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SMALL-SCALE STRUCTURE CHANGE IN PLANT ASSEMBLAGES ON ABANDONED GOLD MINING WASTE DUMPS (ROŞIA MONTANĂ, ROMANIA)

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Abstract: We studied gold mining waste dumps in Roşia Montană (South-eastern Carpathians) that had similar environmental conditions and management histories but different ages due to successive cessation times of mining activities. A cronosequence for four waste dumps was included in the study: WD2, ~ 2 yrs old; WD20, 20–25 yrs old; WD4, 38–45 yrs old; and WD60, ~ 60 yrs old. At each waste dump we recorded all vascular plant species within 5 randomly placed 1 m^2 quadrats. Our hypothesis is that these waste dumps represent distinct seral stages, in terms of total species richness, overall plant composition and relative number of species in various plant functional groups distinguished on the basis of pollen and seed dispersal mode, N-fixing and vegetative lateral spread. We analysed the difference in these parameters between waste dumps of different ages.

Floristically, WD2 is well separated from WD20; WD20 is obscure but clearly different from WD40; and WD40 is well separated of WD60. One ruderal species (*Tussilago farfara*) and one dwarf shrub (*Vaccinium vitis-idaea*) are the best discriminators of WD2 and WD60, respectively. The total number of plant species increased steadily and significantly from WD2 to WD40 but declined on WD60. Significant changes in the relative number of species from each plant functional group were detected between at least two sites along the waste dump cronosequence. Whereas the relative richness of plant functional groups related to pollen/seed dispersal mode do not indicate a succession progress on WD60 as compared with the younger ones, the proportion of N-fixing species and the distribution of total species richness suggest a mid-successional stage associated with the oldest waste dump. This inconsistency may be a sampling effect (small number and size of quadrats) or the consequence of small, recent disturbances.

Keywords: cronosequence, floristic dissimilarity, gold mining waste dumps, plant functional groups, seral stages, species richness, succession

Introduction

The intensive mining of gold has permanently affected the overlying ecosystems, the land-use potential, and the attractiveness of landscapes. Furthermore, mining leaves behind damage stretching over large areas. It is therefore an important task to understand the natural processes related to succession for cost-effective, successful restoration of such areas.

The characterization of community responses to any given disturbance in terms of plant functional groups makes it possible to identify general trends in vegetation changes as well as comparison between communities of differing species composition with respect to specific processes [15, 16, 31]. Highly disturbed landscapes (e.g. mining areas, overgrazed areas, old-fields) with the same abiotic and biotic conditions (soil, potential vegetation, propagule sources, previous and present management activities), provide the opportunity to investigate the relative importance of plant functional groups along successional time.

One of the general trends in succession is that species number increases from early to mid-successional stages and declines toward late-successional stages [2, 21]**.** The increase period is due to species accumulation during the colonization phase, whereas the decreasing part is the consequence of competitive exclusion.

Studies characterizing plant species functional traits during succession have usually dealt with differences between early and late successional species or evaluated the changes in species traits during succession [7, 14, 19, 20, 23, 25, 37]. Successful pioneers are usually dominated by wind- and self-pollinated (autogamous) species [34]. Rydin & Borgegård (1991) showed that most pioneers of recently formed islands in Sweden were self-pollinated. On Mount St Helens, following the 1980 volcanic eruption, 18 of 21 invading species were either wind-pollinated or potentially self-pollinated [18].

For the colonization of bare habitats, availability of seeds is essential. In contrast to a secondary succession, the early stages of a primary succession do not have a seed pool of the previous vegetation at their disposal [8]. Most of the early successional species produce seeds that have adaptations to enhance their long-distance dispersal [1, 32]. This was also observed on uranium waste dumps in Germany, where 70 % of the colonizing plant species are dispersed mainly by wind [27].

In primary succession, vascular plant species with nitrogen-fixing symbionts are often the principal facilitators of plant establishment and make the habitat more hospitable for later successional species to colonize [35]. These plants are most common on glacial moraines and mudflows; to a lesser degree on mining areas, floodplains, and sand-dunes; and least commonly they are found on volcanoes and rock outcrops [33].

Vegetative lateral spread through clonal propagation of plants can be the primary mechanism responsible for the revegetation of technogenic soils [24, 34]. Species with vegetative growth from roots and rhizomes can rapidly cover the newly created surface, but in time their proportion decreases due to insufficient light [36].

