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DIVERSITY OF BRYOPHYTES IN SHOW CAVES IN SLOVENIA AND RELATION TO LIGHT INTENSITIES

DIVERZITETA MAHOV V TURISTIČNIH JAMAH V SLOVENIJI IN POVEZAVA Z INTENZITETO OSVETLJEVANJA

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Abstract UDC 582.32:551.442(497.4)

Janez Mulec & Svatava Kubešová: Diversity of bryophytes in show caves in Slovenia and relation to light intensities

In subterranean environments phototrophic organisms can grow only in the proximity of light sources. In a study from eight Slovenian show caves: Črna jama, Kostanjeviška jama, Krška jama, Pekel pri Zalogu, Pivka jama, Postojnska jama, Škocjanske jame, Županova jama and two mines, Idrija mercury mine and Mežica lead and zinc mine, equipped for tourist visits, 37 taxa of Bryophyta and Pteridophyta were identified. The most frequent organisms were mosses *Amblystegium serpens, Brachythecium* sp., *Eucladium verticillatum* and *Fissidens taxifolius*. The highest diversity of bryophytes was recorded in Mežica mine with 16 identified taxa where lamps are on continuously. Bryophytes were collected at wide range of photosynthetic photon flux densities (PPFD) from 0.2 to 530.0 μmol photons/m^2/s. *Eucladium verticillatum* had the highest span of PPFDs, ranging from 1.4 to 530.0 μmol photons/m^2/s. Bryophytes compensate for low PPFD with longer exposure to light irradiance. *Cratoneuron filicinum* identified in Mežica mine developed sporophytes at 2.1 and 2.4 μmol photons/m^2/s, in Postojnska jama *Brachythecium salebrosum* developed sporophytes at 4.7 μmol photons/m^2/s. Recolonization of lampenflora in show caves where bleach is applied to prevent its growth is still successful at sites that are exposed to long periods of irradiance and high PPFDs.

Keywords: caves, bryophytes, lampenflora, PPFD, Slovenia.

Izvleček UDK 582.32:551.442(497.4)

Janez Mulec & Svatava Kubešová: Diverziteta mahov v turističnih jamah v Sloveniji in povezava z intenziteto osvetljevanja

V podzemelju fototrofni organizmi lahko uspevajo zgolj v bližini vira svetlobe. V raziskavi, ki je vključevala vzorce iz osmih turističnih jam v Sloveniji, iz Črne jame, Kostanjeviške jame, Krške jame, jame Pekel pri Zalogu, Pivke jame, Postojnske jame, Škocjanskih jam, Županove jame in dveh rudnikov, Rudnika živega srebra Idrija in Rudnika svinca in cinka Mežica, ki sta opremljena za turistični obisk, smo identificirali celokupno 37 taksonov mahov in praproti. Najpogosteje zastopani so bili mahovi *Amblystegium serpens, Brachythecium* sp., *Eucladium verticillatum* in *Fissidens taxifolius*. V predelu Rudnika Mežica, kjer so luči stalno prižgane, je bila s 16 taksoni ugotovljena največja pestrost mahov. Mahove smo vzorčevali pri zelo različnih gostotah toka fotonov, potrebnih za fotosintezo (PPFD), in sicer v razponu od 0,2 do 530,0 μmol fotonov/m^2/s. *Eucladium verticillatum* je imel največji razpon PPFD od 1,4 do 530,0 μmol fotonov/m^2/s. Mahovi kompenzirajo nizke vrednosti PPFD z daljšo izpostavljenostjo svetlobnemu osvetljevanju. V Rudniku Mežica je bil identificiran mah *Cratoneuron filicinum* z razvitim sporofitom pri vrednostih 2,1 in 2,4 μmol fotonov/m^2/s, v Postojnski jami pa pri 4,7 μmol fotonov/m^2/s *Brachythecium salebrosum* s prav tako razvitim sporofitom. Na mestih v turističnih jamah, ki so izpostavljena daljšemu osvetljevanju in višjim vrednostim PPFD, in kjer za zatiranje lampenflore uporabljajo belilna sredstva, je njena ponovna kolonizacija vseeno uspešna.

Ključne besede: jame, mahovi, lampenflora, PPFD, Slovenija.

