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# ŠUMSKA VEGETACIJA TEKTONSKIH UDOLINA PIHLJA I VITRA IZNAD VINODOLA (LIBURNIJSKI KRŠ, SJEVEROZAPADNA HRVATSKA)

## FOREST VEGETATION OF TECTONIC DOLINES PIHLJA AND VITRA ABOVE THE VINODOL VALLEY (LIBURNIAN KARST, NW CROATIA)

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**Summary:**

We studied floristic composition, structure and topology of forest stands in tectonic dolines Pihlja and Vitra above Vinodol valley (Liburnian karst, NW Adriatic). Floristically and structurally homogenous stands represent zonal forests of the association *Aristolochio luteae-Quercetum pubescentis* (=*Ostryo carpinifoliae-Quercetum pubescentis*, *Ostryo-Carpinion orientalis*) and cover 1,75 and 2,73 ha, each (85 and 70 % of tectonic dolines, respectively). Preliminary multivariate analyses revealed several incongruences in current synsystematics and forest topology within the alliance *Ostryo-Carpinion orientalis* and raised a need for a thorough revision. Unsettled synsystematics makes addressing the forest vegetation zonation of the area uncertain. We assume that various stands with *Carpinus orientalis* in northwestern Adriatic represent only secondary succession stages in several thermophytic vegetation types. Studied forests in tectonic dolines Pihlja and Vitra represent well preserved stands without any visible traces of wood cutting and are valuable in giving insights into patterns, processes and dynamics of northern-Adriatic vegetation. As such they are in need of a special protection.

KEY WORDS: *Aristolochio luteae-Quercetum pubescentis*, Liburnian karst, NW Adriatic, *Ostryo-Carpinion orientalis*, phytosociology, tectonic dolines, zonal vegetation, Vinodol valley

## Uvod
### Introduction

Increasing complexity of topographic, climatic and geological conditions of any given area results in higher degrees of biodiversity and rapid species turnover even on a smaller scale. However, along ecological gradients on various geographic scales, three types of natural vegetation generally develop in equilibrium with biotic, climatic and edaphic factors (e.g. Walter 1954; Dierschke 1994; Kovar-Eder and Kvaček 2007). Zonal (climax) vegetation (a), developed on a large-scale and more distinctly influenced by overall climatic rather than edaphic factors; for example: in the Liburnian karst (NW Dinaric Alps), Dinaric fir-beech stands (*Omphalodo-Fagetum*) are considered to represent a climax vegetation type forming a forest belt between 600 – 1300 m (e.g. Tregubov 1957; Puncer 1980; Vukelić 2012; Surina and Dakskobler 2013). Due to more extreme climatic conditions, usually at the geographic limits of their distribution areas, vegetation types may react with altitudinal shifts (e.g., from lower to higher elevation) and occupy areas with conditions atypical for the zone. Nice examples are stands of holm oak (*Quercetum ilicis* s.l.) in Northern (Trotter 1927; Mayer 1963; Poldini 1982; Poldini and Lasen 1989; Buffa et al. 1993) and Central Italy (Corbetta and Pirone 1992) and Slovenia (Dakskobler 1997), where they constitute the (b)

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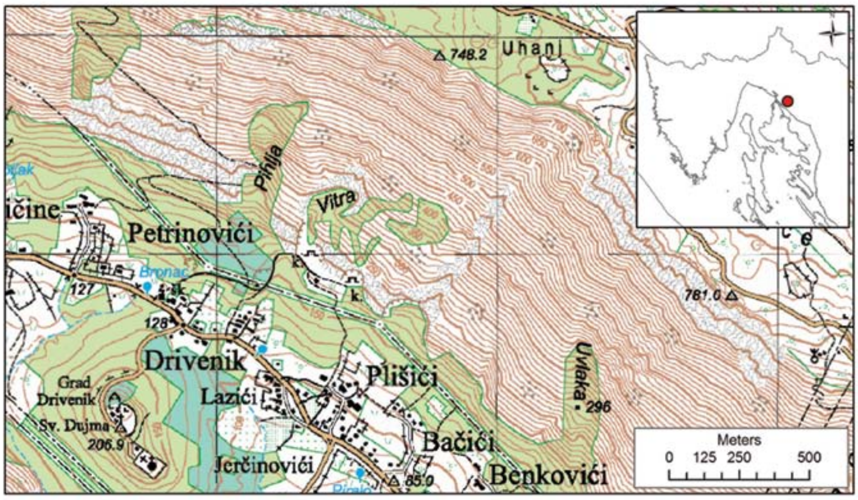


**Figure 2.** Research area
Slika 2. Područje istraživanja

extrazonal vegetation type – evergreen (extrazonal) forests where zonal vegetation (at lower altitudes) is largely temperate broad-leaved. Specific microclimatic conditions due to temperature inversion in freezing dolines of the Dinaric karst resulted in extrazonally developed subalpine beech stands (*Polysticho lonchitis-Fagetum*) and even stands dominated by mountain pine (*Pinetum mugo* s.l.) or subalpine Dinaric tussocks which usually thrive on higher elevated sites, a phenomenon already studied in detail by several researchers (e.g. Krašan 1880; Beck 1906; Wraber 1949; Horvat 1953, 1961; Martinčič 1977; Surina and Vreš 2004; Surina and Rakaj 2007). Additionally, extreme climatic and edaphic conditions (e.g. periglacial deposits – screes and boulders at the bottom of dolines) in afore mentioned dolines result in development of (c) azonal vegetation types. In the NW Dinaric Alps, spruce forests (*Hacquetio-Piceetum, Lonicero caeruleae-Piceetum, Laserpitio krapfii-Piceetum, Aremonio-Piceetum*) by a rule, do not form (extra)zonal vegetation belts but are rather confined to dolines within zonal beech (*Ranunculo platanifolii-Fagetum*) or fir-beech (*Omphalodo-Fagetum*) forests (Horvat 1953; Zupančič 1980). Azonal plant communities are generally more strongly influenced by specific edaphic factors than by climate. For example, forest stands of the associations *Ribeso alpini-Piceetum, Calamagrostido-Abietetum* and *Ostryo-Abietetum* are developed exclusively on calcareous stone blocks and boulders (Zupančič and Accetto 1994; Vukelić et al. 2006, 2007; Vukelić 2012) within zonal fir-beech forests (*Omphalodo-Fagetum*). Due to human impact, natural vegetation does not exist over large regions today. It is usually reconstructed and then termed potential natural vegetation (Kovar-Eder and Kvaček 2007).