The relevance of any particular functional group can only be tested in relation to a specific ecosystem function [16]. In our case the functions of interest are the dispersal, regeneration and nutrition/symbiotic traits of plant species that occurred spontaneously on waste dumps of different ages. These traits are often inferred to be key factors in restoration of highly disturbed landscapes [4, 13, 17, 26, 38, 40].

The aim of this study has been to reveal the floristic differences along a cronosequence of gold mining waste dumps in terms of overall species composition, total species richness and relative richness of certain plant functional groups. Based on current knowledge, we expected: 1) a unimodal or monotonic increasing distribution of total species richness, relative number of N-fixing species and proportion of species with vegetative lateral spread, depending on whether the plant assemblages on the oldest waste dump were structured or not by competitive exclusion; 2) a decrease in the relative number of anemochorous and wind-pollinated species, and an increase in the proportion of zoochorous and insect-pollinated species from pioneer to late successional stages.

Material and Methods

Study area

Roşia Montană (46°180″N, 23°080″E) is situated in the South-eastern Carpathians, within the Apuseni Mountains of Transylvania (Romania), an area known as the Golden Quadrilateral. This area holds the largest deposit of gold in Europe, being documented as a mining settlement called *Alburnus Major* from Romano-Dacian times. The historic mining district is located within the mountains and narrow valleys at a mean altitude of 850 m, in a continental temperate climate. The gold deposits are of epithermal and mesothermal type, associated with Neogene volcanic and sub-volcanic andesite-dacite bodies intruded in a varied lithological assemblage [30]. The rocks at Roşia Montană are rich in metals in addition to gold, and consequently the mining waste dumps are a toxic environment for colonizing plants, which are thus restricted to a narrow group of species.

The field investigations were carried out in 2008 on abandoned gold mining waste dumps placed around the existing opencast pits – Cetate and Cârnic (Fig. 1). The following waste dumps, which had similar environmental conditions and management histories, but differed in the time since the mining activities ceased, were selected: WD2, ~ 2 yrs old; WD20, 20-25 yrs old; WD40, 38-45 yrs old; and WD60, ~ 60 yrs old. The surrounding landscape consisted of a mixture of small arable fields, semi-natural grasslands, ruderal communities and forests. The most common vascular plant species that occurred on the mining dumps studied were: – WD2: *Tussilago farfara, Agrostis capillaris, Carex pairaei, C. caryophyllea* and *Deschampsia flexuosa*; WD20: *Betula pendula, Pinus sylvestris, Populus tremula, Agrostis capillaris* and *Deschampsia flexuosa*; WD40: *Agrostis capillaris, Poa pratensis, Chamaespartium sagittale*; WD60: *Calluna vulgaris, Vaccinium vitis-idaea* and *V. myrtillus*.

