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SPONTANEOUS VEGETATION ON SLAG HEAPS IN SOUTHERN CROATIA

Nenad JASPRICA
Institute for Marine and Coastal Research, University of Dubrovnik, P.O. Box 83, HR-20000 Dubrovnik, Croatia
e-mail: nenad.jasprica@unidu.hr

Marija PANDŽA
Primary School Murterski Škoji, Put Škole 8, HR-22243 Murter, Croatia

Milenko MILOVIĆ
"Antun Vrančić" Grammar School, Put Gimnazije 64, HR-22000 Šibenik, Croatia

ABSTRACT

A phytosociological investigation of spontaneous vegetation on seven-year-old ferro-manganese and silico-manganese slag heaps in southern Croatia showed a predominance of ruderals and weeds (Chenopodietea, Artemisietea vulgaris) *and taxa of dry open habitats* (Festuco-Brometea, Sedo-Scleranthetea). *The limited number and cover of woody taxa seem to indicate an early successional stage in the process of development of natural vegetation. However, we recommend removing the heaps from the area and initiating soil remediation according to Croatian law, EU standards and obligations.*

Key words: phytosociology, ruderal vegetation, industrial waste, Mediterranean climate, Dalmatia, eastern Adriatic

VEGETAZIONE SPONTANEA SU ACCUMULI DI SCORIE NELLA CROAZIA MERIDIONALE

SINTESI

Lo studio fitosociologico della vegetazione spontanea su accumuli di scorie di ferro-manganese e silico-manganese nel sud della Croazia, risalenti a sette anni addietro, ha messo in evidenza una predominanza di specie ruderali e infestanti (Chenopodietea, Artemisietea vulgaris) *e di taxa di habitat aridi e aperti* (Festuco-Brometea, Sedo-Scleranthetea). *Inoltre, un limitato numero di taxa arborei e arbustivi, con ridotta copertura, suggerisce l'insediarsi di un primo stadio della successione nel processo di sviluppo della vegetazione. Tuttavia si consiglia la rimozione degli accumuli di scorie dall'area e l'avvio della bonifica dei suoli, come previsto dalle leggi croate e secondo gli standard e gli obblighi dell'Unione Europea.*

Parole chiave: fitosociologia, vegetazione ruderale, rifiuti industriali, clima mediterraneo, Dalmazia, Adriatico orientale

INTRODUCTION

The Electrodes and Ferroalloys Factory (TEF) in the city of Šibenik, southern Croatia, is a former factory in which the production of pig iron, steel and ferrous alloys took place almost throughout the 20th century, ceasing in 1995. With the decommissioning of the facilities at the TEF site (total surface area of 22 hectares) various types of waste, such as ferro-manganese and silico-manganese slag, tar, phenolic residues, carborundum, graphite electrode scraps, etc. were left at the site. In the period from May 2010 to February 2011, a total of 140,000 tons of ferro-manganese and silico-manganese slag were moved to the village of Biljane Donje near the city of Zadar (Fig. 1). In recent times, only a smaller area with ca. 6,000 m^3 of the slag can still be found at the former TEF site in the city of Šibenik. Slag is typically dumped in heaps with no subsequent remediation.

Dumping sites for ash and slag waste represent a major challenge in terms of biological reclamation and introduction of vegetation. This is due to the disadvantageous properties of such waste, including the absence of soil organic matter (SOM), as well as nitrogen deficiency, high compaction, poor air-water ratio and high alkaline reaction (Kovář, 2004). The onset and development of vegetation at localities of such origin are important topics in restoration ecology (Rehounkova et al., 2011; Prach et al., 2014. and references therein). Such localities offer a unique opportunity for monitoring spontaneous processes of colonization/succession of organisms on these "artificial islands" and following biotic interactions in the process (Prach & Pyšek, 1994).

Fig. 1: Geographical position of the study areas in southern Croatia, eastern Adriatic.
Sl. 1.: Geografska lega raziskanega območja v južni Hrvaški, vzhodni Jadran.

In the NW Balkans, studies of spontaneous vegetation development in these habitats, based on phytosociological research, including description of particular plant associations, have been reported from Bosnia and Herzegovina (Lakušić *et al.*, 1977, 1978; Grgić & Lakušić, 1987) and Montenegro (Vukičević & Avdalović, 1982). In Croatia, such sites are still awaiting phytosociological investigation. The matter is addressed by the present study, which examines spontaneous vegetation on seven-year-old slag heaps in southern Croatia.

