NAT. CROAT. | VOL. 29 | No 1 | 19-28 | ZAGREB | October 30, 2020

original scientific paper / izvorni znanstveni rad
DOI 10.20302/NC.2020.29.3

FLORA OF THE COBBLED STREETS AND PAVEMENTS IN THE MEDITERRANEAN OLD CITY OF DUBROVNIK DURING THE COVID-19 LOCKDOWN

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Jasprica, N. & Milović, M.: Flora of the cobbled streets and pavements in the Mediterranean Old City of Dubrovnik during the COVID-19 lockdown. Nat. Croat., Vol. 29, No. 1, 19-28, Zagreb, 2020.

The flora of the cobbled streets and pavements in the Old City of Dubrovnik, South Croatia, was studied in unusual circumstances with lack of trampling due to the Covid-19 lockdown in April 2020. The features of the flora through analyses of taxonomic composition, life forms, chorotypes and the phytosociological character of species found at eight sites in Dubrovnik Old City and along a transect line on the main street (Stradun) are reported. Altogether, 57 plant species and three subspecies were found. Therophytes, Cosmopolitans and taxa from the *Papaveretea rhoeadis* and *Chenopodietea* prevailed. The study highlights the importance of the investigation of both flora and vegetation within Dubrovnik's city historical centre.

Key words: eastern Adriatic, floristic survey, man-made habitats, Mediterranean, taxonomy

Jasprica, N. & Milović, M.: Flora na ulicama i pločnicima u dubrovačkoj staroj gradskoj jezgri u vrijeme karantene uzrokovane epidemijom COVID-19. Nat. Croat., Vol. 29, No. 1, 19-28, Zagreb, 2020.

U travnju 2020. istraživana je flora ulica i pločnika u staroj gradskoj jezgri u Dubrovniku tijekom razdoblja karantene uslijed epidemije COVID-19. U radu su opisane florističke značajke temljem analize taksonomskog sastava, životnih oblika, flornih elemenata i fitocenološke pripadnosti biljnih svojti na osam lokaliteta te na transektu uzduž Straduna. Ukupno je pronađeno 57 biljnih vrsta i tri podvrste. Najveći udio u flori imali su terofiti, kozmopoliti te svojte svojstvene vegetacijskim razredima *Papaveretea rhoeadis* i *Chenopodietea*. Studija ističe važnost istraživanja flore i vegetacije u povijesnoj jezgri grada Dubrovnika.

Ključne riječi: antropogena staništa, flora, istočni Jadran, Sredozemlje, taksonomija

INTRODUCTION

Dubrovnik is a city located on the eastern coast of the Adriatic Sea in South Croatia (42°39''N, 18°04''E). The city (historically known as *Ragusa*) was founded in the 7th century on a limestone hill that enclosed the bay of the Old City Port on the seaward side (Harris, 2006). The original core was expanded by filling the shallows that separated it from the mainland (today's Stradun or Placa). Two entrances to the Old City, Pile in the west and Ploče in the east, and the city walls (built over the centuries) define the image of the medieval town. The Old City (area of 0.15 km^2), in the shape of an irregular pentagon surrounded by walls, with the wide central Stradun Street and alleys, stairs and squares is the focus of the wider Dubrovnik area (Fig. 1). In 1979, the city of Dubrovnik

joined the UNESCO list of World Heritage Sites. Today, its total population is 42,600 (census 2011), with 1,557 inhabitants in the Old City center (internal census 2016).

Dubrovnik is one of the most prominent tourist destinations of the Mediterranean region. Croatia generally and Dubrovnik in particular has seen a steady annual growth in tourism over the past decade (Mrđa & Carić, 2019). In 2019, 1.44 million arrivals and 4.37 million overnights were recorded in Dubrovnik. Overcrowding by cruise tourism (the total number of cruise-ship visitors was 800,000 in 2019) threatens the degradation of both the environment and of particular historical sites (Carić & Mackelworth, 2014).