**Figure 1.** Tectonic dolines Pihlja (upper left corner) and Vitra (lower right corner) above the Vinodol valley as seen from Drivenik castle
Slika 1. Tektonske udoline Pihlja (gore desno) i Vitra (dole lijevo) iznad Vinodola fotografirane s kaštela Drivenik

Dense forest stands developed within steep calcareous slopes exposed to south and southwest in two tectonic dolines above the Vinodol valley, Pihlja and Vitra, make a strong impression from afar (Fig. 1). Dark green forest canopies hardly emerge over the precipitate walls of the dolines and markedly stand apart from the surroundings. Vegetation cover of steep and partly precipitate calcareous slopes that surrounds the dolines represents floristically depauperate and fragmented petrophytic non-forest stands in various succession stages dominated by *Drypis spinosa, Sedum ochroleucum, Peltaria alliacea, Campanula pyramidalis, Cephalaria leucantha, Satureja montana, Genista sericea, Salvia officinalis, Daphne alpina, Frangula rupestris, Rhamnus saxatilis, Juniperus sabina, Coronilla emerus* subsp. *emeroides, Prunus mahaleb, Carpinus orientalis* and *Fraxinus ornus*.

Occasionally, some individual specimens of evergreen *Quercus ilex* and *Phillyrea latifolia* were observed. At first sight, forest stands in these picturesque dolines represent azonal or at least extrazonal vegetation type. Since these stands are virtually unknown to botanists, our primary goal was to investigate their floristic composition, structure, ecology and topology.

## Investigation area
### Područje istraživanja

The Vinodol valley in NW Adriatic (Fig. 2) is characterized by a distinct morphology as well as complex geological structure (Blašković 1999). The Upper Palaeogene flysch deposits are found in a synclinal position of a narrow valley with a NW-SE strike and are compressed by the Lower Palaeogene and Upper Cretaceous limestones. The contacts between the flysch and calcareous rocks are mainly tectonic with a markedly developed reverse character of displacement. The carbonate rocks that separate Vinodol valley from the sea, form an asymmetric Upper Cretaceous limestone and dolomite anticline with a more steeply inclined north-eastern limb of foraminiferal limestones of Lower and partly Middle Palaeogene age. In the north-western part of the Vinodol valley, in the area between the settlements Križišće and Tribalj, the slopes in fact comprise the more or less inclined southwestern limb of the Cretaceous-Palaeogene anticline. In the area to the southeast of settlement Tribalj, the north-eastern slope is stepped into vertical cliffs. These cliffs were formed by destruction of the crest of the Cretaceous-Palaeogene anticline that was overturned in a south-westerly direction. The aforementioned anticline has a reverse fault contact (Šušnjar et al. 1970). In north-western flanks of the valley, within Upper Cretaceous limestones and dolomites, two tectonic dolines app. 370 m apart, Pihlja and Vitra, surrounded by cliffs, ranging from several meters up to 40 m in height, are located. In both of these dolines, coarse-grained sandstones and marls were found that pertain to the younger part of the Palaeogene clastics app. 150 m higher than the highest point of the flysch and are compressed by a fault within the carbonate complex (Blašković 1999). Some basic geographic and meteorological parameters of tectonic dolines are given in Table 1.

According to (Horvat 1962), the Vinodol valley, specially its floodplains, represents one of the last remnants of azonal stands developed on flysch deposits with *Fraxinus angustifolius* and *Ulmus laevis* (ass. *Fraxino angustifoliae-Ulmetum laevis*), and *Carpinus orientalis* (*Querco-Carpinetum orientalis carpinetosum betulis*) (Randić 2003), once common features of the Vinodol lanscape. Nowadays, a mosaic of meadows with *Molinia caerulea* (*Peucedano-Molinietum litoralis* Horvatić 1934) (ibid.), *Chrysopogon gryllus* and *Danthonia alpina* (*Danthonio-Scorzoneretum villosae* Horvat & Horvatić (1956) 1958) prevail. Zonal vegetation on calcareous flanks surrounding the valley between 100–500 m represent degraded and fragmented stands of the association *Querco pubescentis-Carpinetum orientalis* (Horvat 1962) in various succession stages.

## Methods
### Metode

In summer 2013 we took 11 relevés of forest stands in tectonic dolines of Pihlja and Vitra applying the sigmatistic method (Braun-Blanquet 1928; Westhoff and van der Maarel 1973; Dierschke 1994). The plot size used for sampling averaged 400 $m^2$ and further details on the phytosociological parameters of sites are given in Table 3. The nomenclature and taxonomic source for the names of vascular plants was Flora Europaea (Tutin et al. 2001). Prior to numerical analysis, the original cover-abundance values for individual taxa were transformed into an ordinal scale as proposed by van der Maarel (1979). Groups of vegetation types and similarity (Jaccard similarity – J, Euclid distances – ED) between the stands and syntaxa were ascertained using cluster and ordination analysis with the help of the programme package PAST (Hammer et al. 2001). Analysis of similarity (ANOSIM) was used as non-parametric test of significant difference between two groups of relevés – between tectonic dolines, where large positive R (up to 1) signifies dissimilarity between groups. The significance was computed by permutation of group membership, with 10,000 replicates. The results were deemed significant if the probability of the null hypothesis was less than 0.05. Studied forest stands were compared with floristically and struc-

**Table 1** Some basic geographic and meteorological data for the tectonic dolines Pihlja and Vitra above the Vinodol valley (*Penzar, 1959; **Sliepčević, 1959)

Tablica 1. Neki osnovni geografski i meteorološki parametri tektonskih udolina Pihlje i Vitre iznad Vinodola (*Penzar, 1959; **Sliepčević, 1959)

| Tectonic dolines<br>Tektonske udoline | Pihlja | Vitra |
|---|---|---|
| Geographic latitude and longitude (WGS 84)<br>Zemljopisna širina i dužina (WGS84) | 45⁰°14'49.9"N/14°39'14,2"E | 45°14'40.4"N/14°39'23,4"E |
| Elevation (m)<br>Nadmorska visina (m) | 370–470 | 260–350 |
| Length (m)<br>Dužina (m) | 220 | 240 |
| Width (m)<br>Širina (m) | 85 | 100 |
| Area (ha)<br>Površina (ha) | 1.75 | 2.73 |
| Coverage of forest stands (ha; % of the doline)<br>Površina šumskih sastojina (ha; % udoline) | 1.48 (85 %) | 1.9 (70 %) |
| Mean annual precipitations (mm)*<br>Prosječne godišnje oborine (mm) * | 1287 | |
| Mean annual temperature (°C)**<br>Prosječna godišnja temperatura (°C)** | 14.8 | |

turally similar stands from Croatia, Slovenia and Italy (alliance *Ostryo-Carpinion orientalis*, Table 2). Synoptic table can be obtained from the *author.*