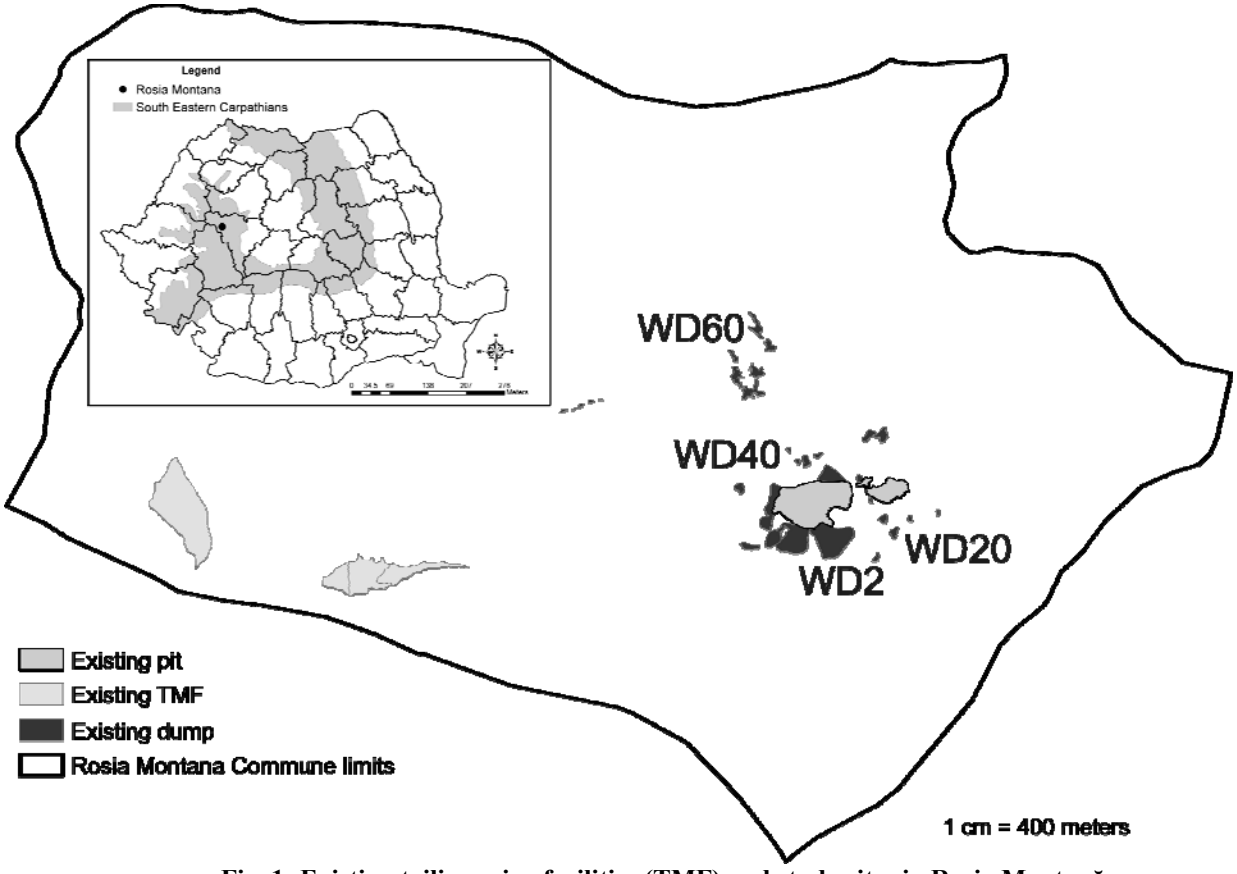

Fig. 1: Existing tailing mine facilities (TMF) and study sites in Roşia Montană.

Data collection

At each waste dump we recorded all vascular plant species within 5 randomly placed 1m^2 quadrats. For the purpose of analysis, the plant species recorded were grouped by functional group according to the following criteria: pollen vector (wind and insect), dispersal mode (anemochory and zoochory), nitrogen-fixation and vegetative lateral spread. Information on plant functional groups was taken from the Ecological Flora Database [9], BiolFlor database [12], and BIOPOP database [22].

Data analysis

We analysed the changes in relative species number within each functional group between waste dumps of different ages using the Kruskal-Wallis test [29]. We applied a non-parametric test because the measurement variables did not meet the normality assumption. One-

way analysis of similarities (ANOSIM) based on the Bray-Curtis index was employed to test statistically whether there was a significant difference between species composition on waste dumps of different ages. The pair-wise R-values reported in the ANOSIM output estimate how floristically distinct the waste dumps were on a scale from 0 (indistinguishable) to 1 (all similarities within groups are less than any similarity between groups). We interpreted the R-values using the following [5]: > 0.75 (well separated); 0.5 - 0.75 (overlapping but clearly different); and 0.25 - 0.50 (barely separable at all).

To detect the species that discriminate most between the waste dumps, we used the analysis of similarity percentages (SIMPER) that computes the percentage contribution of each species to the dissimilarities between all pairs of sites [5].

All probabilities associated with the calculated statistics were estimated through Monte Carlo simulations, each based on 10^6 permutations. We adopted a significance level of alpha probability of 1% in all tests to decide the rejection or acceptance of null hypotheses. Data analyses were performed in SAS 9.2 [28] and PAST 1.94a [10].

Results

Altogether 45 plant species were found across the 20 sampled quadrats. Overall the four waste dumps are well separated floristically. Nevertheless, their profile comparison shows that WD20 is obscurely separated from WD40 (Table 1). On the other hand, the most distinct are WD40 and WD60, which share only one species (*Agrostis capillaris*).

Table 1: Overall and profile comparison of floristic similarities between waste dumps of different ages.

Sites	R	Prob. (>R)
Overall model (all sites)	0.803	<0.0001
WD2 *vs.* WD20	0.850	0.0079
WD20 *vs.* WD40	0.750	0.0159
WD40 *vs.* WD60	1.000	0.0078

The plant species that contributed most to the average dissimilarities between waste dumps are listed in Table 2. *Tussilago farfara* and *Vaccinium vitis-idaea* can be considered the best discriminator species as they occur exclusively on the youngest and oldest waste dump, respectively. The other species in Table 2 are common to at least two sites.