According to Köppen's climate classification (Köppen & Geiger, 1954; Sträβer, 1998) the city lies within the Csa climate zone, i.e. the *Quercetea ilicis* vegetation zone, where the climate is typically Mediterranean: mild and rainy winters, warm and dry summers, and an extended period of sunshine throughout the year. The average annual temperature is 16°C, while average annual rainfall is 1,294 mm (Jasprica *et al*., 2010).

In urban ecosystems, the structures of plant and animal communities are determined by both anthropogenic and natural processes (e.g. Szlavecz *et al*., 2011; Kowarik & von der Lippe, 2018, and references therein). In general, previous studies have advanced the understanding of urban flora in Dubrovnik (Jasprica *et al*., 2010, 2020), but full interpretation of floral diversity did not incorporate an analysis of both historical and recent city activity.

In this study we investigated the flora of the cobbled streets and pavements in the Old City of Dubrovnik in April 2020, when residents and visitors were absent from the streets due to the COVID-19 lockdown. Dubrovnik has not been so quiet and not-trampled since the 1990s war; in "normal" circumstances thousands upon thousands of feet would have been planishing the streets of the Old City. In these unusual circumstances, we were able for the first time to inventory the flora in the heart of the Old City. The object of our study was an analysis of flora based on taxonomic composition, life forms, chorotypes and the phytosociological character of plant species.

MATERIAL AND METHODS

The study was carried out over April 20-24, 2020. Eight sites were randomly chosen in different parts of the Old City of Dubrovnik, including a transect line along the main street (Stradun) (Fig. 1). The area of the sites (squares and streets) ranged from 250 m^2 (near the Cathedral) to 1,900 m^2 (Stradun) (Fig. 2E). In this study, the flora on the vertical wall surfaces was not studied (see Jasprica *et al*., 2020), since we were interested in the lack of feet, i.e. the normal wear to which the ancient pavement stones of the Old City are subjected.

Taxa were determined using the standard determination keys, books and guides reported in Jasprica & Milović (2016) and Milović *et al.* (2016). The taxa in the list are given in alphabetical order of genera and species. Biological form was reported according to categories given in Pignatti (1982), these being based in turn on the classification of Raunkiaer (1934). Regarding chorological forms, reference was made to Jasprica *et al*. (2017, and references therein). The nomenclature of plant taxa follows the Euro+Med PlantBase (Euro+Med, 2006–2020), except for *Campanula austroadriatica* D.Lakušić & Kovačić where the International Plant Names Index was applied (IPNI, 2020). Taxa are associated with vegetation units (classes) using the system of characterizing species reported by Mucina *et al*. (2016) (i.e., for those plants that are considered

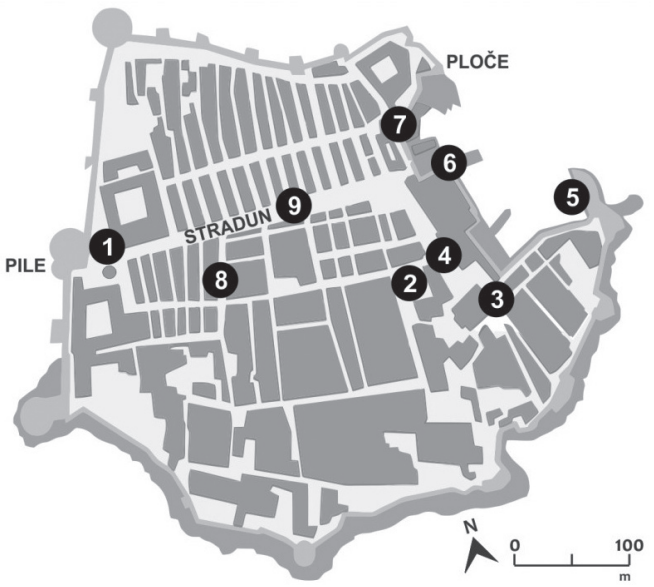

Fig. 1. Position of the study sites on the cobbled streets and pavements within the Old City of Dubrovnik, April 2020: 1 – Large Onofrio Fountain, 2 – Gundulić Square, 3 – Cathedral, 4 – Rector's Palace, 5 – Porporela, St John Fortress, 6 – Old Port area and Luža Square, 7 – Dominican Monastery, 8 – Široka Street, 9 – Stradun (Placa).