## Results
## Rezultati

### Structure and floristic composition of stands

Forest stands of Pihlja and Vitra cover 1.48 ha and 1.9 ha, respectively, majority of the bottom of the dolines (Table 1). Small non-forested parts of dolines represent screes occupied by *Drypis spinosa* subsp. *jacquiniana*, which are located at their northern part; in Vitra, however, another scree in advanced vegetation succession stage is located at the central part of otherwise densely forested doline. Stoniness of sampling plots varies between 10 and 50 % (Me = 20) of the area (Table 3). Stands are moderately diverse in number of vascular plants, ranging from 23 to 31 taxa per plot (Me = 25) with the coefficient of variation of 9.3 %.

Both dolines are densely covered by forest stands where *Quercus pubescens*$^{4-5}$ (present in 100 % rel.), *Fraxinus ornus*$^{+-2}$ (100 %), *Carpinus orientalis*$^{+-3}$ (64 %) and *Ostrya carpinifolia*$^{1-2}$ (64 %) prevail in the tree layer. *Acer monspessulanum*$^{1-2}$ occurs in app. 27 % of rel., while *A. campestre*$^{+}$, *Sorbus aria*$^{+}$, *S. domestica*$^{1}$ and *Tilia platyphyllos*$^{1}$ occur only once in a tree layer. Tree canopy covers 70–100 % of the area (Me = 90). *Quercus pubescens* is the dominant, up to 30 m high tree with respective diameter of 40–60 cm (at breast height). In the easternmost part of Vitra, along the base of precipitate walls and on stabilized and rock fall screes and boulders, *Tilia platyphyllos* builds a small stand. A shrub layer, composed of 25 species, is well developed and covers 50–100 % of the area (Me = 80). *Carpinus orientalis*$^{1-4}$, *Cotinus coggygria*$^{1-4}$ *Coronilla emerus* subsp. *emeroides*$^{1-3}$ and *Juniperus oxycedrus*$^{+-2}$ occur in all relevés. In more than a

**Table 2.** Syntaxa of the alliance Ostryo-Carpinion orientalis from Croatia and adjacent areas used in synoptic analyses
Tablica 2. Sintaksoni unutar sveze Ostryo-Carpinion orientalis iz Hrvatske i susjednih zemalja upotrijebljeni u sinteznim analizama

| | Association<br>Asociacija | Subassociation<br>Subasociacija | No. rel.<br>Br. snimki | Locality<br>Područje | Reference<br>Literatura |
|---|---|---|---|---|---|
| 1 | *Querco pubescentis-Carpinetum orientalis* | *typicum* | 10 | Litoral part of Croatia<br>Hrvatsko Primorje | (Horvat et al., 1974) |
| 2 | | *lauretosum* | 10 | Istrian peninsula<br>Istra | (Horvat et al., 1974) |
| 3 | | *cistetosum salviifolii* | 5 | Istrian peninsula<br>Istra | (Šugar, 1984) |
| 4 | | *typicum* | 8 | surroundings of Dubrovnik<br>okolica Dubrovnika | (Birač, 1973) |
| 5 | *Rhamno intermediate-Paliuretum* | | 11 | Submediterr. part of Croatia<br>submediteranski dio Hrvatske | (Horvatić, 1963) |
| 6 | *Cruciato glabrae-Carpinetum orientalis* | | 7 | surroundings of Krbavsko polje<br>okolica Krbavskog polja | (Šugar and Trinajstić, 1988) |
| 7 | | | 6 | Lika plain<br>Ličko polje | (Pelcer, 1975) |
| 8 | *Aristolochio luteae-Quercetum pubescentis* (=*Ostryo-Quercetum pubescentis*) | *quercetosum pubescentis* | 6 | NW Adriatic<br>SZ Jadran | (Horvat, 1959) |
| 9 | | *quercetosum pubescentis* | 6 | islands of Krk, Cres and Brač<br>otoci Krk, Cres i Brač | (Trinajstić, 1982) |
| 10 | | *sorbetosum ariae* | 20 | Lika plain<br>Ličko polje | (Pelcer, 1975) |
| 11 | | *quercetosum petraeae* | 5 | NW Adriatic<br>SZ Jadran | (Horvat, 1959) |
| 12 | | | 13 | NW Adriatic: Italy and Slovenia – flysch<br>SZ Jadran: Italija i Slovenija – fliš | (Poldini, 1989) |
| 13 | | | 13 | NW Adriatic: Italy and Slovenia – limestone<br>SZ Jadran: Italija i Slovenija – vapnenac | (Poldini, 1989) |
| 14 | *Querco-Ostryetum carpinifoliae* | | 11 | NW Croatia<br>SZ Hrvatska | (Horvat, 1938) |
| 15 | | | 14 | Hrvatsko Zagorje, Strahinščica | (Regula-Bevilacqua, 1978) |
| 16 | *Seslerio sadlerianae-Ostryetum* | | 12 | NW Croatia<br>SZ Hrvatska | (Cerovečki, 2006) |
| 17 | *Quercus pubescens* and *Carpinus orientalis* forest | | 11 | Liburnian karst, Vinodol, Pihlja & Vitra<br>Liburnijski krš, Vinodol, Pihlja i Vitra | This work |

**Table 3.** Analytical table of forest stands in tectonic dolines of Pihlja and Vitra above Vinodol
Tablica 3. Analitička tablica šumskih sastojina tektonskih udolina Pihlje i Vitre iznad Vinodola

