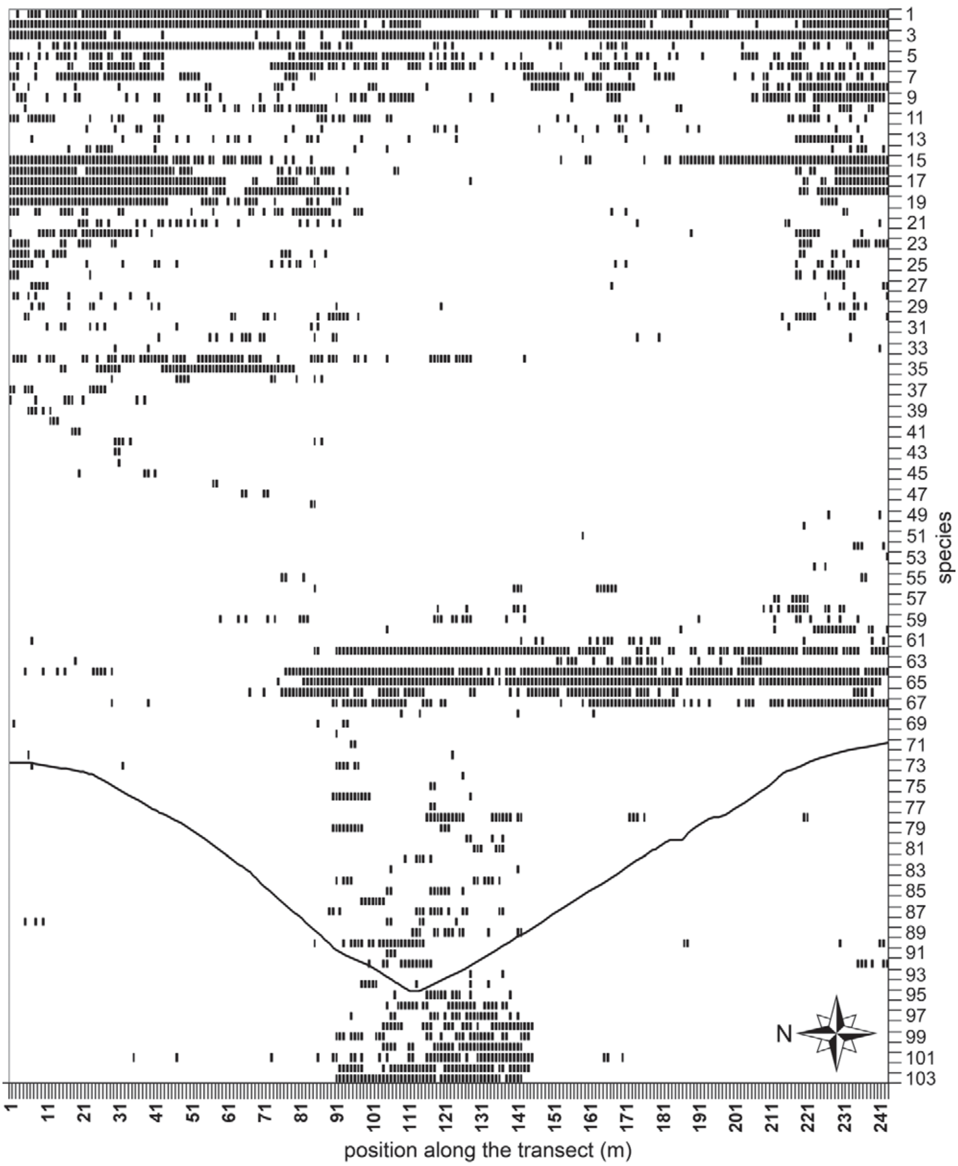
and slopes of the study site. The bottom of larger valleys is covered by beech forests or ravine forests (*Scutellario altissimae-Aceretum* (Horvát 1958) Soó et Borhidi in Soó 1962). This latter vegetation type is also found in the deeper and larger dolines of the Mecsek Mountains (cf. BÁTORI et al. 2009).