'characteristic species' of the classes, see Electronic Appendix S6). The nomenclature of vegetation units also follows Mucina *et al*. (2016).

The neophytes reported in this study were adjusted according to Nikolić (2020). To indicate the degree of naturalization (the invasion status) of a taxon, we have used the terms casual, naturalized and invasive, following the definition of Richardson *et al*. (2000). The assessment of the degree of naturalization was made according to Boršić *et al*. (2008) refined by Nikolić *et al*. (2014) and Nikolić (2020).

RESULTS

In the Old City of Dubrovnik, 60 taxa (57 species and three subspecies) of native and naturalized vascular plants within 25 families and 54 genera were noted (Tab. 1). Families with the highest number of taxa were *Compositae* (eight taxa, or 13%), *Caryophyllaceae* (seven, 12 %) and *Poaceae* (five, 8%).

The flora is dominated by therophytes (40 taxa, 67%) and hemicryptophytes (11.18%) followed by geophytes, chamaephytes and phanerophytes (five taxa in each, or 5%).

The Cosmopolitans (20 taxa, 33%) followed by a considerable proportion of Mediterranean plants (17.29%) dominated the flora. Cultivated and adventive plants, South European and Euroasian geographic elements contributed 15%, 13% and 10%, respectively.

The most frequent taxa were *Parietaria judaica* and *Erigeron sumatrensis* (found at all sites except on Stradun) followed by *Polycarpon tetraphyllum* (seven sites), and *Ochlopoa annua* and *Cymbalaria muralis* (each found at five sites). The number of taxa on the sites