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| exposition/ekspozicija | SSE | SSW | S | SSW | SW | SSW | W | SSW | SSW | WSW | SW | |
| inclination/naklon | 20 | 20 | 30 | 20 | 25 | 20 | 20 | 15 | 15 | 15 | 15 | |
| A (tree layer/sloj drveća) % | 95 | 90 | 90 | 95 | 80 | 90 | 90 | 90 | 100 | 95 | 70 | |
| B (shrub layer/sloj grmlja) % | 50 | 70 | 70 | 70 | 80 | 80 | 90 | 80 | 80 | 80 | 80 | |
| C (herb layer/sloj zelj. bilj.) % | 70 | 30 | 80 | 70 | 60 | 30 | 90 | 40 | 60 | 30 | 70 | |
| S (stoniness/kamenitost) a% | 30 | 50 | 20 | 20 | 10 | 50 | 10 | 20 | 30 | 20 | 20 | |
| tree diameter/promjer drveća (cm) | 50 | 50 | 50 | 40 | 40 | 50 | 60 | 50 | 50 | 60 | 60 | |
| hight/visina | 30 | 30 | 30 | 20 | 25 | 30 | 30 | 30 | 30 | 30 | 30 | |
| no taxa/br. svojti | 29 | 28 | 24 | 25 | 25 | 23 | 25 | 31 | 24 | 27 | 26 | % |
| Tree layer/sloj drveća | | | | | | | | | | | | |
| *Quercus pubescens* | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 5 | 5 | 4 | 4 | 100,0 |
| *Fraxinus ornus* | + | 1 | 1 | 2 | 1 | 2 | 3 | 2 | 2 | 1 | 2 | 100,0 |
| *Carpinus orientalis* | + | 1 | . | . | 2 | . | . | 3 | 2 | 3 | 1 | 63,6 |
| *Ostrya carpinifolia* | 1 | . | 1 | . | . | 1 | . | 1 | 1 | 2 | 2 | 63,6 |
| *Acer monspessulanum* | . | 2 | 2 | 1 | . | . | . | . | . | . | . | 27,3 |
| *Sorbus domestica* | . | . | . | . | . | 1 | . | . | . | . | . | 9,1 |
| *Tilia platyphyllos* | . | . | . | . | . | . | . | . | 1 | . | . | 9,1 |
| *Acer campestre* | . | . | . | . | + | . | . | . | . | . | . | 9,1 |
| *Sorbus aria* | . | . | + | . | . | . | . | . | . | . | . | 9,1 |
| Shrub layer/sloj grmlja | | | | | | | | | | | | |
| *Carpinus orientalis* | 1 | 2 | 1 | 2 | 4 | 3 | 3 | 4 | 4 | 4 | 4 | 100,0 |
| *Cotinus coggygria* | 4 | 3 | 4 | 4 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 100,0 |
| *Coronilla emerus* subsp. *emeroides* | 2 | 2 | 2 | 2 | 3 | 2 | 1 | 3 | 2 | 2 | 3 | 100,0 |
| *Juniperus oxycedrus* | + | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | + | 100,0 |
| *Fraxinus ornus* | 2 | 3 | 3 | 2 | 2 | 3 | 3 | . | 2 | 2 | 3 | 90,9 |
| *Cornus mas* | 2 | 2 | . | 2 | . | 2 | 3 | + | 3 | 3 | 2 | 81,8 |
| *Rosa* sp. | . | + | + | 1 | + | . | . | + | 1 | + | + | 72,7 |
| *Ostrya carpinifolia* | 2 | 2 | 2 | . | + | . | . | . | 1 | 3 | . | 54,5 |
| *Acer monspessulanum* | 1 | . | . | . | 2 | . | 1 | + | 1 | + | . | 54,5 |
| *Sorbus domestica* | . | . | . | + | . | . | . | . | + | 1 | 1 | 36,4 |
| *Euonymus europaea* | + | . | . | . | . | . | . | + | + | 1 | . | 36,4 |
| *Lonicera caprifolium* | + | . | 2 | . | . | . | . | . | + | + | . | 36,4 |
| *Crataegus monogyna* | . | . | + | . | + | . | + | . | . | . | . | 27,3 |
| *Prunus mahaleb* | + | + | . | . | . | . | . | 1 | . | . | . | 27,3 |
| *Ruscus aculeatus* | . | . | . | + | . | . | . | . | 1 | + | . | 27,3 |
| *Tilia platyphyllos* | . | . | . | . | . | . | . | . | + | + | + | 27,3 |
| *Acer campestre* | . | 1 | . | . | . | . | . | . | . | 1 | . | 18,2 |
| *Cornus sanguinea* | . | . | . | . | . | . | . | + | . | . | + | 18,2 |
| *Paliurus australis* | . | . | . | . | . | . | . | . | . | + | 1 | 18,2 |
| *Quercus pubescens* | . | . | . | . | . | . | 1 | . | . | 1 | . | 18,2 |
| *Sorbus aria* | + | 1 | . | . | . | . | . | . | . | . | . | 18,2 |
| *Ulmus minor* | . | . | . | . | . | . | . | . | . | + | + | 18,2 |
| *Viburnum lantana* | . | . | . | . | . | . | + | . | . | + | . | 18,2 |
| *Pistacia terebinthus* | . | + | . | . | . | . | . | . | . | . | . | 9,1 |
| *Pyrus pyraster* | . | . | . | . | . | . | . | . | . | + | . | 9,1 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Herb layer/sloj zeljastog bilja | | | | | | | | | | | | |
