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# FLORISTIC AND MICROCLIMATIC FEATURES OF THE SOVLJAK DOLINE (MT. VELIKA KAPELA, CROATIA)

## FLORISTIČKE I MIKROKLIMATSKE ZNAČAJKE PONIKVE SOVLJAK (VELIKA KAPELA, HRVATSKA)

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## SUMMARY

The relation between floristic composition, microclimate and geomorphology of a large-sized karst doline was analysed in the area of the Sovljak doline located on the Mt. Velika Kapela. Habitat conditions in various parts of the doline, due to its morphology, were described in this work. Geomorphological observations, microclimatic measurements (including air temperature, relative humidity and dew point temperature data) and flora inventory were carried out. Ellenberg's indicator values, life forms, chorological and taxonomical analyses were performed, as well as the analysis of habitat similarity. The doline slopes (northern and southern) appeared to offer different habitat conditions than its bottom, due to their morphological and microclimatic differences, which resulted in high taxa variability along short distances in the doline. Furthermore, the presence of temperature inversion promoted the development of the vegetation inversion, which is common in such large dolines.

**KEY WORDS:** microclimate, geomorphology, flora, Ellenberg's indicator values, vegetation inversion

## INTRODUCTION
## UVOD

Dolines are natural enclosed depressions found in karst landscapes, considered as diagnostic landform of such landscapes. Besides their geomorphological context in karst, dolines are also described as interesting localities due to their special microclimatic, ecological and vegetational features. The climate of the dolines differs from the climate of the surrounding area, mainly because of the different amount of the radiation they receive, which depends on the exposition and inclination of the doline slopes (Cernatič-Gregorič and Zega, 2010). As a concave relief form, they favour the formation of air temperature inversion, more clearly expressed in dolines with greater depth, and in those situated on higher elevations (Šegota and Filipčić, 1996). Furthermore, microclimatic conditions influence the composition and distribution of vegetation, thus, air temperature inversion can also lead to the vegetation inversion in a doline (Horvat, 1962).

As a result of different type of genesis and evolution, dolines differ in their morphological features, which are the main criteria for their classification, together with their morphogenesis (Bondesan et al., 1992). Their horizontal dimensions may range from only a few meters, to a few hundred meters. With the sides ranging from gently sloping to vertical, their depth can vary from a few, to tens of meters. Morphogenetically, dolines can be classified into four main categories,

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concerning the type of the development process, which include dissolution (corrosion), collapse, suffusion or subsidence (Williams, 2004). However, their genesis often includes more than just one process, thus the majority of the dolines have polygenetic origin, even though one process is always dominant (Ford and Williams, 2007).

This study aimed to identify the habitat conditions in different parts of the Sovljak doline, situated on the Mt. Velika Kapela. Also, the aim was to investigate its microclimate, in order to detect a potential temperature inversion, which may, if intense and frequent enough, cause the occurrence of vegetation inversion. Similar investigations were made by Lausi (1964) and Favretto and Poldini (1985) in Italy, Bátori et al. (2009, 2011, 2012, 2016) and Bárány-Kevei (2011) in Hungary, Özkan et al. (2010) in Turkey, Antonić et al. (1997), Vrbek et al. (2010), Buzjak et al. (2011) and Surina (2014) in Croatia.

## RESEARCH AREA
## PODRUČJE ISTRAŽIVANJA

The Sovljak doline was chosen as an interesting site, since it stands out by its funnel shaped morphology and large dimensions. It is situated on the eastern slope of the Mt. Velika Kapela, 8.5 km SSW from the town of Ogulin, between the regions of Ogulinsko-plaščanska udolina valley on the east and the Gorski kotar on the west (Fig. 1).

The researched karst area is mostly covered by thermophilic beech forest (ass. *Ostryo-Fagetum* M. Wraber ex Trinajstić 1972). Considering the Köppen-Geiger climate classification, this area belongs to the moderately warm climate type with warm summer (Cfb), with mean July temperature between 20 and 22 °C and mean January temperature between 0 and -3 °C. The precipitation is equally distributed during the year, with the lack of a dry period (Kottek et al., 2006; Šegota and Filipčić, 1996).

### Basic geological conditions of the doline's geomorphological evolution – *Osnovni geološki uvjeti geomorfološkog oblikovanja ponikve*

The Upper Jurassic carbonate rocks (Malm series) dominate the research area, with two members which can be distinguished. Their characteristics determined by geological conditions and geomorphological processes are contributing to internal biotope conditions. The $^{2}J_{3}$ member is represented