MATERIAL AND METHODS

Study area

The study was carried out in southern Croatia, in two areas: 1) the area of TEF situated in the city of Šibenik (43°44′43.1″ N, 15°52′56.9″ E), and 2) the landfill in the village of Biljane Donje, situated 20 kilometres east of the city of Zadar (44°05′47.9″ N, 15°28′55.5″ E) (Figs. 1 and 2). The slag heaps on the two sites originated from the production of ferroalloys in TEF, and have not been moved or replaced in the last seven years. The altitude of the sites is ca. 10 and 180 m a.s.l. in Šibenik and Biljane Donje, respectively. The heaps top out at about 1.5(–2) to 15 m above the level of the ground. The region has a typical Mediterranean climate: summers are warm and dry, winters mild and rainy, mean annual temperature 15.0–15.4 °C and mean annual precipitation 773–860 mm (data from the meteorological stations of the Croatian Meteorological and Hydrological Service in Šibenik and Zadar for the 1976–2006 period; Milović, 2008; Jasprica *et al.*, 2015). The vegetation surrounding the landfill in Šibenik is mainly composed of planted *Pinus halepensis* and urban ruderal plant communities (Milović, 2002). In Biljane Donje, the vegetation surrounding the landfill is a mosaic of preserved forest patches (mainly dominated by *Carpinus orientalis* and *Quercus pubescens*) and vineyards.

In general, the slag on the sites is alkaline (the pH of the substrate in initial successional stages is 8–9), with a low manganese content (MnO < 20 %) and about 30 % of Si produced by upgrading standard alloy through addition of silicon waste from the iron silicon industry at the end of the ferroalloy production process (Oliveira *et al.*, 2017).

Data collection

Fieldwork was carried out in May 2018. The Braun-Blanquet approach (Braun-Blanquet, 1964; Barkman *et al.*, 1964; Dierschke, 1994) was used for data collection, with category 2 subdivided into 2m, 2a and 2b. Five and four relevés were collected in Šibenik and Biljane Donje, respectively. The plots were selected randomly within each site and the entire surface of the landfills was covered. The size of relevé plots was 25 m^2. The