| *Sesleria autumnalis* | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 2 | 3 | 2 | 3 | 100,0 |
| *Hedera helix* | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 3 | 2 | 2 | 100,0 |
| *Campanula trachelium* | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | + | 2 | 100,0 |
| *Arabis turrita* | + | 1 | + | + | 2 | 2 | 1 | 2 | 2 | 1 | 1 | 100,0 |
| *Quercus pubescens* | 1 | 2 | . | + | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 90,9 |
| *Acer monspessulanum* | + | 1 | . | 1 | 1 | 2 | 2 | + | 2 | + | 1 | 90,9 |
| *Asparagus acutifolius* | + | 1 | . | + | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 90,9 |
| *Fraxinus ornus* | 1 | 1 | . | 1 | + | 2 | 2 | 1 | 2 | . | + | 81,8 |
| *Campanula pyramidalis* | 2 | 2 | 1 | 1 | + | + | + | + | . | . | + | 81,8 |
| *Ulmus minor* | + | . | + | + | . | . | + | + | 2 | 2 | 2 | 72,7 |
| *Carpinus orientalis* | 1 | . | . | 1 | . | 2 | . | 1 | 2 | 1 | 1 | 63,6 |
| *Melittis melissophyllum* | + | . | 2 | 2 | 1 | 2 | . | + | + | . | . | 63,6 |
| *Viola hirta* | + | + | . | . | 1 | 2 | 2 | 1 | 2 | . | . | 63,6 |
| *Epipactis* sp. | . | + | + | 1 | . | . | + | + | . | . | + | 54,5 |
| *Acer campestre* | + | + | . | . | + | . | 1 | . | . | + | . | 45,5 |
| *Colchicum autumnale* | . | + | . | + | + | 2 | 1 | . | . | . | . | 45,5 |
| *Juniperus oxycedrus* | . | . | 1 | 1 | + | . | . | 1 | . | . | + | 45,5 |
| *Festuca heterophylla?* | 1 | . | 3 | . | + | + | . | . | . | . | . | 36,4 |
| *Aristolochia lutea* | . | . | . | . | + | . | 1 | . | + | . | . | 27,3 |
| *Epipactis microphylla* | . | + | . | . | . | . | + | + | . | . | . | 27,3 |
| *Mercurialis ovata* | . | . | . | + | + | + | . | . | . | . | . | 27,3 |
| *Cnidium silaifolium* | + | + | . | + | . | . | . | . | . | . | . | 27,3 |
| *Rhamnus intermedia* | + | . | . | . | . | . | + | . | . | + | . | 27,3 |
| *Sorbus aria* | . | . | + | + | . | . | . | . | . | . | + | 27,3 |
| *Lathyrus venetus* | 2 | . | . | 2 | . | . | . | . | . | . | . | 18,2 |
| *Brachypodium rupestre* | . | . | . | . | . | . | . | . | 1 | . | 2 | 18,2 |
| *Cyclamen purpurascens* | 1 | . | 1 | . | . | . | . | . | . | . | . | 18,2 |
| *Tanacetum corymbosum* | . | + | . | . | 1 | . | . | . | . | . | . | 18,2 |
| *Teucrium chamaedrys* | . | . | 1 | + | . | . | . | . | . | . | . | 18,2 |
| *Frangula rupestris* | . | . | 1 | . | . | . | . | + | . | . | . | 18,2 |
| *Torilis arvensis* | . | . | . | . | . | . | . | + | . | + | . | 18,2 |
| *Lathyrus pratensis* | . | . | . | . | . | + | + | . | . | . | . | 18,2 |
| *Rubus ulmifolius* | + | . | . | . | . | . | . | . | . | . | + | 18,2 |
| *Solidago virgaurea* | . | . | . | . | . | . | . | + | + | . | . | 18,2 |
| *Tilia platyphyllos* | . | . | . | . | . | . | . | . | + | + | . | 18,2 |
| *Campanula* sp. | . | . | . | . | . | . | . | . | . | . | 2 | 9,1 |
| *Trifolium pratense* | . | . | 1 | . | . | . | . | . | . | . | . | 9,1 |
| *Asplenium trichomanes* | . | . | . | . | + | . | . | . | . | . | . | 9,1 |
| *Digitalis laevigata* | . | . | . | . | . | . | . | . | . | . | + | 9,1 |
| *Euphorbia wulfenii* | . | . | . | . | . | . | . | + | . | . | . | 9,1 |
| *Galium* sp. | . | . | . | . | . | . | + | . | . | . | . | 9,1 |
| *Ostrya carpinifolia* | . | . | . | . | + | . | . | . | . | . | . | 9,1 |
| *Peucedanum cervaria* | . | . | . | . | . | . | . | + | . | . | . | 9,1 |
| *Stachys officinalis* | . | . | . | . | . | . | . | + | . | . | . | 9,1 |
| *Teucrium arduinii* | . | . | . | . | . | . | . | + | . | . | . | 9,1 |
| *Verbascum austriacum* | . | . | . | . | . | + | . | . | . | . | . | 9,1 |