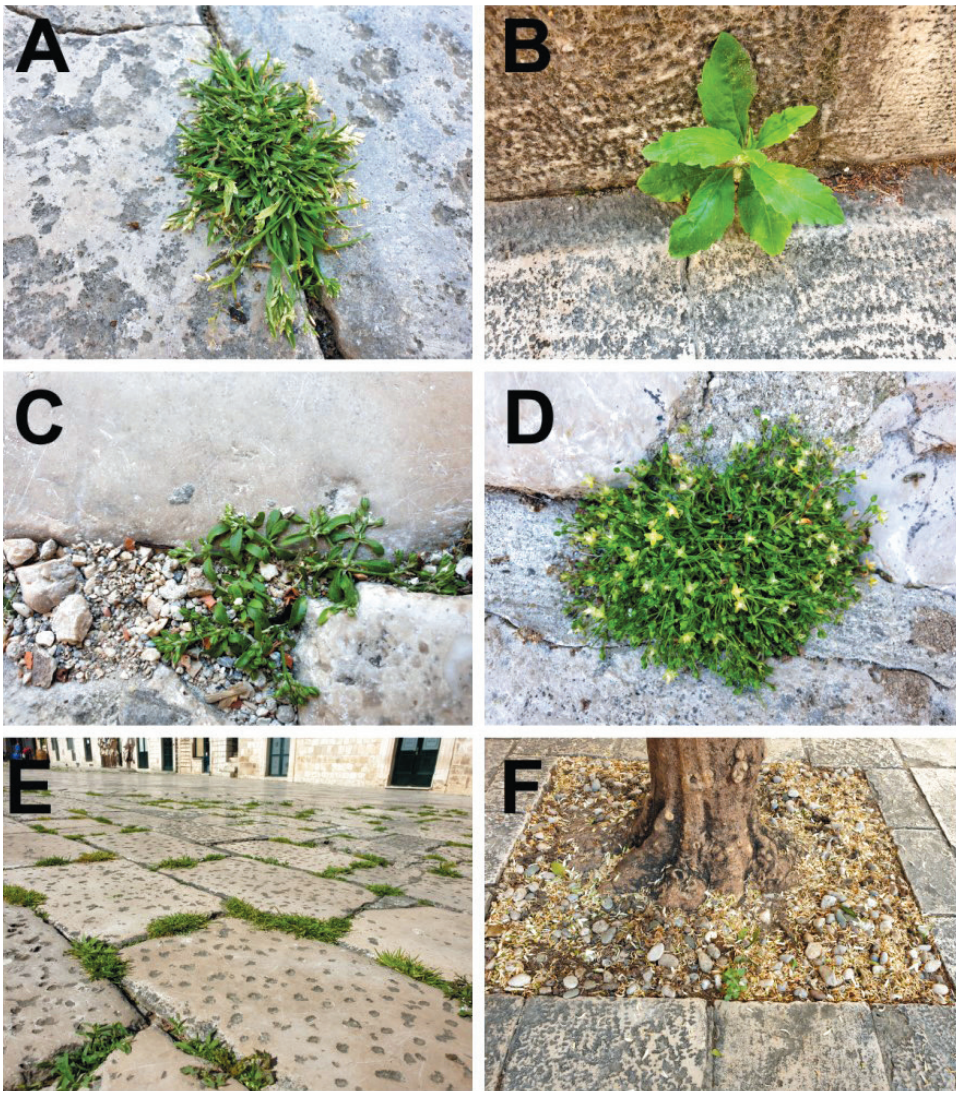

Fig. 2. Some plant species found on the cobbled streets and pavements in the Old City of Dubrovnik in April 2020: A – *Ochlopoa annua* (L.) H.Scholz, B – *Erigeron sumatrensis* Retz., C – *Polycarpon tetraphyllum* (L.) L., D – *Sagina maritima* Don, E – spontaneous overgrowth of vegetation occurs in the Old City: the Gundulić Square, F – only *Parietaria judaica* L. and *Portulaca oleracea* L. were found in a tree circle near the Large Onofrio Fountain, Site 1 (see Šilc *et al*., 2020) (Photo: N. Jasprica).

was between three and 28, with an average of 14 taxa (SD ± 7.7); the highest was on Gundulić Square (28) and at the Large Onofrio Fountain (19) and the lowest was in front of the Rector's Palace (3). Along a transect line on Stradun, only five species were noted, exclusively beside manholes or gratings. Only *Parietaria judaica* and *Portulaca oleracea* were found in two tree-circles located near the Large Onofrio Fountain, Site 1 (see Šilc *et al*., 2020, Fig. 2F).

Tab. 1. The list of the vascular plant taxa found *on the cobbled streets and pavements* in the Old City of Dubrovnik in April 2020. Names of taxa are arranged in the alphabetical order, followed by the family, life form (LF), floral element (FE), status (S) and origin of neophytes (OR; displayed on a gray background), and vegetation class (VC; *sensu* Mucina *et al*. 2016, Electronic Appendix S6). Site codes: 1 – Large Onofrio Fountain, 2 – Gundulić Square, 3 – Cathedral, 4 – Rector's Palace, 5 – Porporela, St John Fortress, 6 – Old-Port area and Luža Square, 7 – Dominican Monastery, 8 – Široka Street, 9 – Stradun (Placa). Life forms (L): Ch – chamaephytes, G – geophytes, H – hemicryptophytes, P – phanerophytes, T – therophytes. Floral elements (FE): CUAD – Cultivated and adventive plants, EA – Euroasian, MED – Mediterranean, SEU – South European, WS – Cosmopolitans. Invasion status (S): cas – casual, nat – naturalized, inv – invasive. Origin of neophytes (OR): Am – Americas, As – Asia, Af – Africa.

