DINARIC KARST POLJES

NATURE CONSERVATION AND RURAL DEVELOPMENT

Edited by:
**Peter Sackl,
Stefan Ferger,
Nermina Sarajlić,
Dražen Kotrošan
& Goran Topić**

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Peter Sackl, Stefan W. Ferger, Nermina Sarajlić, Dražen Kotrošan & Goran Topić (eds.)

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Contents

Helvella corium (Photo: Neven Matočec)

Dinaric karst poljes and their importance for mycobiota

Neven Matočec[1], Nedim Jukić[2], Nihad Omerović[2] & Ivana Kušan[1]

[1] **Ruđer Bošković Institute**,
Bijenička cesta 54, 10000 Zagreb, Croatia;
E-mail: nmatocec@irb.hr
[2] **Mycological Association MycoBH**,
Trg Zlatnih ljiljana 34, 71000 Sarajevo, Bosnia and Herzegovina

Summary

Karst as a geological phenomenon and karst poljes as the largest depressions in the Dinaric Alps represent one of the most important and most diverse relief units globally. The diversity of karst poljes in the Dinaric Alps is one of the most significant worldwide and one of the most heterogeneous, too.

In this study, by using the most relevant variables and delimitation criteria, all recognized Dinaric karst poljes were divided and classified into 30 well differentiated groups and organized in nine main biogeographical regions. During the process of classifying the Dinaric karst poljes, for some of the most important parameters recognizable patterns were defined or established for each group. The mycobiota of 10 Dinaric karst poljes classified into six groups have been intensively studied in Bosnia and Herzegovina and Croatia during various research sessions. All results were evaluated by using standardized variables and a corresponding binary grading scale in order to classify poljes according to their importance for mycobiota. Based on the “cumulative ecological score” (CES), the ratio of the CES/number of all recorded species and the CES/number of research days ratio, the mycologically most important karst poljes were identified. A brief description of specific habitat types of top evaluated poljes is given together with recommendations for the implementation of proper conservation measures in these areas.

Several rare and very vulnerable species of ascomycetes, like *Mollisia uda*, *Patinella hyalophaea*, *Podostroma leucopus*, *Scutellinia peloponnesiaca* and *Lamprospora leptodictya*, were recorded in the investigated poljes. Some of the species which were found during the present study, represent the only known records in the Dinaric Alps and their conservation status has never been assessed before. Recommendations for the protection of these species, based on IUCN criteria, are presented.

Keywords: *Ascomycota*, classification, conservation, ecological score, fungi, Bosnia and Herzegovina, Croatia

Sažetak

Krš kao geološki fenomen, zajedno s krškim poljima koja predstavljaju najveće depresije na površini Dinarida, globalno predstavlja jednu od najvažnijih i najraznolikijih tipova reljefnih cjelina. Dinarska krška polja spadaju među najraznolikije i najkompleksnije krške formacije na svijetu.

U ovom su istraživanju Dinarska krška polja podijeljena i klasificirana u 30 dobro diferenciranih skupina koje su raspoređene u devet glavnih biogeografskih regija, temeljem većeg broja odabranih relevantnih varijabli i kriterija. U postupku klasifikacije dinarskih krških polja utvrđeni su prepoznatljivi obrasci za svaku grupu polja u okviru nekih od najvažnijih parametara. Na odabranih 10 dinarskih krških polja Bosne i Hercegovine te Hrvatske (iz šest skupina polja) provedena su intenzivna istraživanja tijekom različitih istraživačkih projekata. Kako bi se ocijenila važnost istraživanih polja za mikobiotu, dobiveni rezultati su vrednovani pomoću standardiziranih kriterija uz provedbu binarnog ocjenjivanja. Mikološki najvažnija polja identificirana su na temelju postignute "kumulativne ekološke vrijednosti" (CES), omjera CES vrijednosti i broja svih zabilježenih vrsta te omjera CES vrijednosti i broja dana istraživanja (mjere uloženog istraživačkog napora). Uz analizu, priložen je i kratak opis specifičnih tipova staništa najvažnijih za gljive zajedno s preporukama za provedbu odgovarajućih mjera zaštite u tim područjima.

Na istraživanim krškim poljima zabilježen je određeni broj rijetkih i vrlo ranjivih vrsta gljiva iz odjeljka *Ascomycota*, npr. *Mollisia uda*, *Patinella hyalophaea*, *Podostroma leucopus*, *Scutellinia peloponnesiaca* i *Lamprospora leptodictya*. Nalazi nekih vrsta iz posljednjeg bloka istraživanja, predstavljaju jedine poznate nalaze na Dinaridima pa tako ni njihov status ugroženosti još nije ocijenjen. Zbog toga se za te vrste ovdje daju preporuke za njihovu zaštitu na temelju IUCN kriterija.

Ključne riječi: *Ascomycota*, klasifikacija, zaštita, ekološka vrijednost, gljive, Bosna i Hercegovina, Hrvatska

Introduction

Generally, karst poljes represent the largest of five main types of depressions of karstic reliefs (Sauro 2012), whereby recent ice-free karst landscapes occupy between 13% (Stevanović et al. 2016) and 20-25% (Breg Valjavec et al. 2017, Bonacci 1987b) of the total global land area (depending on estimations of different authors). Closed karst poljes (or „poljes inside karst") are larger flat-bottomed depressions in karstic landscapes that are completely surrounded with elevated terrain (with at least one steep-sloped side). Closed poljes have significant historic and/or present hydrological functions including sedimentation processes and karstic drainage through underground outflows. In the close vicinity of local underground water bodies, they were most frequently formed by tectonic activities followed by marginal fluvial, corrosive and sedimentation processes (Roglić 1954, Ford & Williams 2007). Therefore, the bottoms of today's karst poljes are covered by younger (Pleistocene) sediments. Due to their size and specific hydrological-sedimentation functions, karst poljes play an important role in large karstic complexes. This is especially evident when bearing in mind that roughly 50% (or more) of the total land area of Bosnia and Herzegovina, Croatia, Montenegro and Slovenia is covered by karstic terrain. Altogether, karst poljes of all types cover 25% of the area of the Dinaric Alps.

In the Dinaric karst, following to hydrology and fertile soils, karst poljes constitute areas that are most suitable for many groups of organisms, including human civilization. Surrounded by vast areas of porous carbonate massifs and plateaus without surface watercourses, the bottoms of the poljes represent fluvial islands on whose edges karstic springs that feed various surface waterbodies (rivers, streams, lakes, swamps, bogs and fens) are situated. The main goal of this study was to investigate the importance and association of fungi with local habitat types that are formed by specific abiotic factors which dominate the bottoms of the karst poljes. We further tried to classify the Dinaric karst poljes according to the occurrence of different habitat types and their influence on the composition of mycobiota.