half of relevés were recorded *Fraxinus ornus*$^{2-3}$ (91 %), *Cornus mas*$^{+-3}$ (82 %), *Rosa* sp.$^{+-1}$ (73 %), *Acer monspessulanum*$^{+-2}$ and *Ostrya carpinifolia*$^{+-3}$ (both 55 %). Herb layer covers 30–90 % (Me = 60) of sampling plots where *Sesleria autumnalis*$^{2-4}$ (100 %) usually dominates. Beside *S. autumnalis*, in all the relevés *Arabis turrita*$^{+-2}$, *Campanula trachelium*$^{+-3}$ and *Hedera helix*$^{1-3}$ were recorded. *Acer monspessulanum*$^{+-2}$, *Asparagus acutifolius*$^{+-2}$, *Quercus pubescens*$^{+-2}$ (all 91 %), *Campanula pyramidalis*$^{+-2}$, *Fraxinus ornus*$^{+-2}$ (both 82 %), *Ulmus minor*$^{+-2}$ (73 %), *Carpinus orientalis*$^{1-2}$, *Melittis melissophyllum*$^{+-2}$, *Viola hirta*$^{+-2}$ (all 64 %) and *Epipactis* sp.$^{+-1}$ (55 %) occurred in more than half of the relevés.

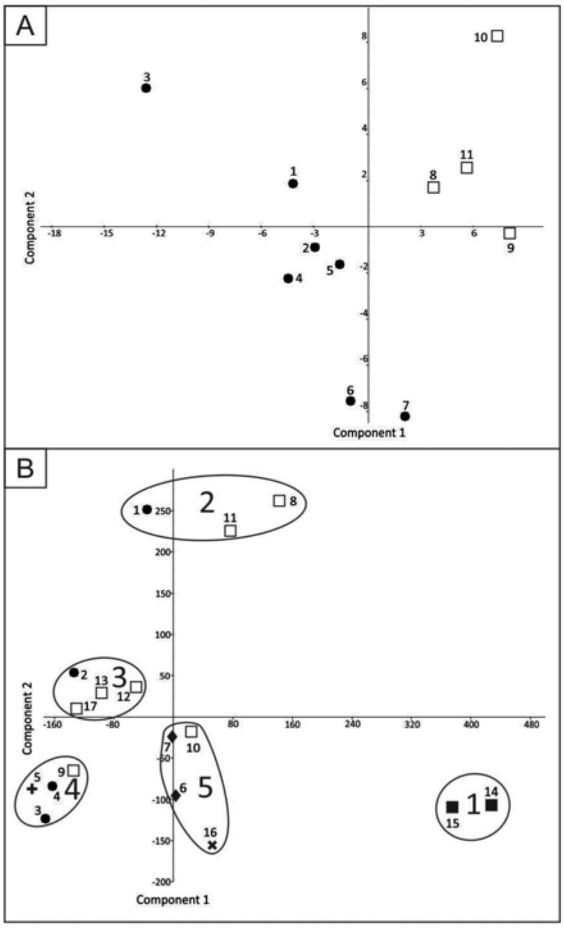


**Figure 3. (A) PCA of forest stands in Pihlja (dots) and Vitra (squares). Eigenvalues: 1 – 38.7, 2 – 25.3, 3 – 17.5, 4 – 15.6; % of variance: 1 – 26.8, 2 – 17.5, 3 – 12.1, 4 – 10.8 (numbers correspond to those in Table 3); (B) PCA of termophytic forest syntaxa from the alliance Ostryo-Carpinion orientalis (Quercetalia pubescentis) from Croatia and adjacent areas (numbers correspond to those in Table 2); *Querco pubescentis-Carpinetum orientalis* – circle, *Rhamno intermediate-Paliuretum* – plus, *Cruciato glabrae-Carpinetum orientalis* – diamond, *Aristolochio luteae-Quercetum pubescentis* – empty square, *Querco-Ostryetum carpinifoliae* – square, *Seslerio sadlerianae-Ostryetum carpinifoliae* – x. Eigenvalues: 1 – 31894.2, 2 – 17482.7, 3 – 10973.1, 4 – 7985.6; % of variance: 1 – 29.0, 2 – 15.9, 3 – 10.0, 4 – 7.3**

Slika 1. PCA analiza šumskih sastojina u Pihlji (točke) i Vitri (kvadrati). Eigenvalues: 1 – 38.7, 2 – 25.3, 3 – 17.5, 4 – 15.6; % of variance: 1 – 26.8, 2 – 17.5, 3 – 12.1, 4 – 10.8. (B) PCA termofilnih šumskih sintaksona sveze Ostryo-Carpinion orientalis (Quercetalia pubescentis) iz Hrvatske i susjednih zemalja (brojevi odgovaraju onima u tablici 2); *Querco pubescentis-Carpinetum orientalis* – krug, *Rhamno intermediate-Paliuretum* – plus, *Cruciato glabrae-Carpinetum orientalis* – diamant, *Aristolochio luteae-Quercetum pubescentis* – prazan kvadrat, *Querco-Ostryetum carpinifoliae* – puni kvadrat, *Seslerio sadlerianae-Ostryetum carpinifoliae* – x. Eigenvalues: 1 – 31894.2, 2 – 17482.7, 3 – 10973.1, 4 – 7985.6; % variance: 1 – 29.0, 2 – 15.9, 3 – 10.0, 4 – 7.3

Similarity between the stands (J) varies between 0,32 and 0,64 (average = 0,46), the relevés no. 3 (0,38) and 10 (0,44) being averagely the most distinct to the rest of relevés. According to the results of the PCA analysis (Fig. 3A), stands from Pihlja are grouped on the left, while stands from Vitra are grouped on the right side of the two-dimensional scatter diagram despite great overall similarity in floristic composition between the stands of both dolines. Nevertheless, ANOSIM yielded R = 0,6336 (p = 0,0042) and showed statistically significant differences between forest stands of the two dolines.

## Forest typology

Results of the PCA analysis (Fig. 3B) as well as similarity and distance indices (Table 4) suggest great floristic similarity between studied forest stands of tectonic dolines and forest stands of the association *Aristolochio luteae-Quercetum pubescentis* from NW Adriatic (Italy and Slovenia – nos. 12 and 13 in Table 4; ED = 393 and 342, respectively) and Adriatic islands of Krk, Cres and Brač (no. 9; ED = 343). While the similarity index (J) also showed generally great similarity of studied stands with forests of the association *Aristolochio luteae-Quercetum pubescentis* (nos. 8, 12 & 13; J = 0,29, 0,27 & 0,29, respectively), the highest value (J = 0,30) resulted from the comparison of studied stands with forests of the association *Querco pubescenti-Carpinetum orientalis* (*lauretosum*; no. 2) from Istrian Peninsula..

The most homogenous group of syntaxa represent forests of the association *Aristolochio luteae-Quercetum pubescentis* from NW Adriatic (Italy, Slovenia), our studied stands, and stands of the subassociation *Querco pubescenti-Carpinetum orientalis lauretosum* from Istrian Peninsula, being developed either on a limestone or flysch (Fig. 3B – group 3). Groups 2 and 4 in Fig. 3B show intermixed syntaxa of the associations *Querco pubescenti-Carpinetum orientalis*, *Aristolochio luteae-Quercetum pubescentis* and *Rhamno intermediate-Paliuretum australis* from the coastal parts of the eastern Adriatic. Continental forests and shrubs of *Quercus pubescens, Carpinus orientalis* and *Ostrya carpinifolia* represented group 5 (Fig. 3B) consisting of three different forest associations: *Aristolochio lutae-Quercetum pubescentis*, *Cruciato glabrae-Carpinetum orientalis* and *Seslerio sadlerianae-Ostryetum*, and are, similarly to group 1, well differentiated from coastal forests by the lack of Mediterranean elements. Generally, according to similarity and distance indices, studied stands showed greater similarity with stands of the association *Aristolochio luteae-Quercetum pubescentis* than with stands of the association *Querco pubes-*

*centi-Carpinetum orientalis* (Table 4). Therefore we propose to classify them within the association *Aristolochio luteae-Quercetum pubescentis* (*Ostryo-Carpinion orientalis, Quercetalia pubescentis*)