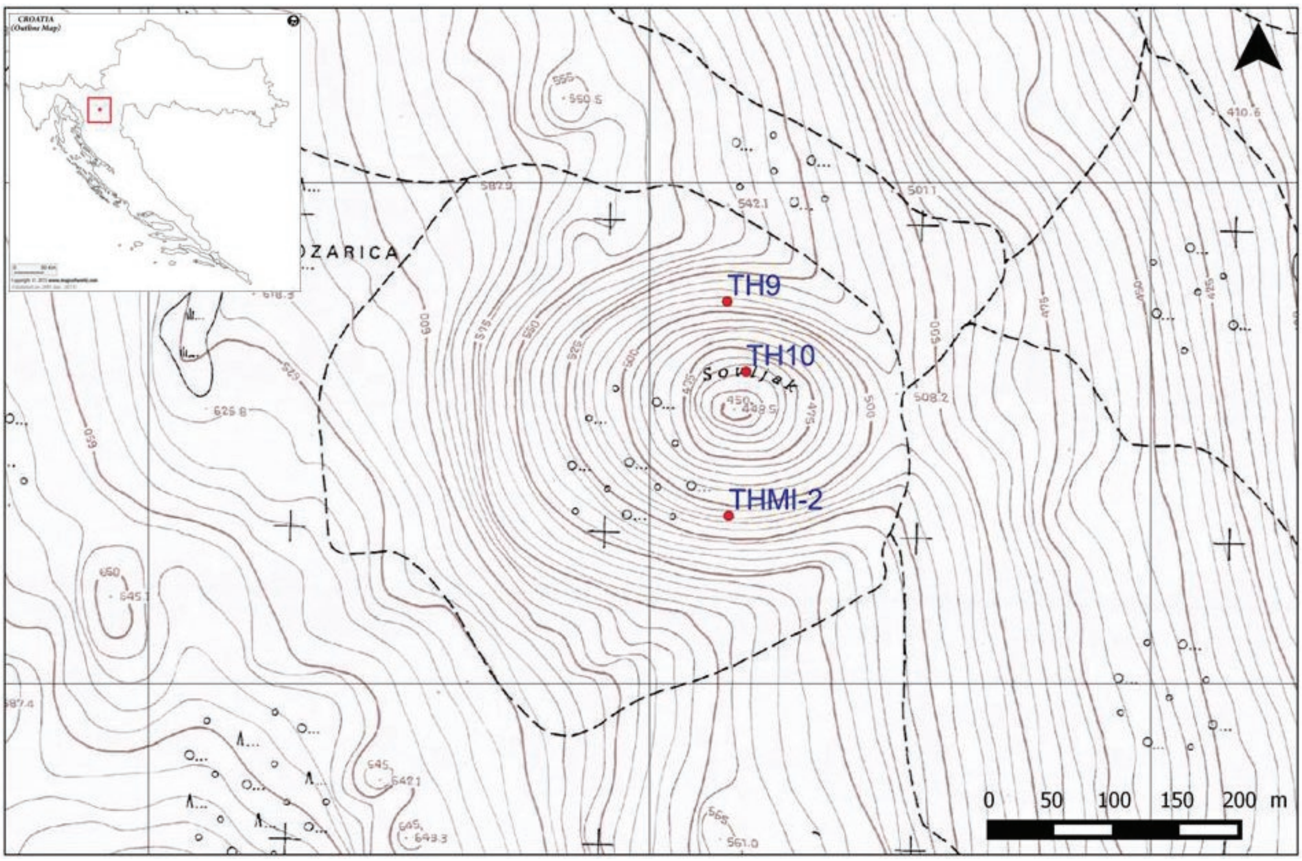


**Figure 1.** Geographic position of the Sovljak doline with the locations of data loggers: TH9 – southern exposition slope, TH10 – bottom of the doline, THMI-2 – northern exposition slope (URL 1)

Slika 1. Geografski položaj ponikve Sovljak s lokacijama termohigrografa na mjernim točkama: TH9 – padina južne ekspozicije, TH10 – dno ponikve, THMI-2 – padina sjeverne ekspozicije (URL1) by algal limestones, dolomites and dolomites with the limestone lens. Its main lithological characteristic is alteration of dolomites and limestones. The younger member $^3J_3$ is represented by algal-foraminiferal limestones and dolomites from the Lower Malm. Various types of limestones with mud or sparicalcitic cement and crystalinic dolomites are a characteristic feature of this member (Velić and Sokač, 1981). The Quartar sediments are mostly eroded, but they appear locally in the doline as the rock-creeped breccias. In the tectonic structure of the researched area, intense tectonic fractures can be distinguished. The facilitating factor for the genesis of the doline was its position on the interception of faults, with the spreading directions NW – S, SE and NE – SW, and also the presence of a few secondary fractures. Due to the limestone/dolomite alternation and by tectonic stress dense network of fissures the doline is characterized by intense rock disintegration and slope processes, especially in the part built of dolomite. Along the fault lines there are steeper slopes with rock debris at the base. Different slope inclination and geomorphological processes therefore resulted in pedogenesis (alternation of bare rocks, shallow brown soils on limestones and dolomites, thicker colluvium deposits below steep slopes), local hydrological paths of water infiltration and microclimate (exposition and humidity).

## MATERIAL AND METHODS
## MATERIJAL I METODE

To gain wider perspective of the investigated area, a few different types of research were included in this study, such as geomorphological, microclimatic and floristic research.

Geomorphological research included the field work, where geomorphological forms and processes were observed, followed by the analysis of cartographic sources. Morphometric analyses were made on Croatian base map 1:5000 (URL 1).

Microclimatic measurements in the doline were performed during the vegetation period of 2015, from April to September, using three data loggers (Onset HOBO Pro v2). They recorded air temperature, relative humidity and dew point temperature with the measurement interval of 30 minutes. Measuring points were set on the slope of the southern exposition (z = 508 m a. s. l.), at the bottom of the doline (z = 464 m a. s. l.) and on the slope of the northern exposition (z = 508 m a. s. l.). Data loggers were set on a tree, fixed on the trunk 1 meter above the ground. The loggers were facing north, to protect them from the direct solar radiation. During the measuring period, two out of three data loggers stopped working due to the battery error.