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INTRODUCTION

To present underground features and to attract visitors, more and more show caves in many areas around the globe are being equipped with electric lighting. In show caves with artificial illumination phototrophs do not grow only at cave entrances where they are exposed to natural sunlight, but also deep in the underground in the vicinity of lamps. Different rocky surfaces, sediments and artificial materials around lamps become colonized by phototrophs. This community of phototrophs named lampenflora is composed of cyanobacteria, algae, bryophytes and ferns – usually prothalli. A prothallus is a short-lived fern haploid structure which forms from a spore with numerous rhizoids growing underneath. Only exceptionally shoots of flowering plants can be recorded deep in the underground (Martinčič *et al.* 1981; Kubešová 2001). Lampenflora organisms are usually typical surface species (Dobat 1998; Mulec 2008). Some cyanobacteria and microalgae from this community can survive even at photon flux densities lower than their photosynthetic compensation point. At the cave temperature the light saturation point of these organisms is quickly reached (Mulec *et al.* 2008). Existence of lampenflora deep in show caves indicates constant and efficient transport of viable plant propagules from outside caves by air currents, water flow, or by animals and humans (Dobat 1970; Rajczy 1989).

Soon after installation of lighting system in a cave the question arises how to prevent growth of this alien vegetation. The best way in controlling lampenflora growth is still the physical approach, e.g., proper selection of time-limited irradiation, reduction of light intensity, separation of lighting of tourist trails from other underground inventory, using light spectrum which does not support photosynthesis, and well-considered illuminated surfaces (Rajczy 1989; Olson 2002; Zelinka *et al.* 2002; Mulec & Kosi 2009). To avoid further infestation of lampenflora its successful removal is a crucial step. However, in some caves lampenflora is preserved as a tourist attraction. Nevertheless, lampenflora in caves shows that natural cave conditions are disturbed which enables invaders from the surface to be more competitive than the originally present troglomorphic organisms (Mulec & Kosi 2009).

In Slovenia cave tourism has a long tradition, with one of the oldest documented show caves in the world – Vilenica from 1633 and world-famous Postojnska jama which is equipped with electric lightening since 1889 (Shaw 2003). The occurrence of plants growing around

Tab. 1: Caves and mines with lampenflora in Slovenia with data on tourist management and light irradiation of sampled sites

Cave/Mine	Lithology	Altitude (m)	Annual number of visitors	Electric equipment	Use of herbicides	Annual illumination (hrs/sector)	PPFD (μmol photons/m²/s) AVG±SD	Min	Max
Črna jama	Cretaceous limestones	540	3,000	1929	+	>70	130	130	130
Kostanjeviška jama	Cretaceous limestones, dolomites	170	10,000	1970	-	>60	71±53	9	213
Krška jama	Jurassic and Triassic limestones, dolomites	540	10,000	1995	-	>100	56±40	7	138
Pekel pri Zalogu	Triassic limestones, dolomites	314	20,000	1972,1976, 1997[b]	+	>100	9±16	1	59
Pivka jama	Cretaceous limestones	540	3,000	1929	+	>70	29±23	5	51
Postojnska jama	Cretaceous limestones	529	500,000	1884	++	1,000	110±124	5	530
Škocjanske jame	Cretaceous and Paleogene limestones	425	90,000	1959	-	477	51±64	2	200
Županova jama	Jurassic limestones	468	10,000	1937	-	>80	74±54	17	173
Idrija, mercury mine	Permocarbonian shales, dolomites	330	25,000	1994	+	>214	5±6	1	18
Mežica, lead and zinc mine	Carnian limestones, Triassic dolomites, shales	500	17,000[a]	2000[a]	-	8.760	0.9±0.8	0.2	2.7

[a] no tourist visit in the area with lampenflora

[b] successive electrification

++ regular, + occasional, - never

lamps in Postojnska jama was addressed as early as 1941 (Morton 1941). Because of long-term experience with lampenflora growth in Slovenian caves (Tab. 1) the objectives of this study were to ascertain how different irradiance levels influence bryophytes distribution and to compare floristic composition with previous studies (e.g., Martinčič *et al.* 1981). In early phases of lampenflora succession cyanobacteria and microalgae play a more important role (Mulec *et al.* 2008). In this paper only Bryophytes and Pteridophytes are studied, which usually appear later in species succession.

MATERIAL AND METHODS

Eight show caves, Črna jama, Postojnska jama, Kostanjeviška jama, Krška jama, Pekel pri Zalogu, Pivka jama, Škocjanske jame, Županova jama and two mines equipped for tourist visit (Idrija mercury mine, Mežica lead and zinc mine) were screened for the presence of Bryophyte lampenflora (Fig. 1). In comparision to the previous studies (Morton 1941; Latzel 1942; Grom 1961, 1962; Dobat 1973; Martinčič *et al.* 1981) few new caves were added to the list of show caves with lampenflora (Tab. 1).