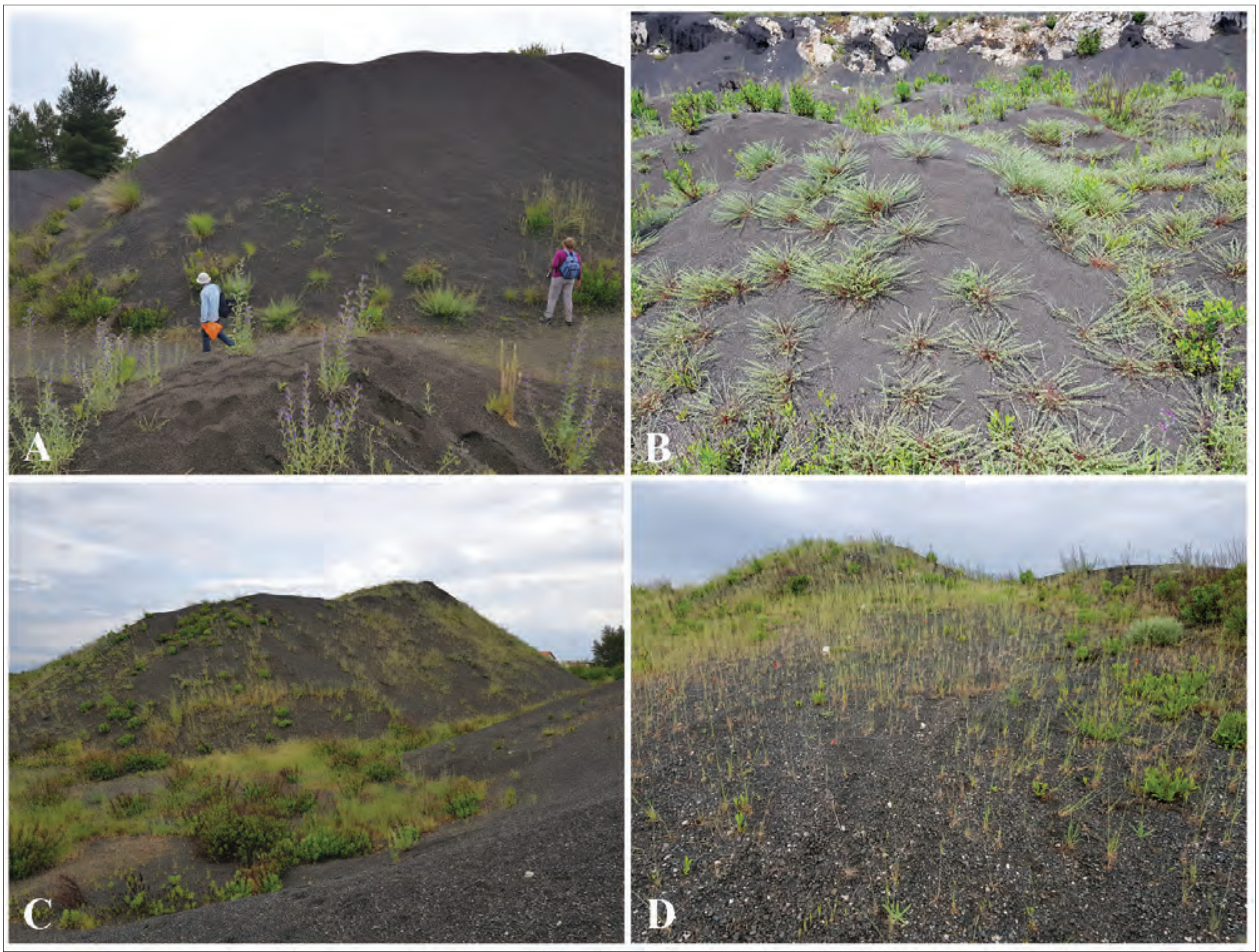

Fig. 2: Ferro-manganese and silico-manganese slag heaps in the area of the former Electrodes and Ferroalloys Factory in the city of Šibenik (A); details of vegetation with *Andrachne telephioides* ***and*** *Dittrichia viscosa* ***in Šibenik (B); heaps in the village of Biljane Donje, Zadar County (C), details of vegetation with*** *Avena barbata* ***and*** *Dittrichia viscosa* ***at the top of a heap in Biljane Donje (D) (Photo: N. Jasprica, May 5, 2018).***

Sl. 2: Feromanganska in silikomanganska jalovina v predelu nekdanje tovarne elektrod in železovih zlitin v Šibeniku (A); detajl vegetacije z vrstama *Andrachne telephioides* ***in*** *Dittrichia viscosa* ***v Šibeniku (B); jalovina v zaselku Biljane Donje v zadrskem okrožju (C), detajl vegetacije z vrstama*** *Avena barbata* ***and*** *Dittrichia viscosa* ***na vrhu jalovine v zaselku Biljane Donje (D) (Foto: N. Jasprica, 5 maj 2018)***

nomenclature of plant taxa follows the *Flora Croatica Database* (Nikolić, 2018). The biological forms were directly verified in the field, labelled with acronyms reported by Pignatti (1982) and based on the classification by Raunkiaer (1934). Regarding chorological forms, reference was made to Jasprica *et al.* (2017), as well as monographs used for taxonomic nomenclature.

Taxa were associated with vegetation units (classes). The system of characterizing species (mostly for those plants that are considered 'characteristic species' of the classes) was mostly derived from Mucina *et al.* (2016). The nomenclature of vegetation units followed Škvorc *et al.* (2017). Constant taxa were defined as those with a frequency 30 % within the vegetation unit. Dominant taxa were defined as those occurring in at least 10 % of the relevés of a vegetation unit with a cover value of 25 %.

RESULTS

There were 64 plant taxa in total (Tab. 1). The vegetation cover varied from 30 % to 80 %, while stands appeared on slopes ranging from 10° to 80°.

The landfills were dominated by Therophytes (57 %) and Hemicryptophytes (28 %). Phanerophytes and Chamaephytes occurred in equal percentages (5 % each).

Mediterranean floral elements (34 %), followed by a considerable share of Cosmopolitans (16 %) and

Tab. 1: Phytosociological table of vegetation on the ferro-manganese and silico-manganese slag heaps. Abbreviations: LF = life form, FE = floral element. Life forms: Ch - chamaephytes, G - geophytes, H - hemicryptophytes, P - phanerophytes, T - therophytes. Floral elements: MED - Mediterranean; SEU - South European; EA - Euroasian; WS - Cosmopolitan; CUAD - Cultivated and adventive plants; * - Illyrian-Adriatic endemic taxon.