Floristic research was conducted during the vegetation season of 2015, to investigate the floristic structure on the slopes of the doline of different expositions. Plant taxa were recorded on the slopes of the southern and northern expositions, and at the bottom of the doline. The taxa were mostly identified in the field, with some exceptions, which were collected and identified subsequently using standard floristic literature (Tutin et al., 1968 – 1980, 1993; Pignatti 1982; Jávorka and Csapody, 1991; Domac, 1994). The plant material is partly deposited in the Herbarium Collection of the Croatian Natural History Museum (CNHM). The nomenclature follows Flora Croatica Database (Nikolić, 2018).

We have performed taxonomic, chorological, Ellenberg's indicator values (hereafter: Eiv) and life form analyses. Besides the analysis of the total flora, the floristic analysis for different parts of the doline was also performed, using the Sörensen index of similarity. Legal protection of taxa was determined according to the Nature Protection Act (Official Gazette 80/2013) and the Ordinance on Strictly Protected Species (Official Gazette 144/2013, 73/2016). Moreover, the taxa listed in the Red Book of Vascular Flora of Croatia (Nikolić and Topić, 2005) were marked using the adequate IUCN designations: VU – Vulnerable, NT – Near Threatened, LC – Least Concern, DD – Data Deficient.

Chorological analysis follows the classification used by Horvatić et al. (1967 – 1968). The chorological groups used in this paper are: 1 – Mediterranean, 2 – Illyrian-Balkan, 3 – South-European, 4 – Atlantic, 5 – East European-Pontic, 6 – Southern-East European, 7 – Central European, 8 – European, 9 – Eurasian, 10 – Circumholarctic, 11 – Widespread. The data were taken from the Flora Croatica Database (Nikolić, 2018) and from the following literature sources: Tutin et al. (1993), Pignatti (1982), Buzjak (2001), Pandža (2010), Nežmah and Ljubičić (2012), Britvec et al. (2014).

Life forms and ecological indicator values were given according to Ellenberg and Leuschner (2010). The data were mostly taken from the Flora Croatica Database (Nikolić, 2018) and supplemented with the following sources: Ellenberg and Leuschner (2010), Pignatti (2005). The following abbreviations were used for the presentation of life forms: P – Macrophanerophytes, N – Nanophanerophytes, Z – Woody Chamaephytes, C – Herbaceous Chamaephytes, H – Hemicryptophytes, G – Geophytes and T – Therophytes. Ecological indicator values included in the analysis were: L – light, T – temperature, F – soil moisture and R – reaction. For three taxa (*Cardamine waldsteinii* Dyer, *Piptatherum virescens* (Trin.) Boiss., *Polystichum × illyricum* (Borbás) Hahne) some of the above mentioned data were not available in the literature; therefore these taxa were excluded from the analysis.

## RESULTS AND DISCUSSION
## REZULTATI I RASPRAVA

### Geomorphology – *Geomorfologija*

Regarding the morphometrical features, the Sovljak doline has a perimeter axis of 310 m in the N-S direction, and 450