Methods

To understand the variability of the ecological conditions that are important for mycobiota and which dominate in the karst poljes of the Dinarides, regardless of previous delimitations of the Dinaric karst since Roglić (1969) onwards, we firstly delimited as precisely as possible the extent of the Dinaric karst (mainly using the micro-relief features with karst-determinative elements). The next step was to identify and characterize all larger karstic depressions attributable to closed karst poljes according to the criteria given by Ford & Williams (2007) and Bonacci (2013).

This was necessary because a full list and database of the Dinaric karst poljes was not available for the authors. It was expected that the extremely high bioclimatic variability and the differences in a number of features among karst poljes are reflected by the occurrence of different habitat types important for fungi and by the regional importance that certain poljes play for their wider surroundings.

Standards and terminology

For the purpose of standardisation and saving space in the text the following terms are here introduced and recommended for international use:

Low karst poljes	(± "poljes of first horizon" in Jelavić 1982), with bottoms between ~0-150 m a.s.l.
Elevated karst poljes	(± "poljes of second horizon" in Jelavić 1982) with bottoms in the range from 150-700 m a.s.l.
Medium high karst poljes	(± "poljes of third horizon" in Jelavić (1982), except for Kupreško and Vukovsko/Ravno polje near Kupres) with bottoms in the range of 700-1000 m a.s.l.
High karst poljes	with bottoms situated at elevations between 1000-1700 m a.s.l.
Karst micro-polje	flat-bottomed closed karstic depressions with at least one steep slope, smaller than "small" poljes (e.g. Srijansko polje, Mt. Mosor or Njeguško polje, Mt. Lovćen) with an underground outflow and with historical and/or currently significant sedimentation processes. In the Dinaric karst they are mostly situated on the Adriatic islands (Bonacci 1991) or in the highest limestone massifs.
Blatina	flooded karst polje near sea-level (cf. Ljubenkov et al. 2010) occupied by a continuous surface of Mediterranean stagnant freshwater (swamps), different from karstic lakes that represent the native (ancient) morphogenetic stage of the development of karst poljes, best represented by Vrana Lake on the Island of Cres (cf. Ožanić & Rubinić 1992, Šegota & Filipčić 2001).
Slatina	karst polje approximately situated at sea-level and covered by a continuous surface of brackish water.
Ponornica	a watercourse that sinks into karstic underground at that point where it reaches contact with porous bedrock (also swallet, stream sink, swallow hole or ponor; see Monroe 1970, Bonacci 1987a, Ford & Williams 2007).

Evaluation of existing maps and remote sensing data

Topographic maps (scale 1:25000) which cover the whole Dinaric Alps, including the Adriatic lowlands and islands, were used for the detection of karst poljes. Together with Gams (1976) and Ranković et al. (1981) the Atlas of the climate of former Yugoslavia for the 1931-1960 period (Hidrometeorološka služba SFRJ 1931-1960) was used for climatic characterisation. All recognised karst poljes were mapped on physical maps with superimposed Dinaric karst range boundaries (own database) and bioclimatic belts compiled from Ozenda (1975), Rivas-Martinez (1980), Stefanović et al. (1983), Quezel & Barbero (1985), Jovanović et al. (1986), Bertović & Lovrić (1992), Antonić et al. (2000) and Kutnar & Kobler (2011). A map of the biomes of former Yugoslavia (Matvejev & Puncer 1989) was used for the same purpose. As a myco-ecological criterion (modelled for *Scutellinia* spp., Matočec et al. 1995) the optimal conditions (temperature and precipitation) for fructification in late spring, summer and early autumn on a monthly scale was used to visualize the variability of ecological conditions in different karst poljes for fungi. Although a minimal size of karstic depressions (length, width, surface) was claimed by some authors to determine karst poljes, this criterion varies greatly between authors (cf. Ford & Williams 2007, Gams 1978, Krklec et al. 2015). Therefore, we used geomorphological, morphogenetical and hydrological criteria. According to these criteria even very small flat-bottomed karstic depressions can be determined as karstic micro-poljes (cf. Frelih 2003, Bonacci 2013). A preliminary database of karst poljes (in Excel software application) was constructed for the analysis and progressive classification of Dinaric karst polje, partly relying on Jelavić's (1967, 1982) classification concept, the only earlier attempt of the classification of the Dinaric karst poljes available to us. Since closed karst poljes are mutually highly diverse but individually entirely confined, we were able to define discrete and mutually completely isolated groups with homogenous abiotic conditions (apart of hydrological objects) which can be classified readily on the descriptive level.

Fieldwork

Ten karst poljes belonging to six groups (Fig. 1; Tab 1) that greatly differ from each other viz. Northwestern Dinaric montane poljes (E1), Mala Kapela poljes (D1), Eastern-Bosnian and Sandžak poljes (I2), Čvrsnica-Vran micro-poljes (G4), Western Bosnian-Herzegovinian mid-altitude poljes (G1) and Dalmatian-Herzegovinian low poljes (A3) have been the subject of recent (2017-2018) and earlier (1981-2010) intensive mycological research. The aim of these studies was to explore the diversity of mycobiota in habitat types that are important for fungi and to ascertain the importance of the given karst polje for mycobiota on a basis of the presence of stenovalent, often sensitive, rare and/or protected species of the largest fungal phylum, *Ascomycota*.

The following karst poljes were investigated: (1) Ponikve near Tršće (2) Sungerski lug high hyperkarst small polje (3) large Ogulinsko-Plaščansko polje in continental area with Mediterranean-like climatic regime, all situated in the northwestern Dinarides (Croatia), (4) altimontane Bijambare karst randpolje, (5) Dugo polje and (6) Gornje/Donje bare of Čvrsnica-Vran high hyperkarst area; (7) Šujičko polje, (8) Duvanjsko polje and (9) Livanjsko polje, all of them medium high poljes of the Central Dinarides (Bosnia and Herzegovina), and (10) Konavosko polje in the Mediterranean lowlands (Croatia).

For calibration of the present evaluation the intensively researched Ponikve on Mt. Medvednica (situated outside the Dinaric karst in Croatia) was selected as an outgroup polje for which previous studies ascertained that it is of low significance for regional mycobiota.

Evaluation of karst poljes by myco-bioindication

The importance of karst poljes which were studied by relatively intensive fieldwork, was preliminary evaluated by summing up the binary (except (d) and (e) rarity categories) grading scale assigned to the recorded ascomycete species, i.e. the "cumulative ecological score" (CES), as follows: (a) ecological stenovalence; (b) local species' habitat exclusivity; (c) species' habitat vulnerability/stability/threat; (d) regional rarity of the species: species known from a single locality in the Dinarides = 1, for species known from 2-5 localities = 0.5, and known from 6 or more localities = 0; and (e) conservation status IUCN status or any other evaluation in any of the countries of the Dinaric Alps.

Results

Stepwise classification of Dinaric karst poljes according to habitat availabilty for fungi

We recognized 30 karst polje groups that can be assembled in nine geographic units (regions) on the basis of geographical, geological, morphological, hydrological, climatic, bioclimatic and myco-ecological criteria (Tab 1).