## Discussion
### Rasprava

Ordination analysis (Fig. 3B) as well as similarity and distance indices (Table 4) suggest that studied stands are floristically most similar to stands of the association *Aristolochio luteae-Quercetum pubescentis* from NW Adriatic. However, Jaccard's similarity index, which takes into account only presence/absence data, was the highest when comparing studied stands and syntaxon *Querco pubescenti-Carpinetum orientalis lauretosum* from Istrian Peninsula, suggesting a different synsystematic treatment of studied stands regardless the type of geological bedrock. Nevertheless, the J-index was only marginally higher than values obtained from comparisons with other syntaxa. Based on the results of ordination analysis (Fig. 3B) and other similarity and distance values (Table 4) we find our synsystematic proposal justified. Although only preliminary, not sufficiently exhaustive and based on fairly uneven or low number of relevés per syntaxa, our results of numerical analyses somewhat depart from established syntaxonomic treatments within the alliance *Ostryo-Carpinion orientalis* (compare Trinajstić 2008; Vukelić 2012). For example: the most distinct and floristically well differentiated stands are those belonging to the continental association *Querco pubescenti-Ostryetum carpinifoliae* (Fig. 3B – group 1). Those stands lack majority of the (sub-)mediterranean taxa and their syntaxonomic position is not questionable. On the other hand, although the indication of groups of syntaxa in Fig. 3B is debatable, but supported by the results of similarity and distance measures (Table 4), analyses showed major incongruences with current syntaxonomic scheme. Stands of the association *Aristolochio luteae-Quercetum pubescentis* are positioned in four different groups (Fig. 3B) and intermixed with other syntaxa of the alliance *Ostryo-Carpinion orientalis.*

The synsystematics of the thermophytic forests on different syntaxonomic ranks were already discussed in several papers (e.g. Trinajstić 1982; Poldini 1988; Čarni et al. 2009; Vukelić 2012). The fact that oriental hornbeam acts as a pioneer species in almost all secondary succession stages of eastern Adriatic thermophytic forests, makes the utility of proposed classification schemes even more difficult (see Horvat 1962). For example: Horvat et al. (1974) treated stands where *Quercus pubescens* and *Carpinus orientalis* dominate in a tree layer as a typical ones within the association *Querco-Carpinetum orientalis* (Table 2, line 1), although the results of our numerical analyses (Fig. 3B – group 2) suggested that they resemble most to stands of the association *Aristolochio luteae-Quercetum pubescentis* (Ta-

**Table 4.** Similarity (Jaccard; upper right hand) and distance indices (Euclid; lower left hand) for thermophytic forest syntaxa of the alliance Ostryo-Carpinion orientalis in Croatia and adjecent areas; the numbers correspond to Table 3 and Fig. 3B

Tablica 4. Koeficijenti sličnosti (Jaccard, gore desno) te (Euklidske) udaljenosti (dolje lijevo) za termofilne šumske sintaksone sveze Ostryo-Carpinion orientalis u Hrvatskoj i susjednim zemljama; brojevi odgovaraju onima u tablici 3 i sliki 3B

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 0,56 | 0,12 | 0,23 | 0,19 | 0,28 | 0,33 | 0,64 | 0,28 | 0,37 | 0,59 | 0,39 | 0,40 | 0,33 | 0,34 | 0,20 | 0,28 |
| 2 | 352 | | 0,14 | 0,21 | 0,20 | 0,25 | 0,29 | 0,44 | 0,27 | 0,27 | 0,38 | 0,43 | 0,40 | 0,23 | 0,25 | 0,18 | 0,30 |
| 3 | 501 | 398 | | 0,10 | 0,15 | 0,07 | 0,05 | 0,07 | 0,15 | 0,04 | 0,06 | 0,11 | 0,13 | 0,02 | 0,04 | 0,03 | 0,08 |
| 4 | 458 | 352 | 328 | | 0,28 | 0,19 | 0,15 | 0,19 | 0,17 | 0,18 | 0,17 | 0,20 | 0,23 | 0,15 | 0,13 | 0,09 | 0,18 |
| 5 | 477 | 388 | 348 | 300 | | 0,17 | 0,14 | 0,15 | 0,13 | 0,14 | 0,14 | 0,16 | 0,20 | 0,05 | 0,08 | 0,08 | 0,20 |
| 6 | 527 | 465 | 465 | 439 | 460 | | 0,39 | 0,30 | 0,21 | 0,37 | 0,31 | 0,23 | 0,22 | 0,26 | 0,23 | 0,20 | 0,17 |
| 7 | 479 | 461 | 477 | 438 | 453 | 382 | | 0,36 | 0,19 | 0,38 | 0,33 | 0,27 | 0,28 | 0,25 | 0,26 | 0,22 | 0,23 |
| 8 | 361 | 500 | 568 | 528 | 551 | 512 | 483 | | 0,26 | 0,46 | 0,78 | 0,40 | 0,39 | 0,39 | 0,37 | 0,27 | 0,29 |
| 9 | 451 | 364 | 311 | 292 | 340 | 407 | 405 | 499 | | 0,19 | 0,24 | 0,22 | 0,23 | 0,16 | 0,18 | 0,12 | 0,21 |
| 10 | 453 | 433 | 427 | 388 | 412 | 368 | 351 | 412 | 337 | | 0,44 | 0,26 | 0,28 | 0,38 | 0,36 | 0,29 | 0,23 |
| 11 | 388 | 484 | 520 | 499 | 517 | 503 | 477 | 321 | 442 | 389 | | 0,36 | 0,35 | 0,36 | 0,38 | 0,24 | 0,27 |
| 12 | 396 | 330 | 401 | 357 | 412 | 462 | 429 | 457 | 346 | 392 | 422 | | 0,68 | 0,29 | 0,29 | 0,20 | 0,27 |
| 13 | 385 | 321 | 373 | 317 | 356 | 430 | 415 | 437 | 299 | 344 | 416 | 284 | | 0,28 | 0,27 | 0,20 | 0,29 |
| 14 | 644 | 653 | 683 | 651 | 692 | 586 | 600 | 567 | 639 | 558 | 597 | 590 | 621 | | 0,56 | 0,36 | 0,16 |
| 15 | 605 | 618 | 635 | 619 | 649 | 589 | 588 | 542 | 600 | 518 | 567 | 558 | 573 | 433 | | 0,49 | 0,17 |
| 16 | 512 | 469 | 404 | 405 | 424 | 447 | 450 | 509 | 358 | 358 | 483 | 419 | 392 | 548 | 454 | | 0,17 |
| 17 | 444 | 381 | 439 | 372 | 399 | 461 | 456 | 507 | 343 | 400 | 474 | 393 | 342 | 669 | 627 | 430 | |

ble 2, lines 8 & 11, – *quercetosum pubescentis* and –*quercetosum petraeae*, respectively) as assigned by the same author (Horvat 1959). Furthermore, it is still an open question whether or not stands of the association *Querco pubescenti-Carpinetum* in NW Adriatic represent zonal vegetation type or only a secondary succession stage of forest stands of the association *Aristolochio luteae-Quercetum pubescentis*. We are inclined to accept the second scenario and treat studied stands of the association *Aristolochio luteae-Quercetum pubescentis* as a zonal vegetation type of the research area. Results of our preliminary analyses additionally pinpoint the need of a thorough synsystematic revision which will result in a more stable classification scheme in Croatia.