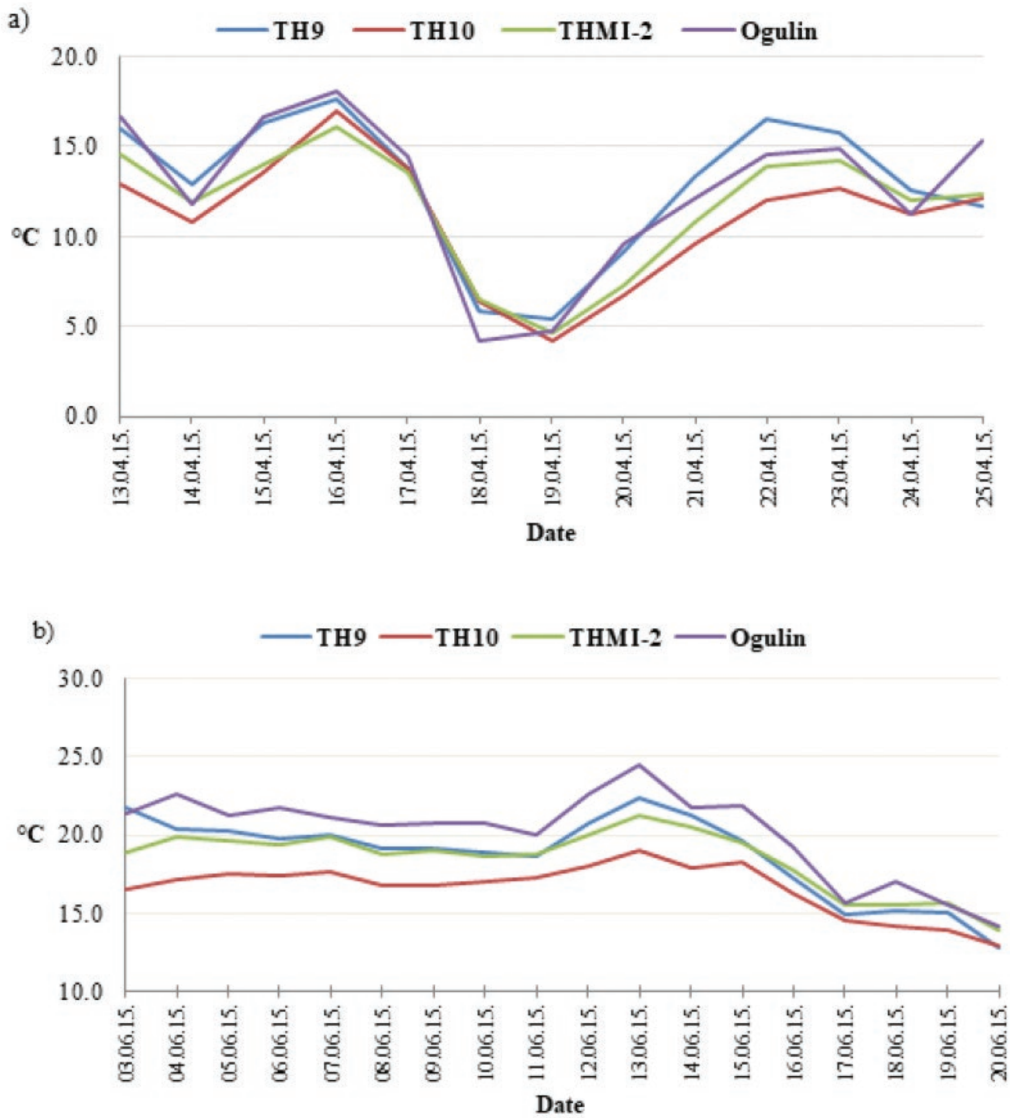


**Figure 2.** Mean air temperature on the southern exposition slope (TH9), at the bottom (TH10), on the northern exposition slope (THMI-2) and on the referent measuring station (Ogulin) for the period of 13 – 25 April 2016 (a) and 03 – 20 June 2016 (b)

Slika 2. Hod srednje dnevne temperature zraka za padinu južne ekspozicije (TH9), dno ponikve (TH10), padinu sjeverne ekspozicije (THMI-2) i za referentnu mjernu postaju (Ogulin) u razdoblju 13. – 25. travnja 2016. (a) i 03. – 20. lipnja 2016. (b)

m in the E-W direction. Its depth is up to 59.7 m, but the highest altitudinal difference, between the highest and the lowest point of the doline, is 111.8 m. The perimeter area amounts to 0.12 $km^2$, while the estimated volume is ~410000 $m^3$. According to the morphology, it can be classified as a bowl-like doline. Regarding the morphogenetic features, the doline is polygenetic in origin, since several processes such as karst corrosion, collapse and slope processes were included in its genesis and evolution. Recently, the most intensive are slope processes; manifested by the appearance of the slope base colluvium. It is composed of unsorted debris material, containing irregularly shaped and different-sized rocky fragments, mostly 10–20 cm in diameter. A great amount of the dolomitic scree found on the southern exposition slope is a clear geoindicator of the cryofraction process. Outbound trunks and bended tree bottoms are bioindicators for the rockslides and creep process present on the slopes regarding to different inclination.

## Microclimate – *Mikroklima*

Two measuring periods were extracted from the total microclimatic data, for the analysis of the microclimatic parameters. The results of the mean air temperature analysis (Fig. 2) showed that the warmest part of the doline for most observed days was the southerly exposed slope; while the bottom was the coldest part of the doline in both analysed periods. Results of the statistical analysis (Tab. 1) show higher values of average temperature on the southerly and northerly exposed slopes, as opposed to the bottom of the doline. Such a result indicates the presence of the tempera-

**Table 1.** Average values for temperature (T), relative humidity (u) and dew point (τ) for the period of 13 – 25 April 2016. (a) and 03 – 20 June 2016 (b)

Tablica 1. Hod srednje dnevne temperature (T), relativne vlažnosti (u) i točke rosišta (τ) u razdoblju 13. – 25. travnja 2016. (a) i 03. – 20. lipnja 2016. (b)

a)

| | T (°C) | | | u (%) | | | τ (°C) | | |
|---|---|---|---|---|---|---|---|---|---|
| | TH9 | TH10 | THMI-2 | TH9 | TH10 | THMI-2 | TH9 | TH10 | THMI-2 |
| **Min** | 0,6 | 0,9 | 1,9 | 25,6 | 32,2 | 34,9 | -1,2 | -1,2 | 0,8 |
| **Max** | 24,9 | 22,2 | 20,3 | 93,2 | 93,0 | 100,0 | 10,2 | 10,5 | 11,3 |
| **Average** | 12,7 | 10,7 | 11,4 | 58,7 | 70,9 | 67,6 | 3,9 | 5,1 | 4,9 |
| **Amplitude** | 24,3 | 21,3 | 18,4 | 67,5 | 60,8 | 65,1 | 11,5 | 11,7 | 10,5 |
| **St. dev.** | 5,6 | 5,1 | 4,5 | 18,9 | 17,6 | 19,3 | 2,6 | 2,6 | 2,2 |
| **Var.** | 43,9 | 47,1 | 39,1 | 32,2 | 24,8 | 28,5 | 65,1 | 50,4 | 45,4 |

b)