In show caves tourists observe various natural karstological features, e.g., flowstone formations and underground river flows, while in mines they learn about history of mining and exploitation of natural resources that is why the illuminated objects in caves and mines usually differ. In show caves and mines where lampenflora was sampled, lamps are periodically turned on due to tourist visits or maintenance of the tourist infrastructure. Time when caves are exposed to lighting varies; the longest period of illumination in caves is in Postojnska jama and Škocjanske jame. In Mežica lead and zinc mine at the sampling location, which is not visited by tourists, lamps are on 24 hours due to constant monitoring of the underground water flow. Bryophytes generally grow on restricted illuminated surfaces around lamps in the underground, except in Mežica mine where around two lamps they covered approximately 15 m^2 of rocky surface (Fig. 4D). Other surfaces in Mežica mine were not colonized with lampenflora. Caves experience different intensities of tourist visits of which Postojnska jama has the longest tradition and highest number of tourists (Tab. 1). The history of lampenflora study and control is different for each cave, for example problem with plants inside Postojnska jama has been reported already by Morton (1941). In Postojnska jama bleach was is used to kill lampenflora every second year.

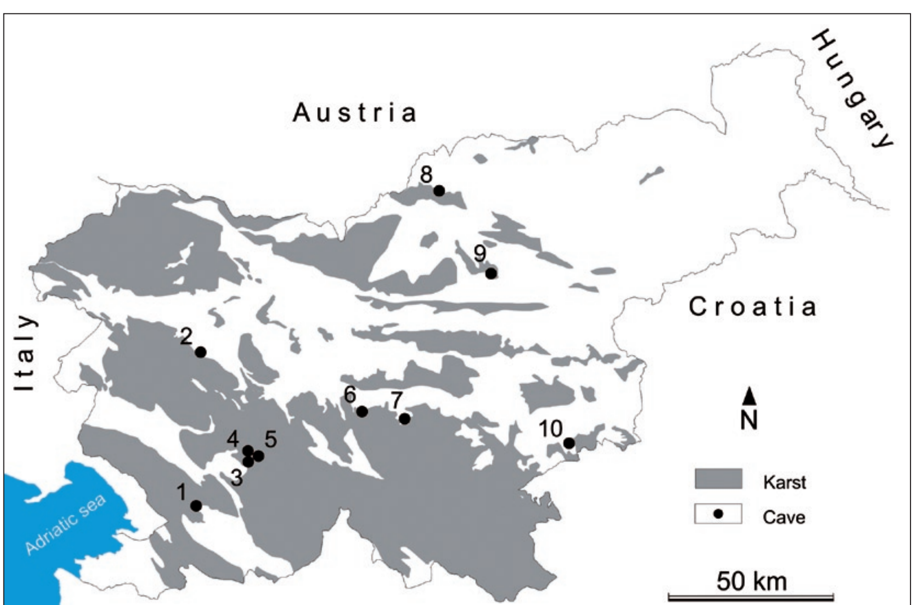

Fig. 1: Geographical location of studied show caves and mines in Slovenia (1-Škocjanske jame, 2-Idrija mine, 3-Postojnska jama, 4-Pivka jama, 5-Črna jama, 6-Županova jama, 7-Krška jama, 8-Mežica mine, 9-Pekel pri Zalogu, 10-Kostanjeviška jama).

Sampling was performed between 23rd and 28th of March 2008. When possible the same sites were selected as for the study of cyanobacteria and algae of lampenflora communities in 2003 (Mulec *et al.* 2008). Prior to taking specimens photosynthetically active radiation at sites was quantified as μmol photons/m^2/s using a LI-COR LI–1000 DataLogger (USA), which is a measure of photosynthetic photon flux density (PPFD). If various plants were observed around a selected lamp several specimens were sampled at different distances. After collection field material was sorted and determined under a binocular microscope and a light microscope (Olympus SZ40 and Olympus CX31, respectively). Identification followed determination keys after Hradílek 1994, Hedenäs 2003 and Frey *et al.* 2006. The nomenclature is according to Frey *et al.* 2006.

RESULTS AND DISCUSSION

From eight caves and two mines equipped with electric illumination in this study 37 taxa of Bryophyta and Pteridophyta were identified. The most frequent organisms identified in studied Slovenian caves and mines were *Amblystegium serpens* (frequency in all studied caves and mines was 0.60), *Brachythecium* sp. (0.50), *Eucladium verticillatum* (0.50) and *Fissidens taxifolius* (0.50) (Tab. 2).