The purpose of this study was to analyse the vegetation pattern of the herb layer in a doline of the Mecsek Mountains. The following questions were addressed: How many vegetation types and vascular plant species can be identified in the doline? What environmental variables influence the vegetation pattern on the slopes?



Material and methods

Our surveys were conducted in a large (diameter > 200 m) and deep (depth > 25 m) doline of the Mecsek Mountains. The herb layer was sampled along a 2 m wide and 243 m long transect consisting of 1 m × 2 m contiguous plots (Figs. 1, 2). The transect was established in a north-south direction traversing the deepest point of the depression. Each plot was surveyed twice: in summer 2008 and spring 2009. In addition, a complete plant species list was compiled for the total area of doline. The total area included the area of the slopes (where the slope angle was over 10°) and the area of the edge (an approximately 15–20 m wide stripe around the doline where the slope angle was less than 10°).

Fig. 1. ← Species occurrences and relief profile along the doline transect. Numbers on the right indicate plant species as follows: 1 – *Fraxinus excelsior* L., 2 – *Cardamine bulbifera* (L.) Crantz, 3 – *Allium ursinum* L., 4 – *Tilia tomentosa* Moench, 5 – *Arum maculatum* L., 6 – *Asarum europaeum* L., 7 – *Hedera helix* L., 8 – *Alliaria petiolata* (M. B.) Cavara et Grande, 9 – *Galium aparine* L., 10 – *Veronica hederifolia* L., 11 – *Helleborus odorus* W. et K., 12 – *Viola reichenbachiana* Jord., 13 – *Acer platanoides* L., 14 – *Acer campestre* L., 15 – *Fraxinus ornus* L., 16 – *Stellaria holostea* L., 17 – *Carex pilosa* Scop., 18 – *Melica uniflora* Retz., 19 – *Dactylis polygama* Horvátovszky, 20 – *Polygonatum multiflorum* (L.) All., 21 – *Quercus petraea* (Mattuschka) Lieblein, 22 – *Euphorbia amygdaloides* L., 23 – *Ligustrum vulgare* L., 24 – *Rosa arvensis* Huds., 25 – *Lathyrus vernus* (L.) Bernh., 26 – *Galium schultesii* Vest, 27 – *Hepatica nobilis* Mill., 28 – *Crataegus laevigata* (Poir.) DC., 29 – *Bromus ramosus* Huds. agg., 30 – *Fallopia dumetorum* (L.) Holub, 31 – *Quercus cerris* L., 32 – *Fagus sylvatica* L., 33 – *Viola alba* Bess., 34 – *Carpinus betulus* L., 35 – *Festuca drymeja* M. et K., 36 – *Lathyrus venetus* (Mill.) Wohlf, 37 – *Campanula rapunculoides* L., 38 – *Symphytum tuberosum* L. subsp. *nodosum* (Schur), 39 – *Convallaria majalis* L., 40 – *Iris graminea* L., 41 – *Glechoma hirsuta* W. et K., 42 – *Ajuga reptans* L., 43 – *Clinopodium vulgare* L., 44 – *Taraxacum officinale* Weber ex Wiggers, 45 – *Sorbus torminalis* (L.) Cr., 46 – *Luzula luzuloides* (Lam.) Dandy et Wilm., 47 – *Luzula forsteri* (Sm.) DC., 48 – *Primula vulgaris* Huds., 49 – *Hordelymus europaeus* (L.) C. O. Harz, 50 – *Mycelis muralis* (L.) Dum., 51 – *Tamus communis* L., 52 – *Milium effusum* L., 53 – *Geum urbanum* L., 54 – *Stachys alpina* L., 55 – *Euonymus europaeus* L., 56 – *Galium odoratum* (L.) Scop., 57 – *Arabis turrita* L., 58 – *Geranium robertianum* L., 59 – *Moehringia trinervia* (L.) Clairv., 60 – *Cardamine impatiens* L., 61 – *Isopyrum thalictroides* L., 62 – *Galeobdolon luteum* Huds. s.l., 63 – *Ruscus hypoglossum* L., 64 – *Galanthus nivalis* L., 65 – *Cardamine enneaphyllos* (L.) Crantz, 66 – *Anemone ranunculoides* L., 67 – *Mercurialis perennis* L., 68 – *Pulmonaria officinalis* L., 69 – *Fragaria vesca* L., 70 – *Carex divulsa* Stokes, 71 – *Pyrus pyraster* (L.) Burgsdorf, 72 – *Hypericum hirsutum* L., 73 – *Veronica chamaedrys* L., 74 – *Erigeron annuus* (L.) Pers., 75 – *Cornus sanguinea* L., 76 – *Rumex sanguineus* L., 77 – *Dryopteris affinis* (Löwe) Fras.-Jenk., 78 – *Rubus hirtus* W. et K. agg., 79 – *Clematis vitalba* L., 80 – *Scrophularia nodosa* L., 81 – *Solanum dulcamara* L., 82 – *Paris quadrifolia* L., 83 – *Dryopteris carthusiana* 8Vill.) H. P., 84 – *Rubus fruticosus* L. agg., 85 – *Veronica montana* L., 86 – *Aconitum vulparia* Rchb., 87 – *Sambucus nigra* L., 88 – *Brachypodium sylvaticum* (Huds.) Roem. et Schult., 89 – *Carex sylvatica* Huds., 90 – *Ranunculus ficaria* L., 91 – *Polystichum setiferum* (Forskål) Woynar, 92 – *Corydalis cava* (L.) Schw. et Koerte, 93 – *Epilobium montanum* L., 94 – *Gagea lutea* (L.) Ker-Gawl., 95 – *Polystichum aculeatum* (L.) Roth, 96 – *Stachys sylvatica* L., 97 – *Eupatorium cannabinum* L., 98 – *Dryopteris filix-mas* (L.) Schott, 99 – *Atropa bella-donna* L., 100 – *Athyrium filix-femina* (L.) Roth, 101 – *Acer pseudoplatanus* L., 102 – *Circaea lutetiana* L., 103 – *Urtica dioica* L.