| | T (°C) | | | u (%) | | | τ (°C) | | |
|---|---|---|---|---|---|---|---|---|---|
| | TH9 | TH10 | THMI-2 | TH9 | TH10 | THMI-2 | TH9 | TH10 | THMI-2 |
| **Min** | 11,3 | 10,1 | 12,0 | 39,7 | 52,5 | 51,8 | 5,0 | 6,0 | 5,6 |
| **Max** | 27,0 | 24,8 | 24,6 | 5,0 | 94,7 | 99,6 | 18,4 | 18,8 | 18,6 |
| **Average** | 18,7 | 16,7 | 18,6 | 73,6 | 85,1 | 78,4 | 13,7 | 14,1 | 14,5 |
| **Amplitude** | 15,7 | 14,6 | 12,6 | 55,3 | 42,2 | 47,8 | 13,4 | 12,8 | 13,0 |
| **St. dev.** | 3,5 | 2,8 | 3,0 | 11,9 | 8,6 | 11,7 | 2,6 | 2,5 | 2,6 |
| **Var.** | 18,9 | 17,0 | 16,1 | 16,2 | 10,1 | 15,0 | 18,8 | 17,9 | 17,8 |

ture inversion during the most observed days in the Sovljak doline. The southerly exposed slope, with the highest value of temperature amplitude, indicates the greater amount of received solar radiation, unlike the other two measuring points in the doline where received solar radiation is restricted by the doline's rim and northern exposition. Results of the measurements of the relative humidity are showing lower values on slopes, than at the bottom of the doline corresponding with the results of the temperature distribution.

Temperature inversion occurs as a consequence of the smaller amount of received solar radiation, caused by the geomorphology of the doline and shading from the vegetation. Whiteman et al. (2004) were studying dolines in the eastern Alps (Austria) during calm, clear-sky conditions, and concluded that the sky-view factor is the most important topographic parameter determining minimum temperatures in dolines of different geometry, as a result of concave topography reducing the view of sky. While studying Viljska ponikva doline in Croatia, Antonić et al. (1997) emphasised the effect of insolation quantity, altogether with the tree canopy shading, and doline altitude on the topoclimate.

Due to the presence of temperature inversion, normal vertical temperature gradient in the Sovljak doline is modified, resulting in increased and negative value. It amounts to approximately -5 °C/100 m, that is 8 times higher than the normal value, which usually amounts to 0.6 °C/100 m (Šegota and Filipčić, 1996). Polli (1961) observed similar phenomenon in the dolines of the Province of Trieste (Italy), where he recorded as much as 12 times higher temperature gradient inside the doline, compared to its surroundings.

## Flora – *Flora*

Altogether 107 taxa (98 species, 2 subspecies and 7 taxa identified only to the genus rank) were recorded in the flora of the Sovljak doline (Tab. 2). Taxa identified only to genus rank were excluded from some analyses. There were 97 taxa belonging to spermatophytes, while 10 taxa were pteridophytes. The largest group were dicots with 80 taxa, followed by monocots with 16 taxa, and conifers with one taxon. The recorded taxa belong to 50 plant families, out of which the most represented were *Lamiaceae* (10.28 %), followed by *Brassicaceae* (5.60 %) and *Ranunculaceae* (5.60 %), while other families account for less than 5 % each.

It is well known that karst dolines, due to specific habitat conditions they provide, have a great potential to preserve relicts, endemic, mountain and wet-woodland species, and also represent an important source of knowledge about vegetation history (Bátori, 2012). The Sovljak doline showed the capacity of preserving endemic taxa (*Cardamine kitaibelii*, *Cardamine waldsteinii*, *Helleborus niger* and *Polystichum × illyricum*), and also included a few species threatened according to the IUCN Red List (Tab. 2).

The phytogeographical spectrum of the Sovljak doline showed the predominance of Eurasian floristic element

**Table 2.** The list of the taxa. W – life forms, IUCN – threat status, P – legal status (S4 – strictly protected plants), E – endemic species, FE – floristic element

Tablica 2. Popis svojti. W – životni oblici, IUCN – podaci o ugroženim svojtama, P – status zaštite (S4 – strogo zaštićene svojte), E – endemi, FE – florni element