The highest number of different phototrophic taxa were identified in Mežica lead and zinc mine (16) with the highest frequency of *Cratoneuron filicinum* (0.57), *Eucladium verticillatum* (0.19) and *Platyhypnidium riparioides* (0.14) followed by jama Pekel with 14 organisms (*Eucladium verticillatum*, 0.43, *Fissidens* cf. *bryoides*, 0.36, *Taxiphyllum* cf. *wissgrillii*, 0.21), Kostanjeviška jama with 13 taxa (*Cratoneuron filicinum*, 0.35, *Fissidens* cf. *bryoides*, 0.35, and *Rhynchostegium murale*, 0.18). Lower taxa numbers were recorded in Postojnska jama with 9 taxa (*Eucladium verticillatum*, 0.94, *Rhynchostegium murale*, 0.17, *Bryum* sp., 0.17), Škocjanske jame with 8 taxa (*Eucladium verticillatum*, 0.91, *Weissia* sp., 0.27), Idrija mercury mine with 7 bryophytes (*Amblystegium serpens*, 0.38, *Brachythecium* sp., 0.38), Županova jama with 8 bryophytes (*Brachythecium* sp., 0.33, *Amblystegium serpens*, 0.22), Krška jama with 6 taxa (*Amblystegium serpens*, 0.40, *Fissidens* sp., 0.30), Pivka jama with 3 bryophytes *Rhynchostegium murale* (1.0), and Črna jama with one bryophyte *Orthothecium intricatum* (1.0).

Based on previous studies floristically the most diverse was lampenflora from Postojnska jama with 30 identified taxa (Tab. 2). In this study we identified only 9 taxa what can be attributed to regular removal of lampen flora using bleach. A similar decrease in taxa linked to chemical removal of lampenflora and reduction of light intensity was experienced also in show caves in the Czech Republic (Kubešová 2001, 2004). Regular removal of lampenflora patches in Postojnska jama is likely the reason for lower diversity of cyanobacteria and algae compared to other caves (Mulec *et al.* 2008). For example previous screening of lampenflora organisms in Postojnska jama revealed out of 13 sampled sites (9 cyanobacterial and 8 algal taxa) only three colonized by mosses and ferns (one moss and one fern species) (Mulec 2005).

The highest diversity was found in Mežica mine with 16 identified taxa indicating that lighting scheme was the most favourable for mosses (Tab. 1). Martinčič and coworkers described jama Pekel as "the greenest cave" in Slovenia where they identified 21 taxa of Bryophyta and Pteridophyta (Martinčič *et al.* 1981). In this study we found only 14 taxa in the cave. Lower number of mosses and ferns from jama Pekel compared to older study can be explained with changed lamps in the cave in the last years which emit lower PPFDs.

In our study lampenflora communities comprised mosses and ferns, but no liverworts were identified. In previous studies they were recorded in jama Pekel and

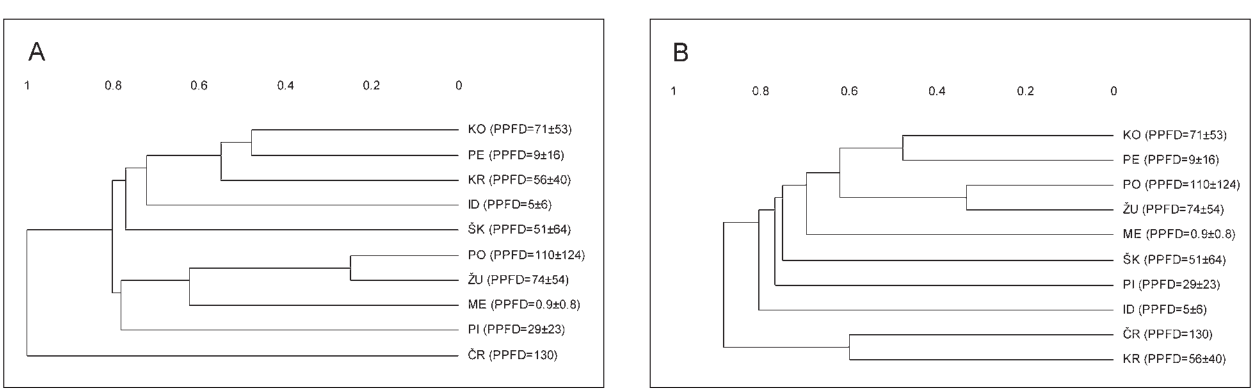

Fig. 2: Bray-Curtis dissimilarity index of lampenflora in Slovenian show caves; A-analysis based on bryophytes, B-analysis based on identified bryophytes and pteridophytes (ČR-Črna jama, ID-Mercury mine in Idrija, KO-Kostanjeviška jama, KR-Krška jama, ME-Lead and zinc mine Mežica, PE-jama Pekel, PI-Pivka jama, PO-Postojnska jama, ŠK-Škocjanske jame, ŽU-Županova jama, PPFD expressed in μmol photons/m^2/s per cave).