Those groups are differentiated from each other by highly diverse abiotic conditions.

Generally, it is known that annual precipitation and cloudiness decreases from the NW, with the NW Dinaric karst poljes receiving around 3,000 mm annual precipitation, to the SE, where some Sandžak high poljes receive below 1,000 mm as well as from the SW to the NE (cf. Hidrometeorološka služba SFRJ (1931-1960), Radičević et al. 1980, Poje et al. 1984). But in the Central-Adriatic arid zone some micro-poljes on the Adriatic Islands receive <600 mm precipitation p.a. On the other hand, global radiation on horizontal surfaces (which approximates the situation on the bottom of karst poljes) increases significantly from the NW Dinarides towards the SE as well as from the N to the S (Matić 2007, www.meteonorm.com). Additionally, along the N-S axis the continental climatic regime (precipitation minimum in the cooler half of the year) turns into the maritime regime (precipitation minimum in the warmer half of the year, cf. Ranković et al. 1981) which has a strong influence on the appearance and fructification period of fungi (see column "Myco-phenology" in Tab. 1). Temperature greatly depends on altitude with higher annual air temperatures in lower altitudes (karst polje bottoms vary from below sea level up to 1,700 m a.s.l.). Besides altitude, the amplitude of annual air temperature increases from the SW, i.e. the Adriatic Sea, towards the NE. Thus, all karst poljes of Mediterranean groups have all-year i.e. 365 days with mean daily temperature above 0 °C (karst poljes from group A with mean annual air temperature ~14–17 °C and poljes from group B with annual air temperature ~10-14 °C). On the other hand, the highest Southeast and Central Dinaric karst poljes (groups G4 and I 1-4) have only 220-260 days with mean daily temperature above 0 °C per year, with mean annual air temperature of only (2) 4–8 °C (see Tab. 1).

The relationship between vegetation and the local climate has been ascertained by Bertović (1975). The Dinaric karst poljes are situated in all bioclimatic belts from the thermo-Mediterranean up to the alti-Mediterranean/Southeastern Dinaric alpine "islands", i.e. from the Mediterranean side to the highest ridges of the Dinaric Alps, and from the alpine to the colline-continental belt on the Pannonian side of the mountains.

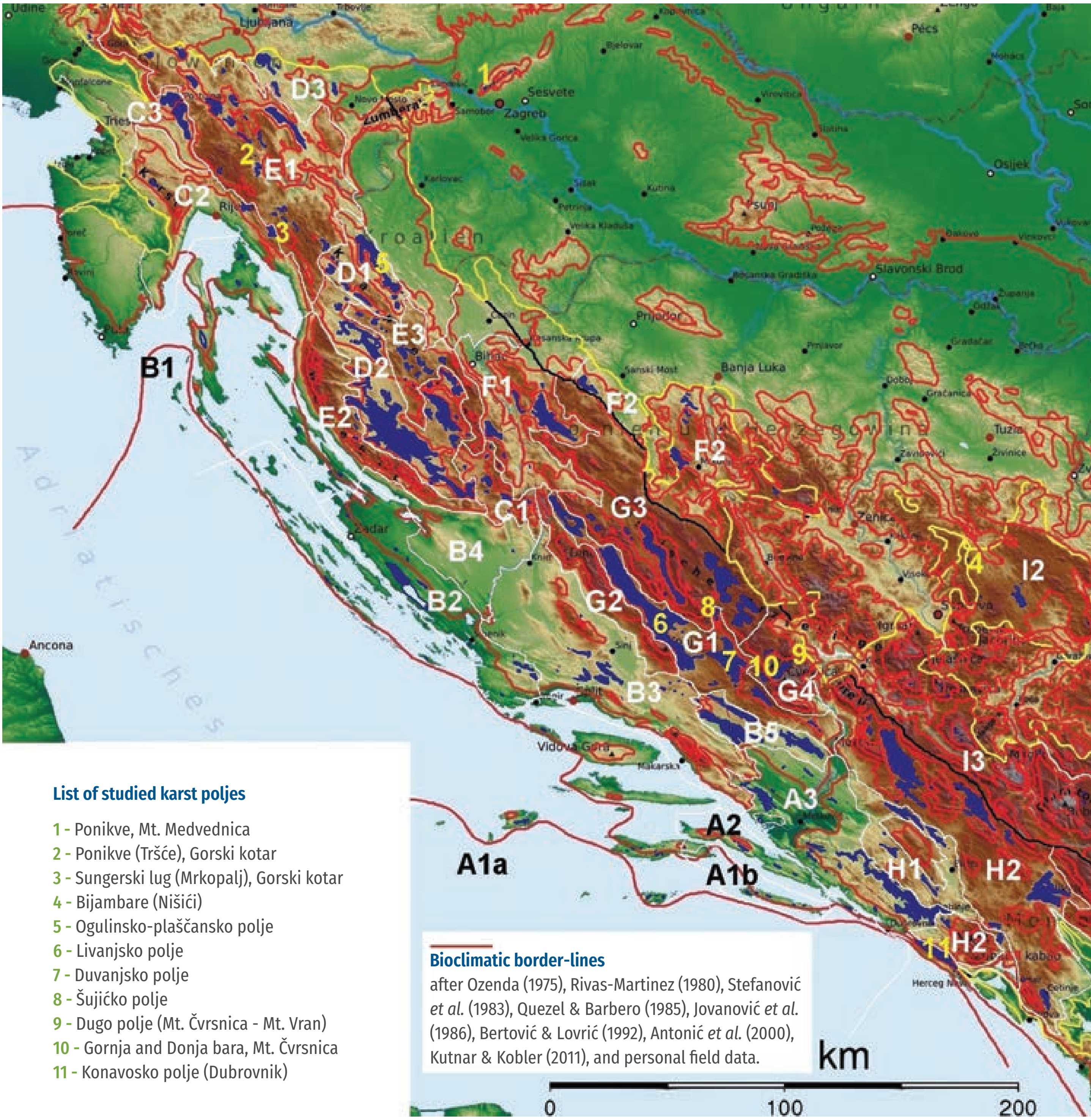


Fig. 1: Dinaric karst poljes overview – Classification and distribution of geographical groups with highlighted position of karst poljes that have been investigated. (Author: Neven Matočec, derived from personal database "Dinaric karst poljes and canyons 1984-2018")

Regarding area size, micro-poljes are prevalent either in the lowest altitudes up to 150 m a.s.l., on islands (groups A1a-b, B1) or in the highest altitudes, mainly between 900 and 1,700 m a.s.l. (groups E2, G2, I1, I3, I4). The largest karst poljes (nearly all being structural, cf. Ford & Williams 2007) except Konavosko and Peštersko polje, are situated on external Dinaric thrust geological unit (cf. Pamić & Jurković 2002, Placer et al. 2010).