| Taxa | W | IUCN | P | E | FE |
|---|---|---|---|---|---|
| ***Abies alba*** **Mill.** | P | | | | 3 |
| ***Acer obtusatum*** **Willd.** | P | | | | 6 |
| ***Acer pseudoplatanus*** **L.** | P | | | | 8 |
| ***Ajuga reptans*** **L.** | H | | | | 9 |
| ***Anemone nemorosa*** **L.** | G | | | | 11 |
| ***Anemone ranunculoides*** **L.** | G | | | | 9 |
| ***Aposeris foetida*** **(L.) Less.** | H | | | | 3 |
| ***Arum maculatum*** **L.** | G | | | | 8 |
| ***Aruncus dioicus*** **(Walter) Fernald** | H | | | | 11 |
| ***Asarum europaeum*** **L.** | H | | | | 9 |
| ***Asparagus tenuifolius*** **Lam.** | G | NT | | | 3 |
| ***Asplenium ruta-muraria*** **L.** | H | | | | 10 |
| ***Asplenium scolopendrium*** **L.** | H | | | | 10 |
| ***Asplenium trichomanes*** **L.** | H | | | | 11 |
| ***Athyrium filix-femina*** **(L.) Roth** | H | | | | 11 |
| ***Brachypodium sylvaticum*** **(Huds.) P. Beauv.** | H | | | | 9 |
| ***Buphthalmum salicifolium*** **L.** | H | | | | 7 |
| ***Calamintha sylvatica*** **Bromf.** | H | | | | 8 |
| ***Cardamine bulbifera*** **(L.) Crantz** | G | | | | 8 |
| ***Cardamine enneaphyllos*** **(L.) Crantz** | G | | | | 3 |
| ***Cardamine kitaibelii*** **Bech.** | G | | S4 | * | 3 |
| ***Cardamine trifolia*** **L.** | H | | | | 3 |
| ***Cardamine waldsteinii*** **Dyer** | G | | S4 | * | 3 |
| ***Carex digitata*** **L.** | H | | | | / |
| Carex sp. | / | | | | / |
| ***Carpinus betulus*** **L.** | P | | | | 7 |
| ***Chrysosplenium alternifolium*** **L.** | H | | | | 10 |
| ***Circaea lutetiana*** **L.** | G | | | | 10 |
| ***Clematis vitalba*** **L.** | P | | | | 8 |
| ***Clinopodium vulgare*** **L.** | H | | | | 11 |
| ***Convallaria majalis*** **L.** | G | | | | 10 |
| ***Cornus mas*** **L.** | P/N | | | | 3 |
| ***Corydalis bulbosa*** **(L.) DC.** | G | | | | 9 |
| ***Corylus avellana*** **L.** | N | | | | 8 |
| ***Cyclamen purpurascens*** **Mill.** | G | NT | | | 3 |
| ***Daphne laureola*** **L.** | N | NT | | | 3 |
| ***Daphne mezereum*** **L.** | N/Z | NT | | | 9 |
| ***Digitalis grandiflora*** **Mill.** | H | NT | | | 8 |
| ***Dryopteris affinis*** **(Lowe) Fraser--Jenk.** | H | | | | 9 |
| ***Dryopteris filix-mas*** **(L.) Schott** | H | | | | 11 |
| ***Euphorbia amygdaloides*** **L.** | Z/C | | | | 7 |
| ***Euphorbia cyparissias*** **L.** | G/H | | | | 9 |
| ***Fagus sylvatica*** **L.** | P | | | | 8 |
| ***Fragaria*** **sp.** | / | | | | / |
| ***Fraxinus ornus*** **L.** | P | LC | | | 3 |
| ***Galanthus nivalis*** **L.** | G | | | | 9 |
| ***Galium odoratum*** **(L.) Scop.** | G | | | | 9 |
| ***Galium*** **sp.** | / | | | | / |
| ***Galium sylvaticum*** **L.** | G | | | | 8 |
| ***Geranium robertianum*** **L.** | T/H | | | | 11 |
| ***Hacquetia epipactis*** **(Scop.) DC.** | H | | | | 6 |
| ***Hedera helix*** **L.** | P/Z | | | | 8 |
| ***Helianthemum nummularium*** **(L.) Mill. ssp. *grandiflorum* (Scop.) Schinz et Thell.** | Z/C | | | | 8 |
| ***Helleborus niger*** **L.** | H | VU | | * | 7 |
| ***Hepatica nobilis*** **Schreber** | H | | | | 10 |
| ***Hippocrepis comosa*** **L.** | C/H | | | | 3 |
| ***Iris graminea*** **L.** | G | LC | S4 | | 3 |
| ***Isopyrum thalictroides*** **L.** | G | | | | 9 |
| ***Lamium galeobdolon*** **(L.) L.** | H | | | | 9 |
| ***Lamium orvala*** **L.** | H | | | | 2 |
| ***Lathyrus vernus*** **(L.) Bernhardt** | H/G | | | | 8 |
| ***Ligustrum vulgare*** **L.** | N | | | | 7 |
| ***Lilium martagon*** **L.** | G | VU | S4 | | 9 |
| ***Lunaria rediviva*** **L.** | H | | | | 8 |
| ***Melampyrum sylvaticum*** **L.** | T | | | | 8 |
| ***Melittis melissophyllum*** **L.** | H | | | | 8 |
| ***Mercurialis perennis*** **L.** | G/H | | | | 8 |
| ***Neottia nidus-avis*** **(L.) Rich.** | G | | S4 | | 9 |
| ***Origanum vulgare*** **L.** | C/H | | | | 9 |
| ***Ostrya carpinifolia*** **Scop.** | P | | | | 1 |
| ***Paris quadrifolia*** **L.** | G | | | | 9 |
| ***Peucedanum austriacum*** **(Jacq.) Koch** | H | | | | 3 |
| ***Phyteuma spicatum*** **L.** | H | | | | 7 |
| ***Piptatherum virescens*** **(Trin.) Boiss.** | H | | | | 6 |
| ***Polygonatum*** **sp.** | / | | | | / |
| ***Polypodium vulgare*** **L.** | H | | | | 11 |
| ***Polystichum aculeatum*** **(L.) Roth** | G/H | | | | 11 |
| ***Polystichum setiferum*** **(Forssk.) Woyn.** | H | | | | 10 |
| ***Polystichum × illyricum*** **(Borbás) Hahne** | G | | S4 | * | / |
| ***Prenanthes purpurea*** **L.** | H | | | | 7 |
| ***Primula vulgaris*** **Huds.** | H | | | | 3 |
| ***Pulmonaria officinalis*** **L.** | H | | | | 8 |
| ***Quercus cerris*** **L.** | P | | | | 3 |
| ***Rosa*** **sp.** | / | | | | / |
| ***Ruscus hypoglossum*** **L.** | Z | NT | | | 3 |
| ***Salvia glutinosa*** **L.** | H | | | | 9 |
| ***Sambucus nigra*** **L.** | N | | | | 8 |
| ***Sanicula europaea*** **L.** | H | | | | 11 |
| ***Scopolia carniolica*** **Jacq.** | H | | | | 3 |
| ***Senecio ovatus*** **(P.Gaertn., B.Mey. et Scherb.) Willd.** | H | | | | 4 |
| ***Silene dioica*** **(L.) Clairv.** | H | | | | 9 |
| ***Silene nutans*** **L.** | H | | | | 9 |
| ***Solidago virgaurea*** **L.** | H | | | | 9 |
| ***Sorbus aria*** **(L.) Crantz** | P | | | | 11 |
| ***Stachys sylvatica*** **L.** | H | | | | 9 |
| ***Staphylea pinnata*** **L.** | N | | | | 7 |
| ***Tamus communis*** **L.** | G | | | | 3 |
| ***Teucrium chamaedrys*** **L.** | Z | | | | 3 |
| ***Teucrium*** **sp.** | / | | | | / |
| ***Urtica dioica*** **L.** | H | | | | 11 |
| ***Valeriana tripteris*** **L.** | H | | | | 3 |
| ***Veratrum album*** **L.** | G | D.D. | | | 9 |
| ***Verbascum*** **sp.** | / | | | | / |
| ***Veronica urticifolia*** **Jacq.** | C/H | | | | 7 |
| ***Viburnum lantana*** **L.** | N | | | | 3 |
| ***Vincetoxicum hirundinaria*** **Medik.** | H | | | | 9 |
| ***Viola reichenbachiana*** **Jord. ex Boreau** | H | | | | 9 |