Table 2: Bryophytes and pteridophytes in Slovenian show caves (ČR-Črna jama, ID-Mercury mine in Idrija, KO-Kostanjeviška jama, KR-Krška jama, ME-Lead and zinc mine Mežica, PE-jama Pekel, PI-Pivka jama, PO-Postojnska jama, ŠK-Škocjanske jame, ŽU-Županova jama, I-previous studies, II-this study)

	Cave															
	ČR		***ID***	***KO***	***KR***	***ME***	***PE***		***PI***		***PO***		***ŠK***		***ŽU***	
	I	***II***	***II***	***II***	***II***	***II***	***I***	***II***	***I***	***II***	***I***	***II***	***I***	***II***	***I***	***II***
BRYOPHYTA																
Liverworts																
Leiocolea bantriensis (Hook.) Jörg.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Pellia epiphylla (L.) Corda	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.
Mosses																
Amblystegium sp. Schimp.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.
Amblystegium subtile (Hedw.) Schimp.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.
Amblystegium serpens subsp. *juratzkanum* (Schimp.) Ren. & Card.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.	.
Amblystegium serpens (Hedw.) Schimp.	.	.	+	+	+	.	.	+	+	+	+	.	.	.	.	+
Amblystegium varium (Hedw.) Lindb.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
Barbula unguiculata Hedw.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Brachythecium sp. Schimp.	.	.	+	+	.	+	+	+	.	.	.	.	.	.	.	+
Brachythecium cf. *campestre* (Müll. Hal.) Schimp.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Brachythecium mildeanum (Schimp.) Schimp.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Brachythecium cf. *plumosum* (Hedw.) Schimp.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Brachythecium cf. *rivulare* Schimp.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Brachythecium rutabulum (Hedw.) Schimp.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Brachythecium cf. *rutabulum* (Hedw.) Schimp.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Brachythecium salebrosum (Hoffm. ex F. Weber & D. Mohr) Schimp.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Brachythecium velutinum (Hedw.) Schimp.	.	.	.	+	+	.	.	+	.	.	+	.	.	.	.	.
Brachythecium cf. *velutinum* (Hedw.) Schimp.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Brachythecium velutinum var. *spelaeorum* Latzel	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Bryoerythrophyllum sp. P. C. Chen	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Bryoerythrophyllum recurvirostrum (Hedw.) P. C. Chen	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Bryum sp. Hedw.	.	.	.	.	.	+	.	.	.	.	.	+	.	.	.	+
Campylium calcareum Crundw. & Nyholm	.	.	.	+	.	.	.	.	.	.	+	.	.	+	.	.
Cirriphyllum tommasinii (Sendt. ex Boulay) Grout	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Cratoneuron filicinum (Hedw.) Spruce	.	.	.	+	.	+	+	+	.	.	.	.	.	.	.	+
Dicranella heteromalla (Hedw.) Schimp.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Didymodon rigidulus Hedw.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Didymodon vinealis (Brid.) R. H. Zander	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	.
Encalypta sp. Hedw.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Encalypta streptocarpa Hedw.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.
Encalypta vulgaris var. *obtusa* Nees. & Hornsch.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Eucladium verticillatum (With.) Bruch & Schimp.	.	.	.	.	.	+	.	+	.	.	.	+	.	+	.	+
Eucladium verticillatum (With.) Bruch & Schimp. subsp. *verticillatum*	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.
Eucladium verticillatum subsp. styriacum (Glow.) J. J. Amann	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.
Eurhynchium sp. Schimp.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Fissidens sp. Hedw.	.	.	.	+	+	.	.	.	.	.	.	.	.	+	.	.
Fissidens bambergeri Schimp. ex Milde	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Fissidens bryoides Hedw.	.	.	.	.	.	.	+	.	.	.	+	.	+	.	+	.
Fissidens cf. *bryoides* Hedw.	.	.	.	+	+	.	.	+	.	.	.	.	.	.	.	.
Fissidens dubius P. Beauv.	.	.	+	.	.	.	+	+	+	.	+	.	.	+	.	.