The occurrence of different habitat types that are important for fungi, depends largely on hydrological conditions of karst polje bottoms. Together with Mediterranean freshwater swamps (blatinas) or brackish waterbodies (slatinas), karst lakes occur either in the lowest Mediterranean region (groups A1b, B1 and B2) or in the highest elevations of the alti-Mediterranean up to the Dinaric-alpine zone (groups I3 and I4). Karst poljes with perennial watercourses and high water levels dominate in the NW Dinaric region. These areas are characterized by very high annual precipitation and a strong maritime climatic regime (groups C3, D1, E1-E3). Central and South-eastern Dinaric poljes that are in hydrological contact with high and large, highly porous carbonate massifs and plateaus with huge underground aquifers (groups G1, G3 and H1) are also rich in perennial watercourses.

Evaluation of karst poljes based on preliminary analyses of the ascomycete fungi

The significance of the investigated karst poljes for mycobiota was evaluated by five criteria, already explained above, and the ascomycetes who were recorded in frame of various projects in 10 karst poljes during the last four decades. The numbers of species recorded per polje, the cumulative "ecological score" (CES) and estimated research level are given in Tab. 2.

As an auxiliary tool for estimating the importance of Dinaric karst poljes for ascomycete fungi and the exploration level we used an extra-Dinaric micro-polje (Ponikve on Mt. Medvednica) situated in a small patch of isolated karst previously assessed as a polje of low significance to regional mycobiota.

Key:

*	Gomance - Adriatic drainage;
**	Čujića krčevina - Black Sea drainage.
SA	Subalpine (continental);
AMT	Altimontane (continental);
MT	Montane (continental);
COL	Colline (continental);
TM	Thermo-Mediterranean;
MM	Meso-Mediterranean;
SM	Sub-Mediterranean;
OM	Oro-Mediterranean;
AM	Alti-Mediterranean;
DA	Dinaric-alpine;
MD	Mediterranoid (continental, colline to montane).

Karst poljes representatives:

A1a	Blatsko polje, Korčula;
A1b	Blatsko polje, Mljet;
A2	Orlovo polje, Pelješac;
A3	Jezero polje (Vrgorac);
B1	Ponikve, Krk;
B2	Bokanjačko blato (Zadar);
B3	Mućko polje;
B4	Bare (Đevrske);
B5	Imotsko polje;
C1	Velikopopinsko polje (Gračac);
C2	Grobničko polje (Rijeka);
C3	Postojnska kotlina;
D1	Drežnički lug;
D2	Krbavsko polje;
D3	Grosupeljsko polje;
E1	Cerkniško polje;
E2	Bunovac, Mt. Velebit;
E3	Vrhovinsko polje;
F1	Petrovačko polje;
F2	Podrašničko polje (Mrkonjić Grad);
G1	Livanjsko polje;
G2	Brezovac, Mt. Dinara;
G3	Kupreško polje;
G4	Dugo polje (Mt. Čvrsnica-Vran);
H1	Dabarsko polje;
H2	Nevesinjsko polje;
I1	Cigovića bare, Mt. Lola;
I2	Pešterško polje;
I3	Masna bara, Mt. Lelija;
I4	Rikavačko jezero, Mt. Žijovo.

Tab. 1: Karst poljes polyphasic classification based on seven types of different delimitatio

Geogr group	Group name	Bioclimat. zone	Drainage	Geolo subdi
A1a	Dalmatian Adriatic island poljes (HR)	TM-MM	Adriatic	Ext-D
A1b	South Dalmatian island blatinas/Baćina lakes (HR)	TM-MM	Adriatic	Ext-D
A2	Korčula-Pelješac elevated poljes (HR)	MM-SM	Adriatic	Ext-D
A3	Dalmatian-Herzegovinian low poljes (HR/BA)	MM-SM	Adriatic	Exter
B1	Kvarnerian-Kras poljes (HR/IT)	MM-SM	Adriatic	Adr/E
B2	Ravni kotari-Šibenik low poljes (HR)	MM-SM	Adriatic	Ext-D
B3	Dalmatian Zagora poljes (HR)	SM	Adriatic	Exter
B4	Northern Dalmatian poljes (HR)	SM	Adriatic	Ext-D
B5	Dalmatian-Herzegovinian elevated poljes (HR/BA)	SM	Adriatic	Ext-D
C1	South-eastern Lika poljes (HR)	SM-OM	Adriatic	Ext-D
C2	Ćićarija-Primorje poljes (HR/SI)	SM-OM	Adriatic	Exter
C3	Postojna region (SI)	SM(OM)	Adr/Bl_Sea	Ext-D
G1	W-Bosnian-Herzegovinian mid-altitude poljes (BA)	SM-OM	Adriatic	Ext-D
D1	Mala Kapela poljes (HR)	MD(MT)	Black Sea	Ext-D
D2	Central & Western Lika poljes (HR)	MD	Adr/Bl_Sea	Ext-D
D3	NW Dinaric colline-continental poljes (SI/HR)	COL	Black Sea	Ext-D
F1	Una drainage poljes (BA/HR)	MD/OM	Black Sea	Ext-D
F2	Sana-Vrbas poljes (BA)	MT-AMT	Black Sea	Inter
E1	NW Dinaric montane poljes (SI/HR)	MT-AMT(SA)	Black Sea*	Ext-D
E2	Velebit high micropoljes (HR)	AMT-SA	Adriatic	Ext-D
E3	Northern Lika montane poljes (HR)	MT-AMT	Adriatic**	Ext-D
G2	Čemernica-Dinara high micropoljes (HR)	OM-AM	Adriatic	Ext-D
G3	W-Bosnian-Herzegovinian high poljes (BA)	AMT	Adr/Bl_Sea	Ext-D
G4	Čvrsnica-Vran high micropoljes (BA)	AM	Adriatic	Ext-D
H1	E-Herzegovinian-Montenegrin elevated poljes (BA/MN)	SM	Adriatic	Ext-D
H2	E-Herzegovinian-Montenegrin high poljes (BA/MN)	OM	Adriatic	Ext-D
I1	Morača-Zeta high micro-poljes (MN)	OM-AM	Adriatic	Ext-D
I2	E-Bosnian-Sandžak high poljes (BA/SRB/MN)	AMT-DA	Black Sea	Inter
I3	Bosnian-Montenegrin high micro-poljes (BA/MN)	AM-DA	Adr/Bl_Sea	Inter
I4	Prokletian high micropoljes (MN/AL)	AM-DA	Adr/Bl_Sea	Inter

Karst polje geographical units (regions)		
A	Mediterranean region of lower Adriatic	B
D	NW Lower Dinarides	E
G	Central Dinarides	H
×	monthly mean precipitation >70 mm	