Tab. 1: Fitosociološka preglednica vegetacije na feromanganski in slikomanganski jalovini. Okrajšave: LF = življenjska oblika, FE = floristični element. Življenjske oblike: Ch – hamefiti, G – geofiti, H – hemikriptofiti, P – fanerofiti, T – terofiti (enoletnice). Floristični elementi: MED – sredozemski, SEU – južnoevropski, EA – evrazijski, WS – kozmopoliti, CUAD – gojene in adventivne rastline, * - ilirsko-jadranski endemit.

Date and location of the relevés/ Datumi in lokalitete popisov: May 5, 2018. Rels. 1-5, Šibenik: Rel. 1. X = 5571400, Y = 4845052; Rel. 2. X = 5571390, Y = 4845085; Rel. 3. X = 5571443, Y = 4845104; Rel. 4. X = 5571441, Y = 4845092; Rel. 5. X = 5571431, Y = 4845006. Rels. 6-9. Biljane Donje, near Zadar: Rel. 6. X = 5538978, Y = 4883653; Rel. 7. X = 5538952, Y = 4883659; Rel. 8. X = 5538959, Y = 4883693; Rel. 9. X = 5538978, Y = 4883713.

		Relevé No.	1	2	3	4	5	6	7	8	9	
		Locality	Šibenik					Biljane Donje				
		Plot size (m²)	25	25	25	25	25	25	25	25	25	
		Aspect	N	NE	.	NE	NE	N	S	W	W	
LF	FE	Slope (°)	10	55	.	70	80	70	70	40	80	
		Vegetation cover (%)	70	50	70	40	30	60	80	80	80	
		Total number of taxa	20	16	10	17	17	17	12	21	16	%
		Chenopodietea										
T	SEU	*Avena barbata* Pott ex Link	3	1	.	+	+	1	3	2a	2m	88
T	MED	*Echium plantagineum* L.	+	.	2a	.	.	+	3	+	+	66
H	MED	*Reseda alba* L.	.	+	.	.	.	+	1	+	+	55
T	MED	*Bromus madritensis* L.	1	.	.	+	+	.	.	.	.	33
T	MED	*Desmazeria rigida* (L.) Tutin	+	.	.	.	.	+	.	+	.	33
T	MED	*Aegilops neglecta* Req. ex Bertol.	.	+	.	.	+		.	+	.	33
H	MED	*Carduus pycnocephalus* L.	.	.	.	+	.	+	.	r	.	33
T	MED	*Lophochloa cristata* (L.) Hyl.	2a	.	.	.	.	.	.	+	.	22
T	MED	*Aegilops triuncialis* L.	+	.	.	.	.	.	.	+	.	22
T	MED	*Crepis sancta* (L.) Babc.	.	.	.	+	.	.	.	.	+	22
T	SEU	*Geranium purpureum* Vill.	.	.	.	.	2a	.	.	.	+	22
T	MED	*Medicago orbicularis* (L.) Bartal.	.	.	.	.	.	.	.	+	+	22
T	MED	*Sonchus asper* (L.) Hill ssp. *glaucescens* (Jord.) Ball	.	+	.	.	.	.	.	.	.	11