	Cave															
	ČR		ID	KO	KR	ME	PE		PI		PO		ŠK		ŽU	
	I	II	II	II	II	II	I	II	I	II	I	II	I	II	I	II
Funaria hygrometrica Hedw.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Homomallium incurvatum (Schrad. ex Brid.) Loeske	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Isothecium myosuroides Brid.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.
Isothecium myosuroides fo. *spelaeum* Grom	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Kindbergia praelonga (Hedw.) Ochyra	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Mnium stellare Reichard ex Hedw.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Orthothecium intricatum (Hartm.) Schimp.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Oxyrrhynchium schleicheri (R. Hedw.) Röll	+	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
Oxyrrhynchium speciosum (Brid.) Warnst.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Oxyrrhynchium stokesii (Turn.) Podp.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Oxyrrhynchium hians (Hedw.) Loeske	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Plagiomnium sp. T. J. Kop.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Plagiomnium affine (Blandow ex Funck) T. J. Kop.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Plagiomnium cuspidatum (Hedw.) T. J. Kop.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Plagiomnium rostratum (Schrad.) T. J. Kop.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.
Platyhypnidium riparioides (Hedw.) Dixon	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Rhizomnium puntatum (Hedw.) T. J. Kop.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Rhynchostegiella tenella (Dicks.) Limpr.	.	.	.	+	.	.	+	.	.	.	+	+	+	+	.	+
Rhynchostegium murale (Hedw.) Schimp.	.	.	.	+	.	.	.	.	.	+	+	+	.	.	.	+
Seligeria donniana (Sm.) Müll. Hal.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Taxiphyllum wissgrillii (Garov.) Wijk & Margad.	.	.	.	.	.	.	+	.	+	.	+	.	+	.	.	.
Taxiphyllum cf. *wissgrillii* (Garov.) Wijk & Margad.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Tortula muralis Hedw.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Weissia sp. Hedw.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.
PTERIDOPHYTA																
Asplenium sp. L.	.	.	.	+	+	.	.	.	.	.	.	.	.	+	.	.
Asplenium ruta-muraria L.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Asplenium scolopendrium L.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Asplenium trichomanes L.	.	.	.	.	.	+	+	+	.	.	+	+	.	.	.	.
Cystopteris fragilis (L.) Bernh.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Cystopteris cf. *fragilis* (L.) Bernh.	.	.	.	.	.	+	.	.	.	.	.	+	.	.	.	.
fern prothallus	.	.	.	.	+	+	.	+	.	.	.	.	.	+	.	.

See for references: ČR-I (Martinčič *et al.* 1981), PE-I (Martinčič *et al.* 1981), PI-I (Martinčič *et al.* 1981), PO-I (Morton 1941; Latzel 1942; Grom 1961, 1962; Dobat 1973; Martinčič *et al.* 1981), ŠK-I (Martinčič *et al.* 1981), ŽU-I (Martinčič *et al.* 1981)

Postojnska jama (Tab. 2). This is rather uncommon as in comparable studies in Hungary (Rajczy 1989) and in the Czech Republic (Kubešová 2001) no such plants were recorded. Older studies from show caves from Moravian karst (Czech Republic) indicated presence of liverworts (Vaněčková 1978), but revision of these herbarium specimens demonstrated that they were in fact fern prothalli (Kubešová 2001).

Comparison of lampenflora among 10 caves and mines based on Bray-Curtis dissimilarity index indicated relatively low similarity except between Postojnska jama and Županova jama (Fig. 2). Two statistical analyses using this index were carried out, on communities of bryophytes and on communities of bryophytes and pteridophytes. Results indicated that there is no pattern; different caves have generally different community of plants. Nevertheless, ferns were not frequent dwellers in Slovenian caves, in this study only five taxa were identified. The most frequently recorded were fern prothalli (0.4, Tab. 2). The most apparent group is Postojnska jama-Županova jama. The cluster Postojnska jama and Županova jama had the highest PPFDs at all sites and the lowest dissimilarity index (0.33 when bryophytes and pteridophytes were included in the study and 0.25 when only communities of mosses were analyzed). This can be attributed to fast growth of lampenflora in Postojnska jama as a result of high PPFDs despite regular physical removal of lampenflora and in Županova jama to con-