Karst polje types (after Ford & Williams 2007, supplemented)		
RP	surface spring → sinkhole (Randpoljes)	SP / BP
DP	no significant hydrology - Dry poljes	AP
SMP	maritime karstic lakes (freshwater or brakish) - Submerged poljes	

n criteria

gical ivision	Altitude	Mean annual temp.	10-d seq. T>°C	Mean annual precip.	Myco-fenology (model-Scutellinia)												Prevalent size	Polje type
					I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII		
in-imbricate	~0-150	15-17	36	600-1250	×	×	×							×	×	×	micro	DP
in-imbricate	(-)50-15	16-17	36	1000-1250	×	×	×	×	×	×			×	×	×	×	micro	SMP
in-imbricate	150-350	14-15	36	1250-1500	×	×	×	×	×				×	×	×	×	small-large	BP
nal-Dinaric	~0-250	14-16	36	1500-2500	×	×	×	×	×	×			×	×	×	×	small-large	DP / BP
xt-Din-imbr	(-)30-100	(12)14-16	36	1000-1500	×	×	×	×	×	×			×	×	×	×	micro-small	SMP
in-imbricate	~0-150	14-16	36	800-1000	×	×							×	×	×	×	small-large	SMP
nal-Dinaric	250-650	10-14	36	1250-1750	×	×	×	×	×	×			×	×	×	×	micro-small	DP / BP
in-imbricate	200-300	12-14	36	1000-1250	×	×			×	×			×	×	×	×	micro	BP
in-thrust	250-600	10-14	36	1250-1750	×	×	×	×	×				×	×	×	×	small-large	SP / DP
in-thrust	600-800	6-10	28-30	1500-1750	×	×	×	×	×	×			×	×	×	×	micro-med.	RP
nal-Dinaric	200-750	6-12	30-35	1000-2500	×	×	×	×	×	×	×	×	×	×	×	×	small-med.	SP
in-thrust	300-600	8-10	30-35	1500-2500	×	×	×	×	×	×	×	×	×	×	×	×	small-large	SP
in-thrust	700-1000	8-12	27-30	1250-1750	×	×	×	×	×	×			×	×	×	×	small-large	SP
in-thrust	300-500	8-10	28-30	1500-2500	×	×	×	×	×	×	×	×	×	×	×	×	small-large	SP
in-thrust	400-700	6-10	28-30	1000-1750	×	×	×	×	×	×			×	×	×	×	small-large	BP
in-thrust	200-450	8-10	30-32	1000-1500	×	×		×	×	×	×	×	×	×	×	×	micro-med.	BP
in-thrust	500-700	6-10	29-30	1250-1750	×	×	×	×	×	×			×	×	×	×	small-large	RP
nal-Dinaric	400-1000	7-10	28-31	1000-1500	×	×		×	×	×	×	×	×	×	×	×	micro-med.	RP
in-thrust	500-1000	6-10	26-30	1750-3000	×	×	×	×	×	×	×	×	×	×	×	×	small-large	SP
in-thrust	700-1250	4-8	26-29	2000-3000	×	×	×	×	×	×	×	×	×	×	×	×	micro	SP
in-thrust	600-800	6-8	26-28	1000-1500	×	×	×	×	×	×			×	×	×	×	small-med.	BP
in-thrust	900-1250	4-8	25-28	1500-2000	×	×	×	×	×	×	×		×	×	×	×	micro	DP
in-thrust	900-1250	4-8 (10)	24-28	1250-1500	×	×	×	×	×	×		×	×	×	×	×	small-large	SP
in-thrust	1200-1400	4-8	25-26	1750-2000	×	×	×	×	×	×		×	×	×	×	×	small-med.	SP / DP
in-thrust	200-700	8-12	36	1500-2500	×	×	×	×	×	×			×	×	×	×	small-large	SP / DP
in-thrust	700-1200	6-10	24-28	1500-3000	×	×	×	×	×	×			×	×	×	×	small-large	SP / DP
in-thrust	900-1680	(2) 4-8	22-26	2000-2500	×	×	×	×	×	×		×	×	×	×	×	micro	SP / DP
nal-Dinaric	700-1700	4-8	22-26	750-1500	×	×	×	×	×	×	×	×	×	×	×	×	small-large	RP
nal-Dinaric	1000-1700	(2) 4-8	21-26	1500-2000	×	×	×	×	×	×	×	×	×	×	×	×	micro	AP
nal-Dinaric	1000-1500	(2) 4-8	21-25	1500-2000	×	×		×	×	×		×	×	×	×	×	micro	AP

Mediterranean region of upper Adriatic

NW higher Dinarides

External SE Dinarides

C NW peri-Mediterranean Dinarides

F Central peri-Pannonian Dinarides

I Alpine SE Dinarides

monthly mean air temperature 10-22 °C

(after Hidrometeorološka služba SFRJ (1931-1960)

karstic spring → sinkhole (Structural poljes or Baselevel poljes)

alpine poljes

a) Photo: Nedim Jukić

b) Photo: Ivana Kušan

e) Photo: Neven Matočec

f) Photo: Neven Matočec

i) Photo: Jasmin Jukić

j) Photo: Neven Matočec

m) Photo: Nedim Jukić

n) Photo: Neven Matočec

o) Photo: Nedim Jukić

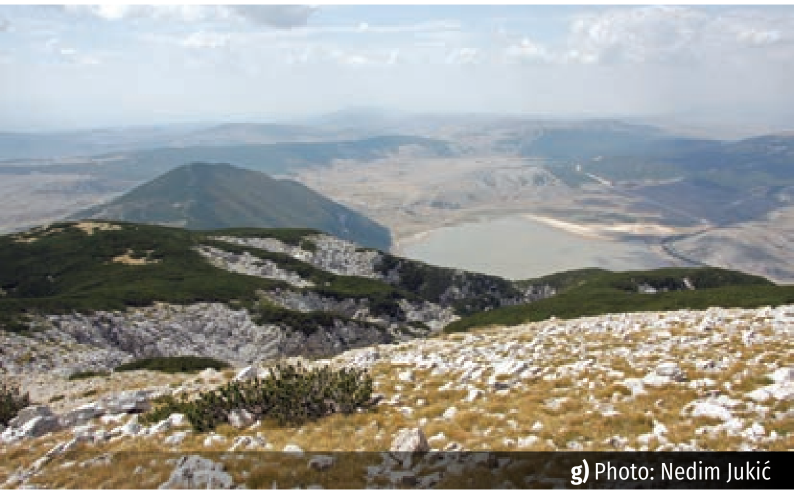


Fig. 2: *Different types and groups of karst poljes and karstic depressions in Croatia and Bosnia and Herzegovina:* **a)** View towards Dugo polje, Bare - Mt. Čvrsnica; **b)** Šujičko polje and its appearance in the peak of the dry season; **c)** Dugo polje landscape with Mt. Čvrsnica massif in the background; **d)** Plaščansko polje with ponornica Dretulja, near the city of Ogulin; **e)** Duvanjsko polje panorama; **f)** Čvrsničke bare micro-poljes with altimontane marsh vegetation; **g)** View on Blidinje Lake and the NW borders of Dugo polje from just below Pločno, the highest peak of Mt. Čvrsnica; **h)** Karstic river Sturba, one of the most important hydrological elements and watercourses of Livanjsko polje; **i)** Livanjsko polje, natural water retention and karstic watercourse near the village Bastasi; **j)** Konavosko polje near the city of Dubrovnik (Konavle municipality); **k)** Acidophilic bog in the area of Protected landscape Bijambare; **l)** Ogulinsko-Plaščansko polje and karstic spring Sabljaki; **m)** Brčanj stream, main watercourse of Brčanjsko polje; **n)** Sungerski lug, acidofilic bog surrounded by coniferous forest; **o)** Livanjsko polje, scenery near the Vrbica village; **p)** Masna Luka, fragmented parts of Dugo polje.