T	MED	*Urospermum picroides* (L.) Scop. ex F.W.Schmidt	.	.	.	.	.	.	.	.	r	11
		Festuco-Brometea										
H	EA	*Melica ciliata* L.	.	+	+	1	+	2b	+	.	.	66
T	EAF	*Arenaria leptoclados* (Reichenb.) Guss.	+	.	.	.	.	.	.	r	.	22
H	*	*Centaurea spinosociliata* Seenus	.	+	.	.	.	.	.	+	.	22
H	SEU	*Sanguisorba minor* Scop. ssp. *muricata* Briq.	.	.	+	+	.	.	.	.	.	22
H	SEU	*Lactuca viminea* (L.) J. et C. Presl	.	.	.	.	.	+	.	.	r	22
H	MED	*Tragopogon porrifolius* L.	.	.	.	.	.	+	.	.	.	11
T	MED	*Lomelosia brachiata* (Sm.) Greuter et Burdet (= *Trenastelma palaestinum*)	.	.	.	.	.	.	1	.	.	11
		Artemisietea vulgaris										
H	MED	*Dittrichia viscosa* (L.) Greuter	.	2a	2a	1	.	2b	1	2b	.	66
H	EA	*Chondrilla juncea* L.	.	.	.	+	+	.	.	+	+	44
H	WS	*Reseda lutea* L.	.	.	+	+	+	.	.	.	.	33
H	EA	*Picris hieracioides* L.	.	.	.	.	.	+	.	.	.	11
T	WS	*Galium aparine* L.	.	.	.	.	.	.	.	.	+	11
H	EA	*Cirsium vulgare* (Savi) Ten.	.	.	.	.	.	.	.	.	r	11
		Sedo-Scleranthetea										
T	WS	*Medicago minima* (L.) Barta	+	+	.	.	.	.	.	3	.	33
T	WS	*Cerastium pumilum* Curtis ssp. *glutinosum* (Fries) Jalas	+	.	.	.	.	.	.	+	.	22
T	EA	*Petrorhagia prolifera* (L.) P. W. Ball ex Heywood	.	+	.	.	.	.	.	+	.	22
T	MED	*Valantia muralis* L.	.	.	.	r	.	.	.	.	.	11

Ch	SEU	*Sedum ochroleucum* Chaix	.	.	.	.	+	.	.	.	.	11
		Lygeo sparti-Stipetea tenacissimae										
H	MED	*Reichardia picroides* (L.) Roth.	.	.	.	.	r	+	.	.	r	33
T	SEU	*Vulpia ciliata* Dumort	2m	.	.	.	.	+	.	.	.	22
H	MED	*Piptatherum miliaceum* (L.) Coss.	.	3	.	+	.	.	.	.	.	22
H	MED	*Brachypodium retusum* (Pers.) P. Beauv.	.	+	.	.	.	.	.	.	.	11
		Papaveretea rhoeadis										
T	CUAD	*Papaver rhoeas* L.	.	.	.	.	r	+	+	.	1	44
T	WS	*Senecio vulgaris* L.	.	.	.	.	.	r	.	r	+	33
T	EAF	*Veronica arvensis* L.	+	.	.	.	.	.	.	.	.	11
G	WS	*Convolvulus arvensis* L.	.	.	.	2a	.	.	.	.	.	11
		Sisymbrietea										
T	EA	*Geranium rotundifolium* L.	+	+	.	.	.	.	.	.	.	22
T	MED	*Sisymbrium orientale* L.	+	+	.	.	.	.	.	.	.	22
T	WS	*Erodium cicutarium* (L.) L' Hér.	+	.	.	.	.	.	.	.	.	11
T	WS	*Xanthium strumarium* L.	.	.	.	.	.	.	r	.	.	11
		Stipo-Trachynietea distachyae										
T	MED	*Linaria simplex* (Willd.) DC.	+	1	2m	1	+	2m	+	.	.	77
Ch	MED	*Andrachne telephioides* L.	.	.	4	+	r	.	r	+	4	66
T	MED	*Psilurus incurvus* (Gouan) Schinz et Thell	+	.	.	.	.	.	.	.	.	11
		Quercetea ilicis										
P	MED	*Juniperus oxycedrus* L. ssp. *oxycedrus*	.	.	.	+	.	.	.	.	.	11
P	MED	*Pinus halepensis* Mill., juv.	.	.	.	.	+	.	.	.	.	11
G	MED	*Asparagus acutifolius* L.	.	.	.	.	.	.	r	.	.	11