Table 2: Species frequencies and overall contribution (%) to the average dissimilarities between waste dumps of different ages (only the first five species with the highest contribution are shown). Species are listed along a floristic gradient as to reveal the sites discriminated (grey versus white cells).

Taxon	WD2	WD20	WD40	WD60	Overall model (all sites)
Tussilago farfara	1	0	0	0	6.015
Poa pratensis	0	0.4	1	0	4.652
Agrostis capillaris	0.2	0.8	0.6	0.8	5.466
Calluna vulgaris	0	0.8	0	1	6.756
Vaccinium vitis-idaea	0	0	0	1	5.563

The total plant species richness changes significantly across waste dumps of different ages. Species number at a $1m^2$ scale increased steadily between WD2 and WD40, suggesting a continuous process of colonization and establishment (Fig. 2). However, species richness declines between WD40 and WD60, which might be an outcome of either intensive inter-specific competition or disturbance (Fig. 2).

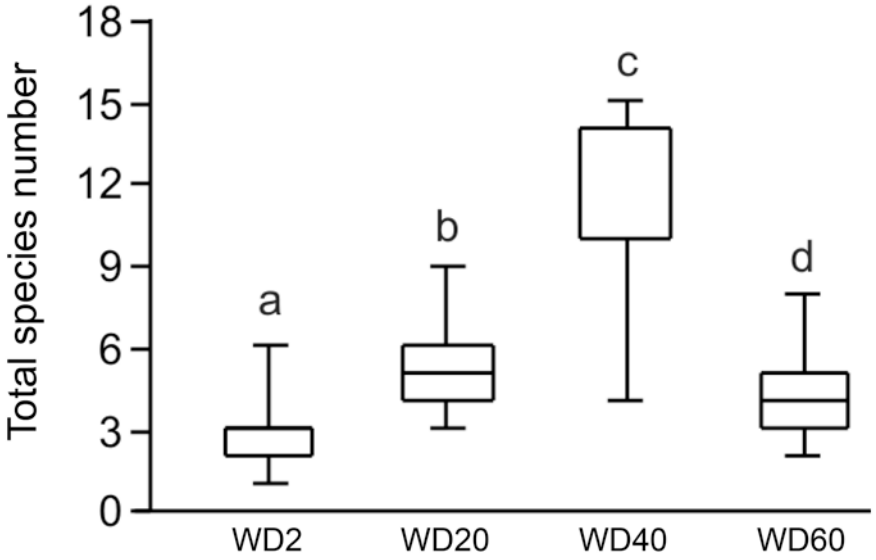

Fig. 2: Distribution of plant species number at a 1m^2 scale by cronosequence-ordered waste dump (different letters indicate statistically significant differences between mining waste dumps based on the Kruskal-Wallis test)**.**

Significant changes in the relative number of species from each plant functional group were detected across waste dumps (Fig. 3). However, not all pair-wise differences are statistically significant.

The proportion of insect-pollinated species is significantly lower only on WD2, but remains at higher levels on the older waste dumps (Fig. 3A). The relative richness of wind-pollinated species decreases steadily from WD2 to WD40, but shows an increase toward WD60 (Fig. 3B).

The proportion of anemochorous species is significantly higher on WD2 as compared with the medium-aged dumps (WD20 and WD40), but not significantly different from WD60 (Fig. 3C). The relative number of zoochorous species rises from the young waste dumps (WD2 and WD20) to WD40 but levels off toward WD60 (Fig. 3D).

The proportion of N-fixing plants (legumes) increases, even if not steadily, from WD2 to WD40, and declines significantly towards WD60 (Fig. 3E).

Finally, the relative number of vegetatively spreading species is significantly higher on WD60 as compared with the younger waste dumps, except for WD40 (Fig. 3F).

Discussion

The four, uneven-aged waste dumps can be considered as different seral stages that differ in terms of floristic composition and/or structure of plant functional groups. The pattern of species frequencies along this acidophilous site cronosequence corresponds roughly to the well-known replacement of pioneer herbs (e.g., *Tussilago farfara*) by grasses (e.g., *Poa pratensis*) and then by mid-successional shrubs (e.g., *Vaccinium vitis-idaea*).