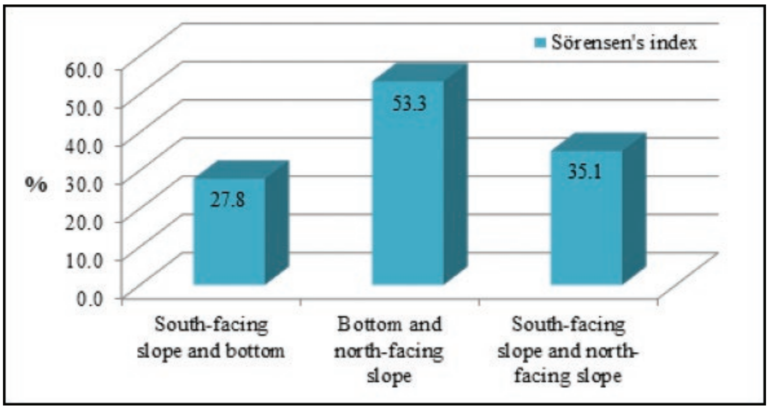


**Figure 3.** Results of the Sörenson's index analysis for the taxa in different parts of the doline
Slika 3. Vrijednosti Sörensen-ovog indeksa za svojte između pojedinih dijelova ponikve

(25 %) followed by South European (21 %), European (18 %) and widespread plants (12 %), while other floristic elements were represented with less than 10 % each. Such composition confirmed that the research area belongs to Euro-Siberian – North-American region of Holoarctic (Horvatić and Trinajstić, 1967 – 1981). The life form analysis showed the largest proportion of taxa belonging to hemicryptophytes (45 %), followed by geophytes (23 %), phanerophytes (10 %), nanophanerophytes (6 %), while chamaephytes and therophytes comprise less than 5 % each. Domination of hemicryptophytes, altogether with the large portion of geophytes and a lower portion of therophytes and phanerophytes, is characteristic for the moderate climatic area where the researched area is situated (Gračanin, 1977). By analysing the different parts of the Sovljak doline we have shown that the southerly exposed slope contains 93 taxa, the bottom of the doline 22 taxa, and north-facing slope 38 taxa. According to the results of the Sörensen's index analysis (Fig. 3), the bottom and the northerly exposed slope have the greatest floristic similarity, while the lowest similarity is found between the southerly exposed slope and the bottom.

According to the analysis of ecological indicator values (Tab. 3), moderately warm-site indicator plants characteristic for moderate submontane habitats dominate in the Sovljak doline. Considering the Eivs for light, the most common are plants of the shade, followed by the plants of semi-shade. Eivs for moisture show the largest number of plants of moist sites, indicating moderately moisturised soils. According to the Eivs for reaction, weakly acidic to weakly alkaline soil indicators dominate in the doline. According to the overall results (Tab. 3), mean ecological indicator values for examined parameters show the transition of habitat conditions between the different parts of the doline. Mean Eivs for light, temperature and reaction show the regularity in the distribution, in which the highest values are found on the southerly exposed slope, followed by the northerly slope, while the lowest values are present at the bottom of the doline. Mean Eivs for the moisture show the opposite result, decreasing from the bottom of the doline towards the southerly exposed slope. Such a distribution indicates that the bottom and the northerly exposed slope represent a well-defined shady habitat, while the southerly exposed slope represents a more thermophilic habitat. As expected, different habitat conditions resulted in the different flora composition between the studied parts. The lower Eivs for temperature at the bottom and the higher ones at the slopes suggest the occurrence of vegetation inversion in the doline Sovljak. The same can be observed from the gradual change in floristic composition across the examined slopes.