		Helianthemetea guttati										
T	SEU	*Crupina crupinastrum* (Moris) Vis	.	.	+	.	+	.	.	.	.	22
T	MED	*Medicago coronata* (L.) Bartal.	+	.	.	.	.	.	.	.	.	11
T	MED	*Minuartia mediterranea* (Link.) K. Malý	+	.	.	.	.	.	.	.	.	11
		Thlaspietea rotundifoliae										
H	SEU	*Scrophularia canina* L. ssp. *bicolor* (Sibth. et Sm.) Greuter	.	.	.	1	.	.	.	.	.	11
T	MED	*Crucianella latifolia* L.	.	.	.	.	2m	.	.	.	.	11
		Digitario sanguinalis-Eragrostietea minoris										
T	MED	*Heliotropium europaeum* L.	.	+	+	+	.	+	+	+	+	77
		Koelerio-Corynephoretea canescentis										
T	EA	*Minuartia hybrida* (Vill.) Schischkin in Komarov	+	.	.	.	.	.	.	.	.	11
		Asplenietea trichomanis										
Ch	MED	*Aurinia sinuata* (L.) Griseb.	.	.	.	.	2a	.	.	.	.	11
		Rhamno-Prunetea										
P	WS	*Rosa canina* L.	.	.	.	.	r	.	.	.	.	11
		Molinio-Arrhenatheretea										
H	WS	*Plantago lanceolata* L.	.	.	.	.	.	.	.	+	.	11
		Others										
T	CUAD	*Conyza canadensis* (L.) Cronquist	+	+	.	.	.	.	.	.	.	22
		Fumaria sp.	.	.	+	.	.	.	.	.	.	11
		Daucus sp.	.	.	.	.	.	+	.	.	.	11
		Anthemis sp.	.	.	.	.	.	.	.	r	.	11

Euroasian plants (13 %), dominated on the landfills. Two non-indigenous species were noted: *Papaver rhoeas* and *Conyza canadensis*. The latter species is considered invasive in Croatia (Nikolić *et al.*, 2014). *Centaurea spinosociliata* was defined as an endemic taxon.

The highest number of taxa belonged to the *Chenopodietea* (14 taxa), followed by *Festuco-Brometea* (7), *Artemisietea vulgaris* (6) and *Sedo-Scleranthetea* (5). The number of taxa in the relevés ranged between 12 and 21 (average 16). The classes *Digitario sanguinalis-Eragrostietea minoris*, *Koelerio-Corynephoretea canescentis*, *Asplenietea trichomanis*, *Rhamno-Prunetea* and *Molinio-Arrhenatheretea* were represented by one taxon each, mostly with a low cover or frequency.

The dominant taxa were as follows: *Avena barbata*, *Echium plantagineum*, *Medicago minima*, *Piptatherum miliaceum* and *Andrachne telephioides*. Constant taxa were: *Avena barbata*, *Echium plantagineum*, *Reseda alba*, *Bromus madritensis*, *Melica ciliata*, *Dittrichia viscosa*, *Chondrilla juncea*, *Reseda lutea*, *Medicago* *minima*, *Reichardia picroides*, *Papaver rhoeas*, *Senecio vulgaris*, *Andrachne telephioides*, *Linaria simplex* and *Heliotropium europaeum*.

DISCUSSION

In the present study, spontaneous vegetation on seven-year-old slag heaps consisted of a relatively low number of taxa. Although we did not study vegetation dynamics, emergence of fast growing annual plant taxa and biennial hemicriptophytes was expected in the first few years, as established in similar studies (Řehounková *et al.*, 2011, and references therein). Transport of diaspores from the surrounding landscape, mainly through zoochory and anemochory, is among the factors governing the development of plant communities in the initial stages of succession (Vaňková & Kovář, 2004). Seeds of plants are sometimes also carried into the heaps by humans during the heaping process.

No bryophytes were found in our study, contrarily to the findings of Grgić & Lakušić (1987), who investigated succession processes on spoil heaps in Bosnia and Herzegovina. This may be generally attributed to the warm and dry Mediterranean climate and/or specific physical and chemical properties of steel slag in a slag heap.

In our case, ruderals and weeds (*Chenopodietea*, *Artemisietea vulgaris*) and taxa of the dry open habitats (*Festuco-Brometea*, *Sedo-Scleranthetea*) were dominant. In this study, contrary to the findings of Lakušić *et al*. (1977), who described some plant associations in the heaps (*Sedo-Scleranthetea*), no characteristic set of taxa was established. The most common taxa from the sites studied were also found in the urban ruderal communities of the surroundings, both in the cities of Šibenik and Zadar (Milović, 2002; Milović & Mitić, 2012) and their environs (Jasprica *et al*., 2017). In general, but not studied here, the presence of the surrounding vegetation and variations in the species pool could also play a role in the different floristic composition and subsequent community transitions on the sites (Vukičević & Avdalović, 1982; Grgić & Lakušić, 1987; Otto *et al*., 2006).

Both the low number and low cover of woody taxa appear to indicate an early successional stage in the process of the development of natural vegetation. Steel slag is highly reactive and when exposed to rainwater it is known to release ecotoxic metals into the surrounding water bodies and soils (Meng & Liu, 2000; Oliveira *et al*., 2017). These biotopes may thus host only a fraction of the potential colonizers (Heckenroth *et al*., 2016).