a) Photo: Neven Matočec


b) Photo: Nedim Jukić


c) Photo: Nedim Jukić


g) Photo: Nihad Omerović

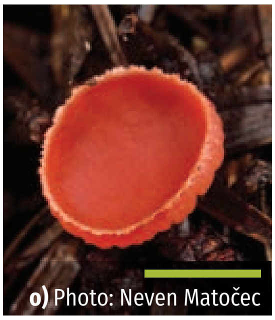
Scale bars:

b), h), j), k), m)	1 mm
a), g), e), l), q), r), s)	2 mm
c), f), i)	0,5 cm
d), n), o), p)	1 cm


h) Photo: Neven Matočec


i) Photo: Neven Matočec


n) Photo: Nedim Jukić


o) Photo: Neven Matočec


p) Photo: Neven Matočec


q) Photo: Nedim Jukić


s) Photo: Nedim Jukić

Fig. 3: Ascomycete fungi recorded in the karst poljes in Croatia and Bosnia and Herzegovina: **a)** *Scutellinia peloponnesiaca*, Ogulinsko-plaščansko polje; **b)** *Lamprospora leptodictya*, Bare - Mt. Čvrsnica; **c)** *Scutellinia subhirtella*, Gornje bare - Mt. Čvrsnica; **d)** *Helvella albella*, Masna Luka - Dugo polje; **e)** *Vibrissea calcaria*, Sturba river - Livanjsko polje; **f)** *Myriosclerotinia* sp., Vrbica - Livanjsko polje; **g)** *Parascutellinia carneosanguinea*, Ostrožac stream, Duvanjsko polje; **h)** *Heyderia abietis*, Ponikve (Tršće); **i)** *Helvella corium*, Ostrožac stream - Duvanjsko polje; **j)** *Patinella hyalophaea*, Bijambare; **k)** *Ascobolus xylophilus*, Bijambare; **l)** *Scutellinia superba*, Šujičko polje; **m)** *Mollisia uda*, Ogulinsko-plaščansko polje; **n)** *Podostroma leucopus*, Bijambare; **o)** *Sarcoscypha macaronesica*, Konavosko polje; **p)** *Peziza obtusapiculata*, Sungerski lug; **q)** *Boudiera tracheia*, Bare - Mt. Čvrsnica; **r)** *Vibrissea truncorum*, Ponikve (Tršće); **s)** *Scutellinia hyperborea*, Masna Luka - Dugo polje.

In the frame of recent mycological research, since 1982, four species were recorded for the first time for the mycobiota of Bosnia and Herzegovina: *Coprotus luteus*, *Helvella albella*, *Lamprospora leptodictya* and *Scutellinia superba*, and two further species for the mycobiota of Croatia: *Mollisia uda* and *Scutellinia peloponnesiaca*. Very rare species which are largely confined to special and often threatened habitat types are: *L. leptodictya*, *M. uda*, *Patinella hyalophaea*, *Podostroma leucopus* and *S. peloponnesiaca* (Fig. 3). The latter species were used to recommend regional protection measures.

Discussion

All ascomycete species which were recorded in the karst poljes that have been studied more or less sporadically and with different levels of intensity during the 1982–2018 period, were used for the evaluation process (Tab. 2). The aim of our assessment was to find objective correlations between different groups of karst poljes and the diversity of mycobiota. We further evaluated the importance for conservation of all investigated poljes based on the fungal species which have been found in the area. According to our analyses, Konavosko polje and Sungerski lug are the most valuable karst poljes with highest "Cumulative ecological scores" (CES). However, at the same time, the degree of exploration for both areas is also highest, as well as for Ponikve on Mt. Medvednica which reached one of the lowest CES values. As a measure for the potential value we calculated the ratio between CES and a number of days representing the research effort for all poljes. Ogulinsko-plaščansko polje, Ponikve near Tršće, Dugo polje, below Mt. Čvrsnica, and Duvanjsko polje reached the highest values, followed by Gornja and Donja bara on Mt. Čvrsnica, Konavosko polje and Livanjsko polje. Similar results were obtained when dividing the CES value through the number of all recorded species.

"Dinaric karst poljes harbour a high species diversity of Ascomycota, as well as a number of species which can be used as bioindicators, and also a number of rare and threatened species. In the frame of recent mycological research, four species were recorded for the first time for the mycobiota of Bosnia and Herzegovina, and two further species for the mycobiota of Croatia."

Nevertheless, several of the localities which were studied, and which harbour habitat types that are important for some ecological or taxonomic groups, we designated regardless of their index value as areas of special conservation interest. These are:

(1) Vrbica is a specific area in Livanjsko polje, the largest karst polje in Bosnia and Herzegovina (group G1; cf. Fig. 1) characterised by *Salix* spp. stands with dense hygrophilous swamp vegetation located in a basin filled with a permanent stagnant waterbody with coarse and rotten woody debris of the willows and with pronounced nitrification processes. This habitat type is extremely rare and difficult to study. It should be, therefore, in the focus of future research. In the area we found a still unidentified species of *Myriosclerotinia*. Nearly all species of this genus are rare and endangered in most countries (i.e., *M. dennisii* is listed as Critically

Endangered in Croatia; cf. Tkalčec et al. 2008). Hence, this is a very important discovery.

(2) Dugo polje and its surrounding karstic landscape (group G4; Fig. 1) is very important for nature protection and its mycobiota due to its large luxuriantly developed relict forest dominated by the SE Dinaric endemic tree *Pinus heldreichii* accompanied with a number of other endemic arborescent species (e.g., *Lonicera* spp.). The polje is situated in the subalpine bioclimatic belt. Together with the upper xeronival belt, the subalpine bioclimatic belt can be found in some of the highest massifs of SE Dinarides. Both bioclimatic belts show a strong Mediterranean influence (cf. Ranković et al. 1981, Jovanović et al. 1986) and represent biogeographical areas that are sharply separated from their Euro-Siberian bioclimatic counterparts (cf. Puşcaş & Choler 2012). Other areas with particularly high indices concern several freshwater habitats: karstic springs, small ponornicas with developed fens and the bank of Blidinje Lake with tall *Salix* and *Phragmites* stands. Among a number of ascomycete fungi recorded in this locality, *Boudiera tracheia* and *Helvella albella* are most important for nature protection. This very important area should be intensively investigated in the future.