Studied stands are completely isolated from other forests; tectonic dolines, enclosed by precipitate walls within non-forest, petrophytic and scarcely developed vegetation types with low coverage, appear as green islands shaped by specific microclimatic conditions of the dolines. Of considerable interest and in light of vegetation succession processes, are fragmented stands with large-leaved lime (*Tilia platyphyllos*) bellow the precipited walls of the eastern flank of Vitra. Similar stands are developed on steep calcareous slopes some 500 m above the tectonic dolines and most probably represent an advanced succession stage after deforestation of stands of the association *Aristolochio luteae-Quercetum pubescentis*. Stands whith large-leaved lime from close vicinity were already mentioned by Horvat (1962) and Vukelić et al. (2006, 2007), who classified them into a subassociation *Calamagrostido-Abietetum tilietosum platyphylli* and association *Ostryo-Abietetum* (though with abundand *Tilia cordata* in a shrub layer), respectively, while Accetto (1991), Dakskobler (2004) and Košir and Surina (2005) classified similar stands with *Tilia platyphyllos* from the Čičarija range into the associations *Corydalido ochroleucae-Aceretum* (on calcareous boulders on northern slopes of Čičarija range, southwestern Slovenia), *Ostryo-Quercetum pubescentis* var. geogr. *Anemone trifolia tilietosum platyphylli* (from the central Soča valley in western Slovenia) and *Paeonio officinalis-Tilietum platyphylli* (on flysch belts within limestone slopes exposed to south, Čičarija range, southwestern Slovenia), respectively, as long-lasting succession stages or even azonal vegetation types. Nevertheless, according to our observation, neither of afore mentioned syntaxa suits the topology of stands with large-leaved lime in the proximity of studied stands.

Despite great overall similarity in floristic composition, structure, as well as homogeneity in number of taxa per relevé of stands of both tectonic dolines (Table 2), ANOSIM detected statistically significant differences (though based on rather low number of samples per group), which are well reflected in Fig. 3A. *Ulmus minor, Tilia platyphyllos* and *Sorbus domestica* appear to contribute most to the differences by means of their exclusive occurrence (*U. minor*) or higher frequency and coverage (*T. platyphyllos* and *S. domestica*) in the tectonic doline Vitra.

Well sheltered by precipitate walls and hard to access, forests in tectonic dolines Pihlja and Vitra represent preserved (remnant) stands with no visible traces of wood exploitation. Nowadays they represent protective forest stands of high scientific importance, giving valuable insights in patterns, processes and dynamics of northern-Adriatic vegetation and as such are in need of a thorough protection.

## Conclusions
### Zaključci

Forest stands developed in tectonic dolines Pihlja and Vitra, located within steep, calcareous slopes between 260 and 470 m above sea level above Drivenik in Vinodol valley, represent zonal forests of the association *Aristolochio luteae-Quercetum pubescentis*. Floristically and structurally homogenous stands host a moderate number of vascular plants per plot (Me=25, CV=9,3 %) and cover 1,75 and 2,73 ha, respectively (85 and 70 % of tectonic dolines, respectively). Studied stands are floristically most similar to stands of the association *Aristolochio luteae-Quercetum pubescentis* from NE Italy, Slovenia and NW Adriatic and subassociation *Querco-Carpinetum orientalis lauretosum* from Istrian Peninsula. Multivariate analyses pinpointed on several incongruences in current synsystematic schemes and forest topology within the alliance *Ostryo-Carpinion orientalis* and a need for a thorough revision. Unsettled synsystematics makes addressing the forest vegetation zonation of the area uncertain, but we nevertheless assume that stands with *Carpinus orientalis* (i.e., *Querco pubescenti-Carpinetum orientalis*) represent only secondary succession stages in various thermophytic vegetation types and do not represent zonal vegetation in northwestern Adriatic. Studied forests in tectonic dolines Pihlja and Vitra represent well preserved forest stands without any visible traces of wood cutting and are valuable in giving insides into patterns, processes and dynamics of northern-Adriatic vegetation. As such they are in need of special protection.

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## Sažetak

Pomoću sigmatističke metode istražili smo floristički sastav, strukturu i tipologiju šumskih sastojina razvijenih u tektonskim udolinama Pihlja i Vitra iznad Vinodola (Liburnijski krš, sjeverozapadni Jadran). U florističkom i strukturnom pogledu homogene sastojine predstavljaju zonalne šume medunca zajednice *Aristolochio luteae-Quercetum pubescentis* (=*Ostryo carpinifoliae-Quercetum pubescentis*, *Ostryo-Carpinion orientalis*) koje pokrivaju 1,75 odnosno 2,73 ha (85 i 70 % površine udolina). Rezultati preliminarnih multivariatnih analiza su ukazali na brojna odstupanja od postojeće klasifikacije unutar sveze *Ostryo-Carpinion orientalis* te potrebu za opsežnom revizijom. Zbog sintaksonomske problematike unutar sveze *Ostryo-Carpinion orientalis* nije moguće pouzdano ustvrditi tipologiju zajednica odnosno zonalnosti vegetacijskih tipova. Ipak smo mišljenja da sastojine u kojima se javlja bjeli grab (primj. *Querco pubescenti-Carpinetum orientalis*) na području sjeverozapadnog Jadrana ne predstavljaju zonalan tip vegetacije, već različite sekundarne sukcesijske faze koje vode prema zonalnim sastojinama zajednice *Aristolochio luteae-Quercetum pubescentis*. Šumske sastojine tektonskih udolina predstavljaju teže dostupne i dobro očuvane šume medunca u kojima nismo naišli na vidljive tragove sječe. Kao takve imaju veliku znanstvenu vrijednost davajući uvid u uzorke, procese i dinamiku vegetacije u sjeverozapadnom Jadranu, pa su potrebne posebne zaštite.

KLJUČNE RIJEČI: *Aristolochio luteae-Quercetum pubescentis*, fitocenologija, Liburnijski krš, *Ostryo-Carpinion orientalis*, sjevero-zapadni Jadran, tektonske udoline, Vinodol, zonalna vegetacija