During the fieldwork, we have registered a thermophilic beech forest, developed on the approach road to the Sovljak doline, leading from the direction of lake Sabljaci across the eastern slope of the Mt. Velika Kapela. In addition, a thermophilic habitat, with characteristic plant species, such as *Ostrya carpinifolia*, *Fraxinus ornus*, *Acer obtusatum*, *Quercus cerris*, *Cornus mas*, *Sorbus aria* and *Vincetoxicum hirundinaria,* was recorded on the rim of the doline and in the upper part of the southerly exposed slope, while *Fagus sylvatica* occurred only sporadically. In the lower part of the southerly exposed slope, thermophilic character of the vegetation weakens, thus *F. sylvatica* starts dominating the tree canopy. In addition, typical beech forest species such as *Acer pseudoplatanus*, *Polystichum setiferum* and *Lamium orvala* start to occur in this area. The bottom of the doline represents a shaded habitat, with the ground floor covered with

**Table 3.** Mean ecological indicator values for light (L), temperature (T), soil moisture (F) and reaction (R) for the studied parts of the doline
Tablica 3. Srednje vrijednosti ekoloških indikatorskih vrijednosti za svjetlo (L), temperaturu (T), vlažnost tla (F) i pH tla (R) po dijelovima ponikve

| | Southern exposition slope | Bottom | Northern exposition slope |
|---|---|---|---|
| L | 4,80 | 3,90 | 3,97 |
| T | 5,33 | 5,00 | 5,16 |
| F | 4,81 | 5,71 | 5,35 |
| R | 6,67 | 6,47 | 6,54 |

species preferring less insolation, such as *Lunaria rediviva*, *Scopolia carniolica* and *Cardamine waldsteinii* which also require soils rich in humus. In this area *F. sylvatica* dominates in the tree layer, while *A. pseudoplatanus* and *Corylus avellana* occur sporadically. On the northerly exposed slope, *F. sylvatica* is the most significant tree species along with the rest of the fagetal species, while *Abies alba* and *Sambucus nigra* rarely occur in the tree and shrub layer. Similar scenario was registered in the dolines of Trieste karst, where Lausi (1964) observed the replacement of climatogenic association with the new association which is adapted to the intricate mosaics of factors deeper in the dolines, including depth, exposition, continentality, etc.

Considering the large size of the researched doline, the occurrence of vegetation inversion is in accordance with the work of Bátori (2012), which finds that the vegetation inversion is more pronounced in larger dolines compared to the smaller ones, based on the analysis of 20 dolines in Hungary. The work of Özkan (2010) investigated relationships between the species distribution and slope positions inside 20 dolines in Turkey, and found significant differences in the plant distribution inside dolines, along with high plant variability across short distances, similar to our results.

## CONCLUSIONS
## ZAKLJUČCI

Different habitat conditions were determined for all the investigated parts of the Sovljak doline caused by the geomorphology and microclimate conditions. Those transitions in habitat conditions between different parts of the doline were reflected in floristic composition, resulting in the gradual change across the examined slopes. Temperature inversion was the dominant characteristic of microclimate of the doline during the research period. While the bottom had the lowest temperature values, the northerly exposed slope had higher, and the southerly exposed slope the highest values. As a consequence of temperature inversion, the results proposed the occurrence of the vegetation inversion in the doline, which is evident from the weakening of thermophilic character of the vegetation towards its bottom. Vegetation inversion suggests that temperature inversion is characteristic phenomenon in the microclimate of the Sovljak doline. Microclimatic measurements in duration of at least a year would be necessary to confirm these findings.

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## SAŽETAK


Na području ponikve Sovljak smještene na Velikoj Kapeli proučavana je povezanost geomorfoloških i mikroklimatskih čimbenika te vegetacije u velikim krškim ponikvama. U radu su opisani stanišni uvjeti koji vladaju na različitim dijelovima ponikve ovisno o njenoj morfologiji. U ponikvi su izvršena geomorfološka opažanja, mikroklimatska mjerenja (temperature zraka, relativne vlažnosti i temperature rosišta) i inventarizacija flore. Za popisane biljne svojte napravljena je taksonomska analiza, analiza ekoloških indikatorskih vrijednosti prema Ellenbergu, analiza životnih oblika i flornih elemenata. Također je napravljena i analiza sličnosti staništa pomoću Sörensenovog indeksa. Ponikva je oblikovana u karbonatnim naslagama djelovanjem procesa korozije, padinskih procesa i urušavanja, a njezin je postanak bio predisponiran izrazitim tektonskim pukotinama. Proučavane padine (sjeverna i južna) i dno pružaju različite stanišne uvjete (Tab. 3), što proizlazi iz razlika u njihovoj morfologiji i mikroklimi te rezultira velikom raznolikošću vrsta na maloj udaljenosti unutar ponikve. Prisutnost temperaturne inverzije (Sl. 2) u ponikvi uvjetovala je razvoj inverzije vegetacije (Tab. 3), što je česta pojava u velikim ponikvama kao što je ponikva Sovljak. Ukupno je zabilježeno 107 svojti biljaka, od kojih je 6 zaštićeno Zakonom o zaštiti prirode i Pravilnikom o strogo zaštićenim vrstama, 10 ih se nalazi u Crvenoj knjizi vaskularne flore Hrvatske, a zabilježena su i 4 endema (Tab 2).



**KLJUČNE RIJEČI:** mikroklima, geomorfologija, flora, Ellenbergove indikatorske vrijednosti, inverzija vegetacije