(3) For the purpose of this study Gornja and Donja Čvrsnička bara (group G4; Fig. 1) are considered as a micro-polje complex. These two small karstic depressions with steep sides harbour small watercourses and karstic springs, some temporary but most of it perennial water bodies. The special importance of these localities lies in its location in high altitudes between 1,300 and 1,400 m a.s.l.). They represent the only near-alpine karst poljes in group G4 (Tab.1, Fig. 1) with a strong Mediterranean influence. Karst poljes in comparable localities are known only from a few sites in the high SE Dinarides (groups I1 and I4; cf. also Ranković et al. 1981, Jovanović et al. 1986). In some localities, like in Gornje bare, water is retained on the soil surface for a whole year. These conditions are favourable for fungal species associated with cyperaceous and juncaceous plants and their remnants. Furthermore, the area soaked with water around springs and rivulets is the habitat for some very rare and sensitive arctic-alpine fungal species. Besides *Boudiera tracheia* (a species listed as Endangered in Bosnia and Herzegovina, Jukić & Omerović 2017) the very rare bryo-parasitic fungus *Lamprospora leptodictya* was recorded in Donje bare polje. This find represents the first known record in the Dinaric Alps for the species which is hitherto known from the Arctic and northern European countries (Schumacher 1993). Therefore, the species should be strictly protected in Bosnia and Herzegovina.

(4) Bijambare represents a very valuable and rather large complex of habitat types of old growth altimontane coniferous forests rich in coarse woody debris. These forests are adapted to frequent and heavy frosts during winter (group I2; Fig.1). They are tremendously rich in fungal species (cf. Ódor et al. 2006) and therefore of high importance for mycobiota. The permanently wet conditions further favoured the development of a bog, a special freshwater habitat with very specific assemblages of fungi. In Bijambare we recorded the highest number of fungi (Tab. 2). The area is therefore of particular interest. *Patinella hyalophaea* and *Podostroma leucopus* inhabit very sensitive and endangered habitat types. Both species were recorded in the Protected Landscape Bijambare and were identified as candidates for a special protection status in Bosnia and Herzegovina.

Very similar habitat types exist in (5) Sungerski lug and (6) in the Ponikve area near Tršće, situated in the perhumide climate of the NW Dinarides (group E1; Fig. 1). In these areas bogs are much smaller and situated in significantly lower altitudes then in Bijambare. Nevertheless, the importance of both localities under extreme climatic conditions is evident in Tab. 2.

(7) In contrast to the former areas Konavosko polje is situated in the Mediterranean climatic zone (group A3; Fig. 1) with all-year air mean temperatures above 0 °C and yearly mean temperature above 14 °C. However, it is situated in an area of relative high precipitation. The importance of this polje derives from several strong karstic and flysch springs and rather short ponornicas with some of them embedded in tall evergreen laurel-oak forest. These few small but permanently moist and shady habitats are of the highest importance for mycobiota. The bottom of the polje is still occupied by extensive Mediterranean traditionally managed grasslands important for specific grassland fungi (e.g. *Geoglossum* spp.).

Previous research conducted during the past decades in Croatian karst poljes, and current research in the Central Dinarides of Bosnia and

Tab. 2: Evaluation of Dinaric karst poljes based on ascomycetous fungi. In addition, protected species and/or species which were used

Polje name	Geographical orientation	Country	Size class	Spec. no.	Res. days	CES	CES/sp	CES/da
Ponikve	Mt. Medvednica, NW from Zagreb	HR	micro	28	16	9,5	0,34	0,59
Ponikve	Tršće, NW from Delnice	HR	micro	9	3	24	2,67	8
Sungerski lug	Sunger, SSE from Delnice	HR	small	46	24	70,5	1,53	2,94
Bijambare	Nišići, NNE from Sarajevo	BA	small	23	13	49,5	2,15	3,81
Ogulinsko-plaščansko polje	Ogulin	HR	large	6	2	21	3,5	10,5
Livanjsko polje	Livno	BA	large	5	2	8	1,6	4
Duvanjsko polje	Tomislavgrad	BA	large	4	1	6,5	1,63	6,5
Šujičko polje	Šujica	BA	medium	3	1	1	0,33	1
Dugo polje	Blidinje jezero	BA	medium	14	4	26	1,86	6,5
Gornja i donja bara	pl. Čvrsnica	BA	micro	3	2	8,5	2,83	4,25
Konavosko polje	Čilipi	HR	large	33	17	73,5	2,23	4,32

Herzegovina, show that a number of the Dinaric karst poljes harbour a high species diversity of *Ascomycota*, as well as a number of species which can be used as bioindicators, and also a number of rare and threatened species. Their significance is evident (Tab. 2) by comparing these localities to isolated, extra-Dinaric micro-polje in the colline continental humid zone (Ponikve, Mt. Medvednica; Fig. 1). Presumably, much more species of fungi, characteristic for the biogeographic region, will be discovered by future research which would be in line with research that up to now has been conducted on other groups of living organisms (Lakušić 1970, Lovrić & Rac 1989, Bertović & Lovrić 1992, Ozimec et al. 2013b, 2013c, Stumberger 2015) and with analyses of the presence of particular habitat types in some large karst poljes (Schwarz 2013, Sackl et al. 2014). Like other researchers, we conclude that many karst poljes, in comparison to surrounding vast areas of waterless dry limestone massifs (see Fig. 1) are some kind of oases of high habitat diversity with otherwise rare and exclusive habitats which function as key refugia and strongholds for many rare, endangered and endemic plants, fishes, birds, invertebrates and also for a vast number of fungi.

for the present evaluation are shown

ay	**Exclusive polje's habitat of special value to mycobiota**	**Protected and/or evaluated species**
	none	*Helvella phlebophora* (HR: VU)
	bog	*Vibrissea truncorum* (HR: VU), *Heyderia abietis* (HR: NT)
	small bogs surrounded by tall old growth coniferous forest	*Discina fastigiata* (HR: CR), *Caloscypha fulgens* (HR: VU), *Geopyxis majalis* (HR: VU), *Trichoglossum hirsutum* (HR: VU), *Peziza obtusapiculata* (HR: DD), *Heyderia abietis* (HR: NT)
	bog, old growth coniferous altimontane forest	*Cudonia circinans* (HR: VU), *Heyderia abietis* (HR: NT), *Ascobolus xylophilus* (BA: CR), *Plicaria trachycarpa* (BA:VU), *Patinella hyalophaea* (BA candidate: EN), *Podostroma leucopus* (BA: candidate EN)
	fens and riparian forest in mediterranoid continental belt	*Mollisia uda* (HR candidate: EN), *Scutellinia peloponnesiaca* HR candidate: VU)
	fens, two types of riparian forests, swamp, traditionally managed grassland	*Myriosclerotinia* sp. (*M. dennisii* HR: CR)
	various oro-Mediterranean brooks, traditionally managed grassland	*Helvella corium* (BA: EN), *Parascutellinia carneosanguinea* (BA: VU)
	tall riparian forest	none
	fens and *Pinus heldreichii* endemic (alti-Mediterranean) forest, traditionally managed grassland	*Helvella albella* (HR: CR), *Boudiera tracheia* (BA: EN)
	fens in alti-Mediterranean belt	*Boudiera tracheia* (BA: EN) *Lamprospora leptodictya* (BA candidate: EN)
	karstic springs and riparian forest in Mediterranean belt	*Geoglossum cookeianum* (HR: VU), *Geoglossum umbratile* (HR: VU), *Sarcoscypha macaronesica* (HR: VU)