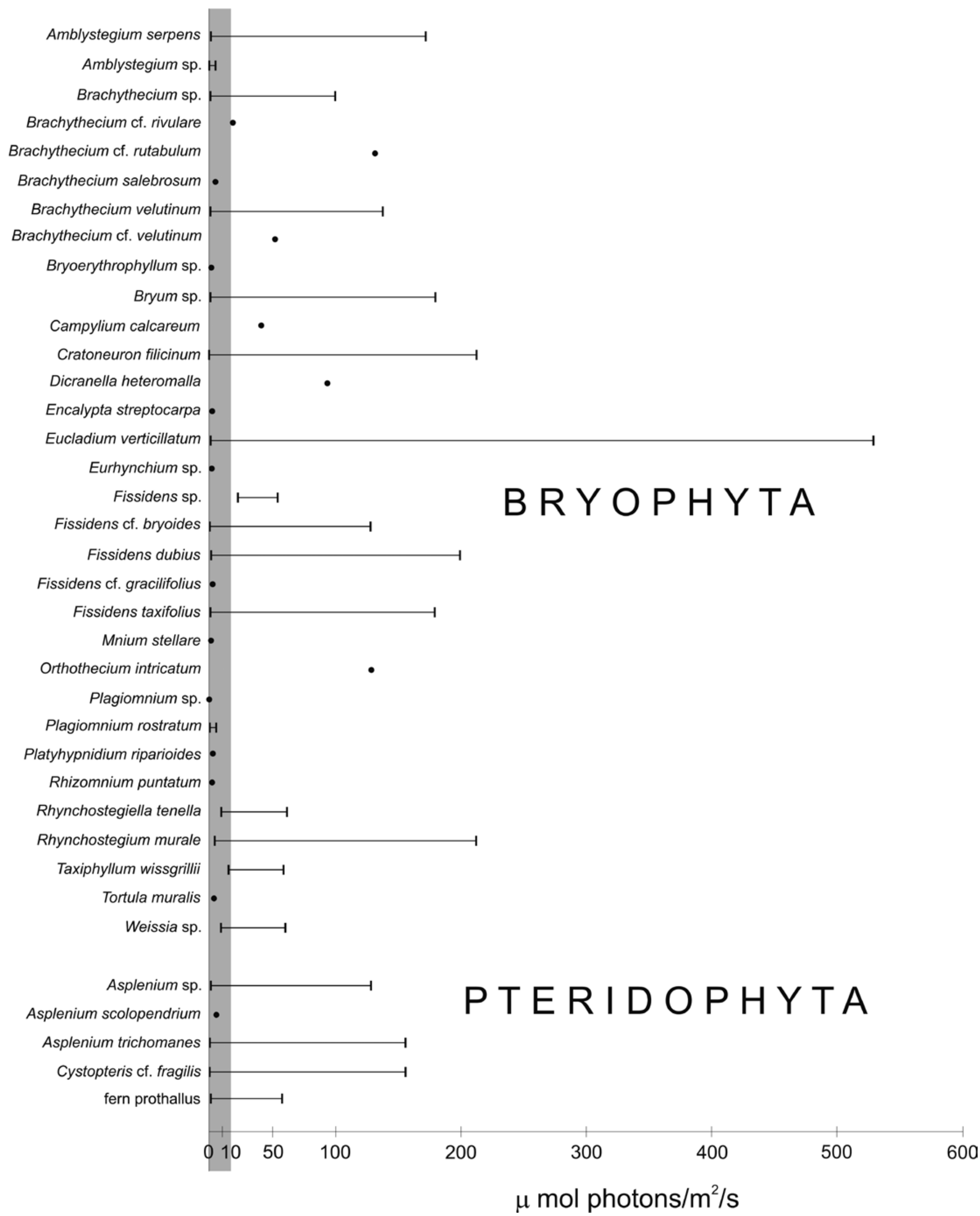

Fig. 3: Span of photosynthetic photon flux density for individual species of mosses and ferns identified in lampenflora community in Slovenian show caves. The second quartile (Q_2) is indicated with grey, i.e. 17 µmol photons/m²/s.

stant, but lower PPFDs and no physical removal of plants since establishing of electric illumination (Tab. 1).

Interestingly, lampenflora from Mežica clustered with Postojnska jama-Županova jama group in both analyses; average PPFD was 0.9 ±0.8 μmol photons/m^2/s with lights on 24 hrs per day. This indicates that bryophytes compensated extremely low PPFDs (0.2 – 2.7 μmol photons/m^2/s) with longer exposition to light irradiation. Furthermore, in Mežica *Cratoneuron filicinum* was identified with developed sporophyte at photon fluxes at 2.1 and 2.4 μmol photons/m^2/s. In Postojnska jama *Brachythecium salebrosum* was identified with fully developed sporophyte at PPFD of 4.7 μmol photons/m^2/s (Fig. 4A). Low PPFDs at which plants were collected indicate their low light compensation point in caves, equal or higher to the measured values. It is known that in extreme habitats light compensation point of bryophytes is similar to that of algal communities. For example in Antarctic lakes *Drepanocladus* s.l. had light compensation point of approximately 0.5 μmol photons/m^2/s and *Calliergon* in shallower water around 2.9 μmol photons/m^2/s (Glime 2007).

Communities of mosses from Pivka jama and Črna jama were not diverse and were represented by only three and one species, respectively. In these two caves development of moss lampenflora was still in initial phase, and as in 2003 no bryophytes were observed there (Mulec 2005).

Some bryophytes are able to grow over a relatively wide range of light intensities (Glime 2007). Light irradiation at which lampenflora in Slovenian show caves was sampled ranged from 0.2 to 530 μmol photons/m^2/s (first quartile Q_1=2, second quartile Q_2=17, third quartile Q_3=55 μmol photons/m^2/s). For some taxa PPFDs at which particular organism was identified varied a lot, especially *Eucladium verticillatum* (1.4-530.0 μmol photons/m^2/s), *Cratoneuron filicinum* (0.2-213.0 μmol photons/m^2/s), *Rhynchostegium murale* (4.7-213.0 μmol photons/m^2/s), *Fissidens dubius* (1.0-200.0 μmol photons/m^2/s), *Bryum* sp. (0.9-180.5 μmol photons/m^2/s), *Fissidens taxifolius* (1.4-150.5 μmol photons/m^2/s), *Amblystegium serpens* (1.0-172.5 μmol photons/m^2/s), *Brachythecium velutinum* (0.8-137.7 μmol photons/m^2/s), *Fissidens* cf. *bryoides* (0.9-128.9 μmol photons/m^2/s), and *Brachythecium* sp. (0.7-100.3 μmol photons/m^2/s). Among ferns *Cystopteris* cf. *fragilis* (0.4-160.0 μmol photons/m^2/s), *Asplenium trichomanes* (0.5-160 μmol photons/m^2/s) and *Asplenium* sp. (2.0-128.9 μmol photons/m^2/s) had the largest span of PPFD at which they were recorded (Fig. 3). In show caves bryophytes were found close to lamps where also temperature is higher due to heat emissions of lights.