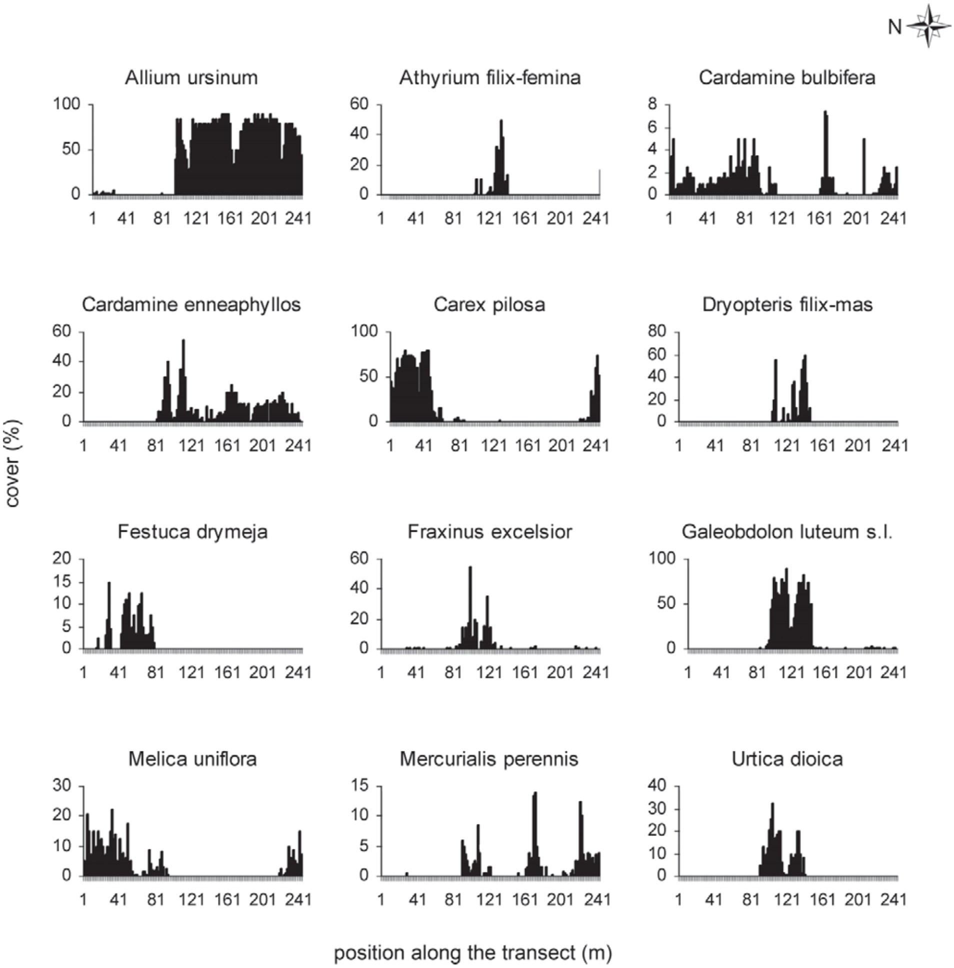


Fig. 2. Cover of the 12 most abundant plant species along the transect.

Presence-absence data were analysed using hierarchical classification (HC; Complete link, Sorensen index) to identify the vegetation types on the slopes. However, field observations were also performed to specify the result of the classification. Cluster analysis was done with the program package SYN-TAX 2000 (PODANI 2001).

Air temperature (°C) and humidity (%) were measured for 24 hours by SN21140CA sensors 25 cm above the ground surface in 50 sampling plots at 5 m intervals. Spectrum – Fieldscout TDR-300 was used to detect soil moisture values (%; in 12 cm depth) at the same 50 plots. All measures were carried out in summer, after a dry period, under clear weather conditions. Slope angles were also measured along the transect, from which altitude values were calculated for each plot.

We performed constrained ordinations using the Vegan R package (OKSANEN et al. 2009, R development core team 2009) and SYN-TAX 2000 to determine the main environmental parameters affecting the distribution pattern of plant species along the transect. We used a series of the linear ordination method, redundancy analysis (RAO 1964) to identify parameters that explain significant variation of species. We calculated the marginal and conditional effect of each term and assessed their significance using Monte-Carlo permutation tests with 5000 permutations (e.g. MUFF et al. 2009, GALLÉ and TORMA 2009). The following data were used in the analysis: presence-absence data of species, mean air temperature, mean air humidity, soil moisture and altitude values (Fig. 3). For interpretability, data of the summer aspect were used only in the redundancy analysis.

Figures were prepared with Microsoft EXCEL and Adobe Photoshop CS2. Plant community names were used according to BORHIDI (2003), while the names of plant taxa follow SIMON (2000).