In 2017, in particular during the research in the karst poljes of the Central Dinarides (groups G1 and G4), we encountered climatic extremities never before recorded in the area since the beginning of meteorological observations. For several months there was a severe drought with high temperatures and frequent strong winds. However, even under such harsh conditions our research was surprisingly fruitful. In particular, in sheltered and shady stands with high substrate humidity we found many fungi. The occurrence of drought intolerant ascomycetes in karst poljes is mainly owed to their specific hydrological features. Large water bodies in karstic underground that feed surface watercourses in structural polje's bottoms are not so susceptible to drying out as dense networks of watercourses over watertight bedrock (cf. Bonacci 2015). Simultaneously, a number of Pannonian permanent rivulets and large fishponds outside of the Dinaric karst dried out completely. Even the smallest karst polje often generates its own microclimate with temperature inversions and the retention of fog (cf. Gams 1978) as an additional ecological influence that is often reflected in an "inverse" zonation of vegetation (Horvat 1953). Therefore, wet structural karst poljes have tremendously high capabilities for the retention of substrate moisture which is important for fungi in a number of habitat types, e.g. a variety of freshwater habitats (especially swamps and fens) and their inundation zones and in riparian old growth forests (in particular, stands of *Salix* spp., *Fraxinus angustifolia*, *Alnus glutunosa* and in Adriatic *Quercus robur*, *Q. frainetto* and Dinaric *Q. cerris* tall forests; cf. Jovanović et al. 1986).

Beside numerous epigean habitat types present in structural poljes typically there are also permanent cave springs, artesian (vauclusian) karstic springs and ponors situated at the polje's edges that play an important role not only for water circulation (Bonacci 1987a), but also (like during certain geological periods) for many fungal groups. In karst areas owing to long and intensive corrosive processes large subterranean spaces developed which provided a shelter for many fungi during several ice ages. Many of those species evolved afterwards under specific ecological conditions (constant and complete darkness, high humidity, low but above zero temperatures, poor nutrition levels) into true cave organisms incapable of resettling surface habitats after the withdrawal of the ice and climate warming (Matočec et al. 2014).

Following to current global climate warming, modern observers will probably witness considerable changes of karst polje's ecosystems. It can be expected that the magnitude of change will differ between karst poljes (some poljes may show more environmental shifts while others may be more resilient to environment change). In that case differences between certain poljes will probably remain comparably high over longer periods of time. Measurements of the hydrological regime of Vrgorsko polje (Jezero) between 1926 and 2006 (Bonacci 2013) may illustrate certain climatological trends. A number of fungi from different taxonomic and ecological groups have been ascertained as good bioindicators of climate shifts (e.g., Ing 2005, Kauserud et al. 2009, Buentgen et al. 2013, Ohenoja et al. 2013). This is confirmed also by our own monitoring data some of it covering a period of more than 30 years.

The general ecological importance of karst poljes, the international significance of the large Dinaric karst poljes, their natural and cultural values as well as their need for protection is unquestionable (Bonacci 2015, Sackl et al. 2014). Following to considerable morphological, climatological and hydrological differences between the karst poljes of the Dinaric Alps, the species diversity and importance of different karst poljes for mycobiota differs, according to the present assessment, heavily between the different groups of poljes in Tab. 2. In this respect we can draw the following general but preliminary conclusions:

1) The overall importance for mycobiota (here modelled for ascomycete fungi) is greater for karst poljes (especially of those with continual fluvial inflow) situated in regions which are exposed to longer period of drought and/or higher temperatures, and a precipitation deficiency during the warmer half of the year (resulting in the intensive and fast drying of the substrate).
2) The importance of the Dinaric karst poljes for general diversity of ascomycete fungi, the number of rare as well as aquatic/subaquatic species is greater if the climate at the polje's bottom is more humid and when the polje harbours some freshwater waterbody (ponornica, spring, lake, swamp, bog or fen).
3) The importance of Dinaric karst poljes for regional/local ascomycete mycobiota is greater if the polje is situated farther from the karst area edge or is more isolated from the continuous area of the Dinaric karst on the islands in the Adriatic Sea. Structural poljes of the central Dinaric karst or in the Adriatic lowlands and micro-poljes on the Adriatic Islands are more pronounced "oases" than randpoljes situated along the continental edge of the Dinaric karst. They make more contrasts in ecological conditions and habitat types favourable to most fungi in relation to surrounding dry karstic massifs and plateaus.
4) The overall importance of Dinaric karst poljes for ascomycetes is not correlated with polje size unless the polje houses a high number of different habitat types.
5) Small micro-poljes situated in higher altitudes in semi-alpine or alpine areas, especially those poljes which are partly influenced by Mediterranean or sub-Mediterranean climates, are particularly important for ascomycetes because these karst poljes harbour arctic-alpine species.

Our preliminary analyses show that many habitat types of the highest importance for fungi in the vast area of the Dinaric karst are largely restricted to the bottoms of karst poljes. Regardless of their size and the bioclimatic zone these habitat types are stable in many karst poljes and provide the basis for high habitat diversity and species diversity of mycobiota in the poljes. The most significant habitats for fungi are periodical or perennial freshwater habitats, like ponornicas, riparian old growth forests, bogs, fens, swamps, lakes, karst springs, humid cave entrances etc. In addition, traditionally used grasslands, artificial ponds and old, shady and wet foot trails are of great importance for mycobiota as well. These habitats should be protected and carefully managed by, e. g., traditional and sustainable forms of land use or by eco-tourism.

In particular, the mycobiota of karst poljes with low exploration level but high "ecological scores" (Tab. 2) as well as some poljes that were not yet studied, should be intensively investigated in the future. This is especially important in wet poljes with unique, rare and widely endangered habitats (e.g., poljes of the groups D1, E1, E2, G1, G3 and G4). Because human interests often have negative effects for the biodiversity of karst poljes (cf. Bonacci 1985) this research will be a significant contribution to the regional and international Important Fungus Area system (cf. Anderson 2002, Tkalčec et al. 2005, Jukić & Omerović 2017). Thanks to the usefulness of different mycobioindication methods, calibrated for regional ecological conditions (e.g., Matočec 2000, Matočec et al. 2000, Alebić-Juretić & Arko-Pijevac 2005, Ódor et al. 2006, Ozimec et al. 2013a, Kušan & Matočec 2017, 2018) the results of such research may also help in planning and implementing regional sustainable economies.

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