Taxon	Records from sites	Family	LF	FE	S	OR	VC
Adiantum capillus-veneris L.	5, 8, 9	Pteridaceae	G	MED			*Adiantetea*
Ajuga chamaepitys (L.) Schreb.	1	Lamiaceae	T	MED			*Papaveretea rhoeadis*
Amaranthus deflexus L.	6	Amaranthaceae	T	CUAD	inv	Am	*Digitario sanguinalis-Eragrostietea minoris*
Anthemis arvensis L.	3, 4, 5	Compositae	T	WS			*Papaveretea rhoeadis*
Antirrhinum majus L.	3, 7	Plantaginaceae	Ch	CUAD			*Cymbalario-Parietarietea diffusae*
Arenaria leptoclados (Rchb.) Guss.	3, 5	Caryophyllaceae	T	EA			*Festuco-Brometea*
Arenaria serpyllifolia L.	3	Caryophyllaceae	T	WS			*Sedo-Scleranthetea*
Atriplex prostrata DC.	6	Chenopodiaceae	T	WS			*Crithmo-Staticetea*
Campanula austroadriatica D.Lakušić & Kovačić*	1, 3, 7, 8	Campanulaceae	T	MED			*Asplenietea trichomanis*
Catapodium marinum (L.) C.E. Hubb.	5	Poaceae	T	MED			*Saginetea maritimae*
Celtis australis L.	1	Ulmaceae	T	SEU			*Quercetea pubescentis*
Chenopodium album L.	1, 6	Chenopodiaceae	T	WS			*Sisymbrietea*
Crepis sancta (L.) Bornm.	3	Compositae	T	MED			*Chenopodietea*
Crithmum maritimum L.	5, 6	Apiaceae	Ch	MED			*Crithmo-Staticetea*
Cymbalaria muralis P.Gaertn., B.Mey. & Scherb.	1, 2, 6, 7, 8	Plantaginaceae	H	SEU			*Cymbalario-Parietarietea diffusae*
Cynodon dactylon (L.) Pers.	2, 3, 4,	Poaceae	G	WS			*Polygono-Poetea annuae*
Draba verna L	3	Brassicaceae	T	WS			*Sedo-Scleranthetea*
Eleusine indica (L.) Gaertn.	2	Poaceae	T	CUAD	inv	Af	*Digitario sanguinalis-Eragrostietea minoris*
Erigeron sumatrensis Retz.	1, 2, 3, 5, 6, 7, 8, 9	Compositae	T	CUAD	inv	Am	*Digitario sanguinalis-Eragrostietea minoris*
Erodium cicutarium (L.) L'Hér.	2, 3	Geraniaceae	T	WS			*Sisymbrietea*
Euphorbia maculata L.	1	Euphorbiaceae	T	CUAD	inv	Am	*Digitario sanguinalis-Eragrostietea minoris*
Ficus carica L.	5, 6	Moraceae	P	MED			*Cymbalario-Parietarietea diffusae*
Galium murale (L.) All.	3	Rubiaceae	T	MED			*Chenopodietea*
Geranium rotundifolium L.	1	Geraniaceae	T	EA			*Sisymbrietea*
Herniaria glabra L.	3	Caryophyllaceae	T	EA			*Polygono-Poetea annuae*
Hyoscyamus albus L.	3, 7	Solanaceaee	T	MED			*Sisymbrietea*
Jacobaea maritima (L.) Pelser & Meijden	6	Compositae	Ch	MED			*Crithmo-Staticetea*
Lamium amplexicaule L.	3	Lamiaceae	T	EA			*Papaveretea rhoeadis*
Lobularia maritima (L.) Desv.	3, 9	Brassicaceae	H	CUAD			*Ammophiletea*