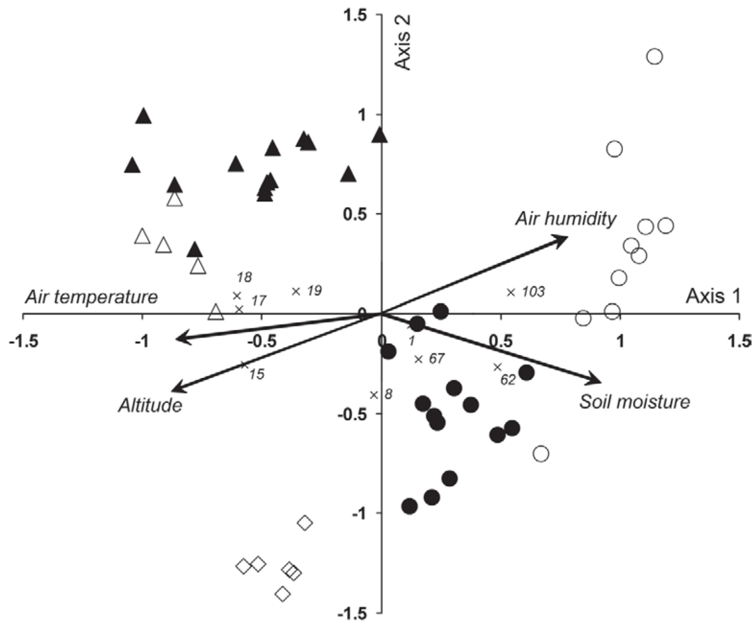


Fig. 3. Redundancy analysis ordination diagram with 50 plots (△: plots of the south-facing edge, ▲: plots of the south-facing slope, ◇: plots of the north-facing edge, ●: plots of the north-facing slope, ○: plots of the doline bottom), environmental variables (arrows) and the most frequent plant species (italic numbers 1, 8, 15, 17–19, 62, 67, 103, according to Fig. 1) of the plot groups.

Results

A total of 144 vascular plant species were detected in the doline (Fig. 1, Tab. 1). We found a strong correlation between species composition and doline morphology. Some species occur in every part of the doline (e.g. *Asarum europaeum*, *Cardamine bulbifera*, *Fraxinus excelsior*), while others occur only on the south-facing slope (e.g. *Clinopodium vulgare*, *Festuca drymeja*, *Lathyrus venetus*), the north-facing slope (e.g. *Arabis turrita*, *Isopyrum thalictroides*, *Milium effusum*) or in the doline bottom (e.g. *Dryopteris affinis*, *Polystichum aculeatum*, *Solanum dulcamara*). From a floristic point of view, the doline

Tab. 1. List of plant species outside the doline transect.

South-facing edge and slope
104: *Allium oleraceum* L., 105: *Astragalus glycyphyllos* L., 106: *Buglossoides purpureo-coerulea* (L.) I. M. Johnst., 107: *Campanula persicifolia* L., 108: *Chaerophyllum temulum* L., 109: *Cornus mas* L., 110: *Crataegus monogyna* Jacq., 111: *Cruciata glabra* (L.) Ehrend., 112: *Euonymus verrucosus* Scop., 113: *Euphorbia cyparissias* L., 114: *Festuca heterophylla* Lam., 115: *Galium lucidum* All., 116: *Lamium maculatum* L., 117: *Lapsana communis* L., 118: *Lathyrus niger* (L.) Bernh., 119: *Lilium martagon* L., 120: *Lysimachia nummularia* L., 121: *Lysimachia punctata* L., 122: *Melittis carpatica* Klok., 123: *Poa nemoralis* L., 124: *Potentilla micrantha* Ram., 125: *Scutellaria altissima* L., 126: *Silene viridiflora* L., 127: *Vicia sepium* L., 128: *Viola odorata* L.
North-facing edge
129: *Asperula taurina* L.
Doline bottom
130: *Aethusa cynapium* L., 131: *Actaea spicata* L., 132: *Arctium minus* (Hill) Bernh, 133: *Asplenium scolopendrium* L., 134: *Calamagrostis epigeios* (L.) Roth, 135: *Carex pendula* Huds., 136: *Cirsium arvense* (L.) Scop., 137: *Festuca gigantea* (L.) Vill., 138: *Galeopsis speciosa* Mill., 139: *Heracleum sphondylium* L., 140: *Knautia drymeia* Heuff., 141: *Phytolacca americana* L., 142: *Staphylea pinnata* L., 143: *Tilia cordata* Mill., 144: *Tilia platyphyllos* Scop.

bottom is the most important, because it preserves the highest number of mountain species (e.g. *Aconitum vulparia*, *Actaea spicata*, *Asplenium scolopendrium*, *Dryopteris affinis* and *Polystichum aculeatum*). The glacial relict plant *Stachys alpina* was found only on the upper part of the north-facing slope. Species cover is also strongly correlated with slope position and exposition along the transect (Fig. 2). For example, *Festuca drymeja* is abundant only on the south-facing slope, *Allium ursinum* and *Cardamine enneaphyllos* on the north-facing slope and in the doline bottom, while *Galeobdolon luteum* s.l. is abundant only in the doline bottom.