In accordance with our hypothesis, species number generally increases from the youngest waste dumps toward the older ones. This pattern is obviously associated with the colonization and establishment of new species after disturbance. However, we observed a decline in species richness on the oldest waste dump, which could represent a mid-successional stage when competitive exclusion occurs in plant assemblages. This outcome is consistent with the general pattern observed in terrestrial ecosystems, i.e. a decrease in species numbers as successional species are lost [3, 21]. However, the change in species richness during succession also depends

on the environmental context [3]. Therefore, the decline observed on the oldest waste dump might be the consequence of small disturbances that occurred before our survey time.

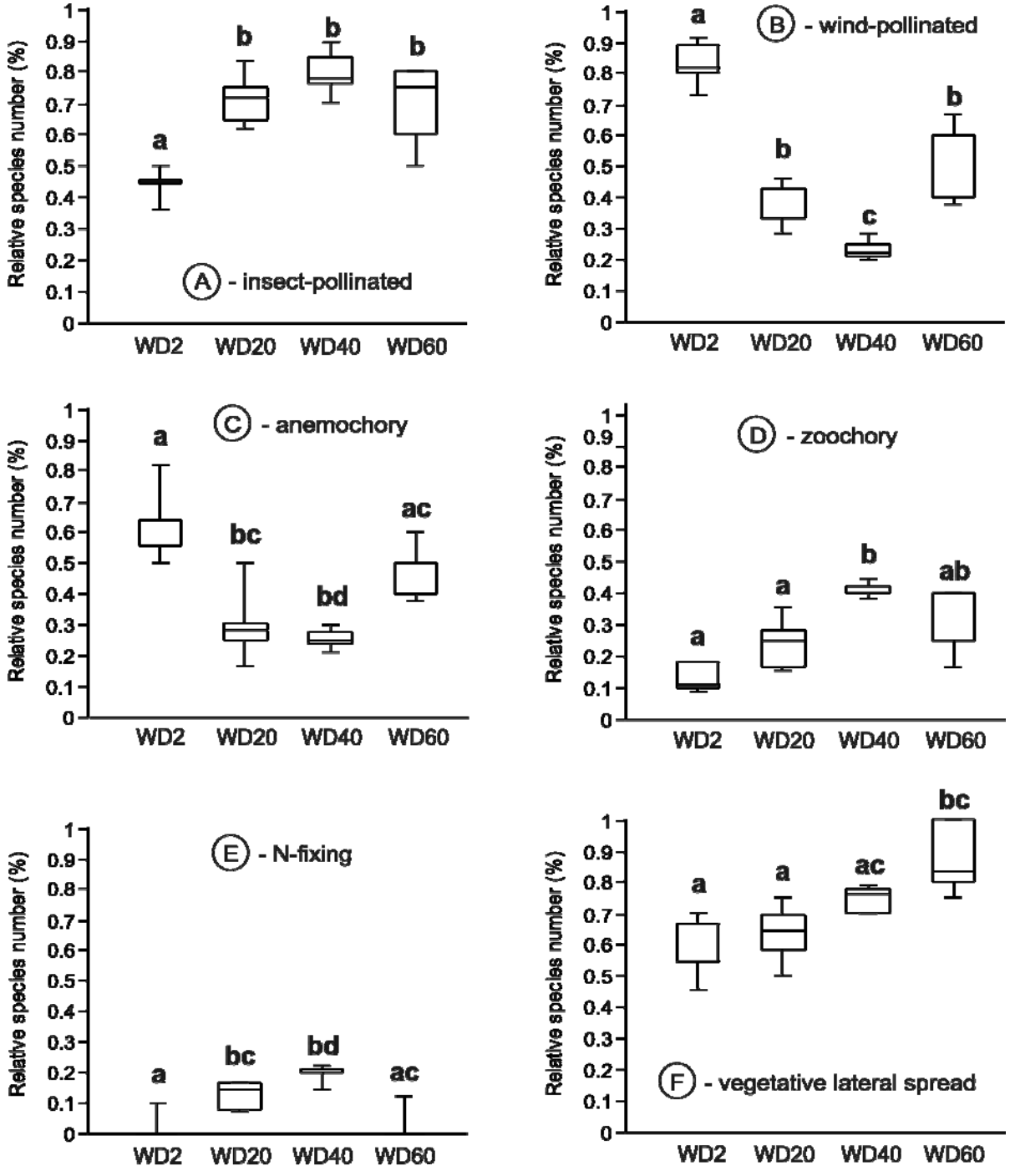

Fig. 3: Distribution of the relative number of species in each plant functional group by cronosequence-ordered waste dump (different and same letters indicate statistically significant and non-significant differences, respectively between mining waste dumps)**.**

We found that the youngest waste dump is colonized mostly by wind-pollinated species, whereas on older waste dumps the importance of insect-pollinated species becomes larger. Such a pattern fits into the 1996 classification scheme of Kelly & Woodward [11], which assigns wind-pollinated species a greater range size than non-wind pollinated species. Wind-pollination enables more intensive and widespread gene exchange than other modes, thus supporting a

higher genetic plasticity that may be advantageous for colonizing plants [2]. Also, many studies provide evidence that newly created habitats are more easily colonized by plants that do not depend on mutualistic relationships with other organisms, such as insect pollinators [6, 23, 39].