Tab. 1. Continued

Taxon	Records from sites	Family	LF	FE	S	OR	VC
Lycopersicon esculentum Mill.	1	Solanaceae	T	CUAD	cas	Am	*Bidentetea*
Medicago lupulina L.	3, 6	Fabaceae	T	WS			*Artemisietea vulgaris*
Medicago prostrata Jacq.	1,	Fabaceae	H	SEU			*Festuco-Brometea*
Misopates orontium (L.) Raf.	1, 7	Scrophulariaceae	T	EA			*Sisymbrietea*
Ochlopoa annua (L.) H. Scholz	2, 5, 6, 8, 9	Poaceae	T	WS			*Polygono-Poetea annuae*
Oxalis articulata Savigny	2	Oxalidaceae	G	CUAD	cas	Am	*Artemisietea vulgaris*
Oxalis corniculata L.	3, 8	Oxalidaceae	H	WS			*Papaveretea rhoeadis*
Parietaria judaica L.	1, 2, 3, 4, 5, 6, 7, 8	Urticaceae	H	SEU			*Cymbalario-Parietarietea diffusae*
Plantago lanceolata L.	1	Plantaginaceae	H	WS			*Artemisietea vulgaris*
Plantago major L. ssp. *intermedia* (Gilib.) Lange	1, 3, 7	Plantaginaceae	H	WS			*Molinio-Arrhenatheretea*
Polycarpon tetraphyllum (L.) L.	1, 2, 3, 5, 6, 8, 9	Caryophyllaceae	T	SEU			*Polygono-Poetea annuae*
Polygonum depressum Meisn.	2, 7	Polygonaceae	T	WS			*Polygono-Poetea annuae*
Portulaca oleracea L.	6	Portulacaceae	T	WS			*Digitario sanguinalis-Eragrostietea minoris*
Rostraria cristata (L.) Tzvelev	5	Poaceae	T	MED			*Chenopodietea*
Rumex pulcher L.	3, 6	Polygonaceae	H	SEU			*Chenopodietea*
Sagina maritima Don	5, 6	Caryophyllaceae	T	MED			*Saginetea maritimae*
Saxifraga tridactylites L.	3	Saxifragaceae	T	WS			*Sedo-Scleranthetea*
Senecio vulgaris L.	3	Compositae	T	WS			*Papaveretea rhoeadis*
Sonchus asper (L.) Hill ssp. *glaucescens* (Jord.) Ball	7	Compositae	H	MED			*Chenopodietea*
Sonchus oleraceus L.	3, 6, 7	Compositae	T	WS			*Papaveretea rhoeadis*
Spergularia marina (L.) Griseb.	1, 2	Caryophyllaceae	T	WS			*Saginetea maritimae*
Stellaria media (L.) Cirillo	2, 3,	Caryophyllaceae	T	WS			*Papaveretea rhoeadis*
Taraxacum officinale agg. F.H. Wigg.	2,	Compositae	H	WS			*Molinio-Arrhenatheretea*
Theligonum cynocrambe L.	1, 3	Rubiaceae	T	SEU			*Chenopodietea*
Trifolium nigrescens Viv.	1	Fabaceae	T	MED			*Chenopodietea*
Ulmus pumila L. (*U. pinnato-ramosa* Dieck ex Koehne)	3	Ulmaceae	P	CUAD	nat	As	.
Valantia muralis L.	1	Rubiaceae	T	MED			*Chenopodietea*
Veronica arvensis L.	3	Scrophulariaceae	T	EA			*Papaveretea rhoeadis*
Veronica cymbalaria Bodard	6	Scrophulariaceae	T	SEU			*Cymbalario-Parietarietea diffusae*
Viola suavis M.Bieb. ssp. *austrodalmatica* Mereda & Hodálová	7	Violaceae	H	MED			*Asplenietea trichomanis*
Vitex agnus-castus L.	5	Lamiaceae	P	MED			*Nerio-Tamaricetea*

Two taxa (*Campanula austroadriatica*, *Viola suavis* ssp. *austrodalmatica*) are considered to be endemic, belonging to the group of Illyrian-Adriatic endemics (Nikolić *et al*., 2015; Nikolić, 2020). In addition, two statutorily strictly protected taxa, as statutorily defined in Croatia (*Catapodium marinum*, *Viola suavis* ssp. *austrodalmatica*), are also noted (Anonymous, 2013ab). Additionally, *Catapodium marinum* is a vulnerable (VU) taxon and listed in the Red Book of Vascular Flora of Croatia (Nikolić & Topić, 2005; Nikolić, 2020; IUCN, 2020).

Six neophytes were recorded. Among them, the most frequent (present at all sites, except on Stradun) was *Erigeron sumatrensis* (Tab. 1, Fig. 2B). Up to four taxa found in the Old City are considered to be invasive in Croatian territory.

In the phytosociological spectrum, the largest element was made up of taxa from *Papaveretea rhoeadis* and *Chenopodietea* (eight taxa in each, i.e. 13%), followed by taxa from *Digitario sanguinalis-Eragrostietea minoris*, *Polygono-Poetea annuae*, *Cymbalario-Parietarietea diffusae* and *Sisymbrietea* (five taxa in each, 10%).