In summary, this study adds to the base of information on the structure of vegetation communities on industrial waste deposits in the Mediterranean climate. Nevertheless, given the relatively small area studied and low number of relevés, the results should be considered in the context of anthropogenic influences occurring as a generalized phenomenon throughout the Mediterranean Basin and elsewhere. Taking into account the origin, properties and locations of this waste material, we recommend removing the heaps from the area and undertaking soil remediation according to Croatian law, EU standards and obligations.

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SPONTANA VEGETACIJA NA JALOVINAH V JUŽNI HRVAŠKI

Nenad JASPRICA
Institute for Marine and Coastal Research, University of Dubrovnik, P.O. Box 83, HR-20000 Dubrovnik, Croatia
e-mail: nenad.jasprica@unidu.hr

Marija PANDŽA
Primary School Murterski Škoji, Put Škole 8, HR-22243 Murter, Croatia

Milenko MILOVIĆ
"Antun Vrančić" Grammar School, Put Gimnazije 64, HR-22000 Šibenik, Croatia

POVZETEK

Fitosociološka raziskava spontane vegetacije na sedemletni feromanganski in silikomanganski jalovini v južni Hrvaški je pokazala prevladovanje ruderalnih rastlin in plevelov (Chenopodietea*,* Artemisietea vulgaris) *ter vrst odprtih habitatov* (Festuco-Brometea, Sedo-Scleranthetea). *Omejena pokrovnost gozdnih taksonov kaže na zgodnji stadij sukcesije v procesu razvoja naravne vegetacije. Avtorji priporočajo odstranjevanje jalovin z obravnavanega območja in pričetek remediacije prsti v skladu s hrvaško zakonodajo, evropskimi standardi in zahtevami.*

Ključne besede: fitosociologija, ruderalna vegetacija, industrijski odpadki, sredozemsko podnebje, Dalmacija, vzhodni Jadran

REFERENCES

Braun-Blanquet, J. (1964): Pflanzensoziologie. Grundzüge der Vegetationskunde. 3rd ed., Springer-Verlag, Wien-New York, 865 pp.

Barkman, J.J., H. Doing & S. Segal (1964): Kritische Bemerkungen und Vorschläge zur quantitativen Vegetationsanalyse. Acta Bot. Neerl., 13, 394-419.

Dierschke, H. (1994): Pflanzensoziologie. Grundlagen und Methoden. Verlag Eugen Ulmer, Stuttgart, 683 pp.

Gilardelli, F., S. Sgorbati, S. Armiraglio, S. Citterio & R. Gentili (2016): Assigning plant communities to a successional phase: Time trends in abandoned limestone quarries. Plant Biosyst., 150, 799-808.

Grgić, P. & R. Lakušić (1987): Pioneer plant communities on the ash heap disposals. God. Biol. inst. Univ. Sarajevo, 40, 17-25. (In Bosnian)

Heckenroth, A., J. Rabier, T. Dutoit, F. Torre, P. Prudent & I. Laffont-Schwob (2016): Selection of native plants with phytoremediation potential for highly contaminated Mediterranean soil restoration: Tools for a non-destructive and integrative approach. J. Environ. Manage., 183, 850-863.

Jasprica, N., M. Milović & Romić, M. (2015): Phytosociology and ecology of *Cressa cretica* L. (Convolvulaceae) on the eastern Adriatic coast. Hacquetia, 14, 265-276.

Jasprica, N., M. Milović, K. Dolina & A. Lasić (2017): Analyses of flora of railway stations in the Mediterranean and sub-Mediterranean areas of Croatia and Bosnia and Herzegovina. Nat. Croat., 26, 271-303.

Kovář, P. (ed.) (2004): Natural recovery of human-made deposits in the landscape (Biotic interactions and ore/ash-slag artificial ecosystem). Academia, Praha, 358 pp.

Lakušić, R., D. Pavlović, S. Abadžić & P. Grgić (1977): Prodromus of the plant communities of Bosnia and Herzegovina. God. Biol. inst. Univ. Sarajevo (spec. ed.), 30, 1-87. (In Bosnian)

Lakušić, R., L. Kutleša, P. Grgić, D. Pavlović, S. Abadžić & S. Bratović (1978): Spontaneous succession of the vegetation on the spoil heaps in the vicinity of Kakanj and Breza. Zemljište i biljka, 27, 137-144. (In Bosnian)

Meng, H.D. & L. Liu (2000): Stability processing technology and application prospect of steel slag. Steelmaking, 25, 74-78.