Four vegetation types were detected along the transect. A turkey oak-sessile oak forest (*Potentillo micranthae-Quercetum dalechampii* Horvát A. O. 1981) and an oak-hornbeam forest transition occurs on the south-facing edge (0–43 m), an oak-hornbeam forest on the south-facing slope and on the north-facing edge (44–71 m and 218–243 m), a beech forest on the lower part of the south-facing slope and on the north-facing slope (72–90 m and 146–217 m), and a ravine forest fragment in the bottom of the doline (91–145 m).

Summary statistics for redundancy analysis are shown in table 2. The subsequent Monte-Carlo permutation test indicates the significance of both the marginal and the conditional effect of the studied parameters ($p < 0.001$). The redundancy analysis triplot shows that doline vegetation is arranged along a moisture and temperature gradient (Fig. 3). The south-facing edge and south-facing slope are the driest and warmest, while the doline bottom is the moistest and coldest. Plots of the north-facing edge and north-facing slope occupy a transitional area in the ordination space. The maximum mean diurnal air temperature was detected in a plot of the south-facing edge (19.87 °C) and the minimum in a plot of the doline bottom (17.56 °C). In contrast, the maximum (57.9%) and minimum (7.3%) soil moisture, and the maximum (93.86%) and minimum (78.58%) mean diurnal air humidity values showed a reverse distribution.

Tab. 2. Summary statistics for redundancy analysis with the four environmental variables.

Axes	1	2	3	4
Eigenvalues	0.110	0.044	0.038	0.029
Species-environment correlations	0.9305	0.8834	0.8298	0.8047
Cumulative % variance				
of species data	11.0	15.4	19.2	22.1
of species-environment relationship	50	69.7	86.8	100
Sum of all eigenvalues: 1				
Sum of all canonical eigenvalues: 0.22				

Discussion

Our study revealed the close relationships between the variation of geomorphological and vegetation pattern in a karst depression at the spatial scale of the study. The most important finding of this study is that the vegetation pattern is strongly correlated with slope exposition and the depth of the doline.

A former study by BÁTORI et al. (2009) showed that plant associations of the karst of Mecsek Mountains are arranged along a moisture and nutrient gradient. However, despite being the first detailed description of the doline vegetation and its surroundings of this area, that study only addressed the large-scale vegetation pattern (Braun-Blanquet scale) of the bottom of the dolines, and used exclusively ecological-indicator values to reveal the habitat conditions in the depressions.

In contrast, our present study reveals the fine-scale vegetation pattern along a doline transect and shows that there are remarkable differences among the species composition of the south-facing slope, the north-facing slope and the bottom of the doline. This is a consequence of the special microclimate that often determines both abiotic and biotic parameters of karst depressions (GEIGER 1950, WHITEMAN et al. 2004, GARGANO et al. 2010, OZIMEC et al. 2010, VRBEK et al. 2010). In Hungary, south-facing slopes receive higher solar radiation (JAKUCS 1971), which affects temperature, air humidity and soil moisture, and ultimately, affects the vegetation. In the case of the investigated doline, mixed-oak forests cover the major part of the south-facing slope. In contrast, the north-facing slope receives lower solar radiation, which results in lower mean temperatures and lower evapotranspiration. Due to the cooler climate, the north-facing slope and the lower part of the south-facing slope are covered by beech forests. Therefore, a vegetation inversion is formed, which is a common phenomenon in karst depressions (BECK-MANNAGETTA 1906, HORVAT 1953, LAUSI 1964, FAVRETTO and POLDINI 1985). The vegetation pattern also changes in the bottom of the doline, where the special ecological conditions have led to the development of a ravine forest. Our results are in good agreement with those of HOYK (1999), who pointed out that dolines of the Mecsek Mts play an important role in the landscape due to their characteristic shape and valuable flora.

Considering the special microclimatic conditions, geomorphological features, vegetation pattern and species composition, dolines are especially important and valuable for scientific research and nature conservation.

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