DISCUSSION

Although the territory of the city of Dubrovnik includes a wide range of habitats, we have restricted the survey of the area in the Old City to the time in which anthropogenic influences were extremely low. In this study, the location of investigated sites in the Old City of Dubrovnik was mostly in concordance with a heritage crowding map of the sites based on remoteness, area size, area shape, visitor perception and attraction quality (Mrđa & Carić, 2019: 172). However, we did not estimate the relationship between flora richness and area at particular sites.

In this ecological niche (pavements and squares), the soil is spatially confined and, unlike semi-natural soils, temperatures are always quite high given the close contact with stone materials. These habitats exhibit strong drying conditions and soil compaction due to trampling (Lehmann, 2006).

Therophytes were dominant in the life-form spectrum, as has been previously reported for the flora of anthropogenic habitats subjected to strong human pressure (see e.g., Salinitro *et al*., 2018, and references therein). This is not unexpected, as their short generation time and high number of easily dispersed seeds make therophytes very effective colonizers with high tolerance to disturbance. The life-form distribution retains a similarity with the spectrum of the regional pool (e.g., Milović, 2002, etc.). Future studies in the area will show whether the perennials (e.g., *Cynodon dactylon*) take over the dominant role at these sites later in the year (Grime, 1979).

The high percentage contribution of Cosmopolitans suggests a high degree of human impact, while co-domination of Mediterranean taxa shows that the Mediterranean climate acts only partially as a strong ecological filter (e.g., Dunnett & Hitchmough, 2004). Generally, these taxa have a significant influence on the physiognomy of this type of man-made habitat.

Additionally, the phytosociological spectrum, and in particular a considerable participation of taxa from the *Papaveretea rhoeadis* and *Chenopodietea* classes, alongside others, indicates that the flora of the studied sites does not retain links with the plant communities of its biogeographic context. Interestingly, the most frequent taxa (e.g., *Parietaria judaica*, *Erigeron sumatrensis* and *Polycarpon tetraphyllum*) are associated with different classes, and they vary considerably according to the type of disturbance, differing at a higher level according to disturbance type.

The Old City of Dubrovnik hosts some endemics and protected entities. To allow species to thrive in urban areas, management of green spaces and weed control in impermeable areas should take into account the biology and phenology of these species. On the other hand, these plants colonize stone monuments causing conservation problems.

In the present study, neophytes contributed 10 % of identified flora. This is only partly consistent with the proportion of neophytes in urban flora of the main Croatian coastal cities (Jasprica *et al*., 2010, 2017; Milović & Mitić, 2012). In general, the pattern of neophytes is most strongly influenced by site conditions (Šilc *et al*., 2012). Alongside these, in COVID-19 circumstances, the thousands and thousands of visitors that might have been carrying adventive species on the soles of their shoes were absent.

We are aware that this study covers only a small part of the important aspects of floristic investigations. It contributes to the knowledge of pavement flora during low anthropogenic influence when the spontaneous overgrowth of vegetation also occurred (Fig. 2E). However, data obtained here need to be extended with further investigation later in spring or summer when thermophilic trampled habitats can more usefully be investigated in the Mediterranean macrobioclimate (e.g., Čarni & Jogan, 1998). From a purely scientific standpoint, it will be intriguing to define species richness and their phytosociology, present at the same sites in the Old City after the tourist season (i.e., in October 2020), and again next in April 2021, if times get "normal" again. Then, our analysis will contribute to the establishment of a broader understanding of the management and conservation potential of this habitat type. Generally, the flora and vegetation of Dubrovnik city's historical centre have not figured prominently and deserve further investigation.

ACKNOWLEDGEMENTS

The first author sincerely thanks colleague Dr Mirna Batistić for her support and friendship in early stage of the study. We also thank Steve Latham (UK) for improving the English and the two anonymous reviewers for their helpful comments and the editor for their efforts in improving this report.

Received May 1, 2020

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