Calcite precipitates accumulating on *Eucladium verticillatum* termed "eucladioliths" (Dalby 1966) can be found in Slovenian caves, too (Fig. 4B, compare with Fig. 4C).

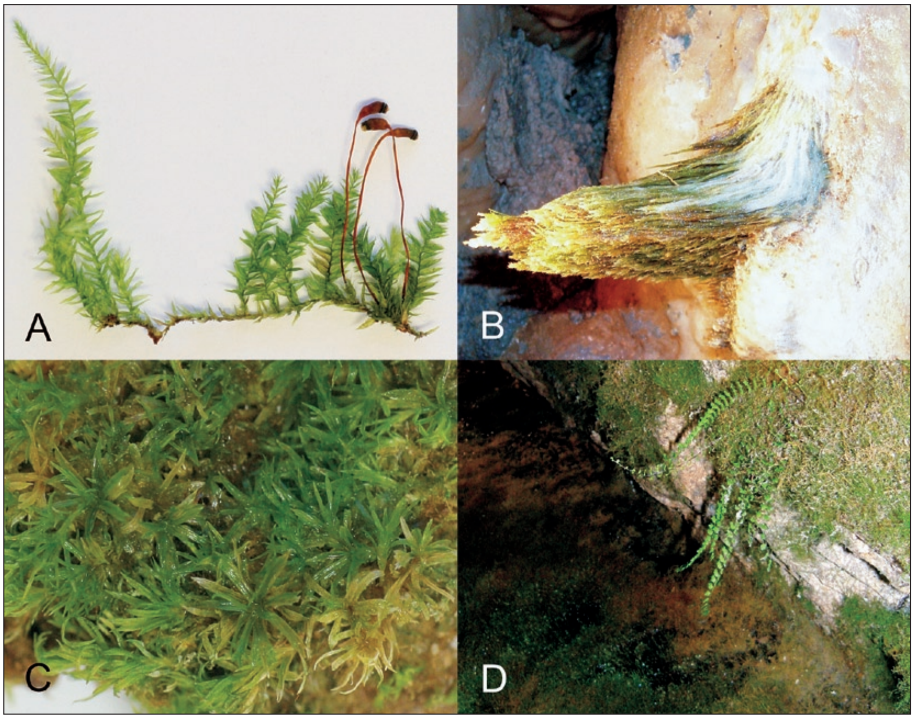

Fig. 4: Bryophytes from lampenflora communities (A-Brachythecium salebrosum with sporophyte from Postojnska jama, B-calcified Eucladium verticillatum, a biogenic plant-shoot speleothem growing towards lit lamp from Postojnska jama, C-Eucladium verticillatum from Škocjanske jame, D-lawn of mosses in Mežica mine, photo: S. Kubešová).

CONCLUSIONS

In eight Slovenian show caves and two mines equipped with electric illumination 37 taxa of Bryophyta and Pteridophyta were identified. The highest diversity of bryophytes was found in Mežica mine with 16 identified taxa indicating that lighting regime influenced diversity the most.

Light irradiation at which bryophyte lampenflora was recorded started from 0.2 and exceeded 500 µmol photons/m^2/s. For some organisms photosynthetic photon flux density at which particular organism grow, varies considerably. For example, PPFD which enables growth of *Eucladium verticillatum* ranged from 1.4 to 530.0 µmol photons/m^2/s.

For growth bryophytes compensate low PPFD with longer exposure to light irradiance. In Mežica mine *Cratoneuron filicinum* was identified with developed sporophyte at 2.1 and 2.4 µmol photons/m^2/s. Similarly in Postojnska jama *Brachythecium salebrosum* was identified with fully developed sporophyte at 4.7 µmol photons/m^2/s.

Using of highly toxic bleach (NaClO) which effectively kills lampenflora but has only transitory effect in preventing growth without efficient changes of lighting regime and light quality is thus questionable. Recolonization of lampenflora in caves is rather successful at sites which are exposed to long irradiance period and high PPFDs.

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