Milović, M. (2002): The flora of Šibenik and its surroundings. Nat. Croat., 11, 171-223.

Milović, M. (2008): Urban flora of the city of Zadar. PhD Thesis. Faculty of Science, University of Zagreb, 95 pp. (In Croatian).

Milović, M. & B. Mitić (2012): The urban flora of the city of Zadar (Dalmatia, Croatia). Nat. Croat., 21, 65-100.

Mucina, L., H. Bültmann, K. Dierßen, J.-P. Theurillat, T. Raus, A. Čarni, K. Šumberová, W. Willner, J. Dengler, R. Gavilán García, M. Chytrý, M. Hájek, R. Di Pietro, R., D. Iakushenko, J. Pallas, F.J.A. Daniëls, E. Bergmeier, A. Santos Guerra, N. Ermakov, M. Valachovič, J.H.J. Schaminée, T. Lysenko, Y.P. Didukh, S. Pignatti, J.S. Rodwell, J. Capelo, H.E. Weber, A. Solomeshch, P. Dimopoulos, C. Aguiar, S.M. Hennekens & L. Tichý (2016): Vegetation of Europe: Hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. Appl. Veg. Sci., 19, Suppl. 1, 3-264.

Nikolić, T., B. Mitić & I. Boršić (2014): Flora Hrvatske – invazivne biljke. Alfa d.d., Zagreb, 296 pp.

Nikolić, T. (ed.) (2018): Flora Croatica database. Available on http:// hirc.botanic.hr/fcd. [Last accessed May 10 2018].

Oliveira, R.W.H., G., Fernandes, F.C. Sousa & R.A. Barreto (2017): Chemical and mineralogical characterization of silicon manganese iron slag as railway ballast. Rem: Int. Eng. J., 70, 385-391.

Otto, R., B.O. Krüsi, C.A. Burga & J.M. Fernández-Palacios (2006): Old-field succession along a precipitation gradient in the semi-arid coastal region of Tenerife. J. Arid Environ., 65, 156-178.

Pignatti, S. (1982): Flora of Italy. 1–3. Edagricole, Bologna. (In Italian)

Prach, K. & P. Pyšek (1994): Clonal plants – What is their role in succession? Folia Geobot. Phytotax., 29, 307-320.

Prach, K., K. Řehounková, K. Lencová, A. Jírová, P. Konvalinková, O. Mudrák, V. Študent, Z. Vaněček, L. Tichý, P. Petřík, P. Šmilauer & P. Pyšek (2014): Vegetation succession in restoration of disturbed sites in Central Europe: the direction of succession and species richness across 19 seres. Appl. Veg. Sci., 17, 193-200.

Raunkiaer, C. (1934): The life forms of plants and statistical plant geography. Clarendon Press, Oxford, 631 pp.

Řehounková, K., J. Řehounek & K. Prach (eds.) (2011): Near-natural restoration vs. technical reclamationof mining sites in the Czech Republic. University of South Bohemia in České Budějovice, České Budějovice, 112 pp.

Škvorc, Ž., N. Jasprica, A. Alegro, S. Kovačić, J. Franjić, D. Krstonošić, A. Vraneša & A. Čarni (2017): Vegetation of Croatia: Phytosociological classifcation of the high-rank syntaxa. Acta Bot. Croat., 76, 200-224.

Vaňková, J. & P. Kovář (2004): Plant species diversity in the biotopes unreclaimed industrial deposits as artificial islands in the landscpe. In: Kovář, P. (ed.): Natural recovery of human-made deposits in the landscape (Biotic interactions and ore/ash-slag artificial ecosystem), Academia, Praha, pp. 30-45.

Vukičević, E. & V. Avdalović (1982): Some observations on the formation of pioneer plant communities at the landfills of coal mines in Pljevlja. Glasn. Šumarsk. Fak. Univ. Beograd, C, Hort., 59, 19-25. (In Montenegrin)

Walker, L.R. & R. del Moral (2003): Primary succession and ecosystem rehabilitation. University Press, Cambridge, 456 pp.