Our observations show that plant species with anemochorous dissemination are the main participants in colonization and natural re-vegetation of gold mining dumps. This is consistent with other observations performed on uranium mining sites [27]. Again, this demonstrates that a long-distance seed/pollen dispersal mode, mainly wind dispersal, is very important for a species to be among the early colonizers of an empty site. However, the oldest waste dump does not follow the theoretical hypothesis regarding the relative number of species that rely on wind as the main vector for pollen and seed dispersal. This deviation from the general pattern is probably related to the drop in species richness following small-scale disturbances or to the dominance of dwarf, heath-forming shrubs.

The distribution of the relative number of N-fixing species is consistent with current theories on primary successions that acknowledge the role of these symbiotic plants in middle successional stages, that is to facilitate the establishment of late successional species [35]. The further decline in the proportion of legumes on the oldest waste dump may be related to competitive exclusion driven by the newly established plants or to the occurrence of occasional disturbances.

As expected, the proportion of lateral spreading species increases generally from young to older waste dumps, but we did not observe their decline – that is likely to occur toward mid-late successional stages. This hypothesis relies on a common trait related to this functional group, which consists of shade-intolerant species [36].

Conclusions

Similar to other studies, our findings suggest that the selection for different sets of plant traits plays an important role in vegetation recovery on mining waste dumps.

Some of our results are contradictory with respect to the status of the oldest waste dump in terms of successional stage. Whereas the relative richness of plant functional groups distinguished by pollen/seed dispersal mode does not indicate a perceptible succession progress on the 60-year old waste dump as compared with the younger ones, the distributions of total species richness and N-fixing species suggest a mid-succesional stage associated with the oldest waste dump. This inconsistency may be a sampling effect or the consequence of small, recent disturbances. In fact, the small sample size in terms of both number and area of quadrats could have prevented the detection of some expected patterns. Whereas the scale of 1 m^2 was appropriate for the open, sparse vegetation of the youngest waste dump, it was probably too small for sampling the composition of plant assemblages from the 60-year old waste dump. Nevertheless, the equal size of quadrats was a necessary condition for a direct comparison of species richness between the waste dumps studied.

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MODIFICĂRI LA SCARĂ MICĂ ÎN STRUCTURA GRUPĂRILOR VEGETALE DE PE HALDELE DE STERIL REZULTATE ÎN URMA EXPLOATĂRILOR MINIERE AURIFERE (ROŞIA MONTANĂ, ROMÂNIA)

(Rezumat)

Haldele de steril rezultate în urma exploatării zăcămintelor aurifere de la Roşia Montană au fost abandonate la momente diferite, însă prezintă condiţii staţionale similare, datorate - printre altele - şi aceluiaşi mod de exploatare practicat. Obiectivul acestui studiu a fost acela de a evidenţia diferenţele dintre haldele de vârste diferite în ceea ce priveşte bogăţia şi compoziţia specifică, precum şi numărul relativ de specii din diverse grupuri funcţionale de plante, diferenţiate după tipul de dispersie a polenului şi seminţelor, capacitatea de fixare a azotului şi modalitatea de înmulţire vegetativă.

S-a luat în studiu o cronosecvenţă de patru halde de steril: WD2 ~ 2 ani vechime; WD20: 20-25 ani vechime; WD40: 38-45 ani vechime şi WD60 ~ 60 ani vechime. Pe fiecare haldă de steril au fost amplasate aleatoriu 5 suprafeţe de probă pătrate de câte 1 m^2, în interiorul cărora au fost inventariate toate speciile de plante vasculare. Ipoteza de lucru a fost că aceste halde de steril reprezintă stadii succesionale distincte, între care parametrii structurali menţionaţi anterior ar trebui să înregistreze variaţii semnificative, conform teoriilor ecologice actuale. Estimarea semnificaţiei diferenţelor dintre haldele de steril de vârste diferite s-a realizat prin analize statistice specifice (analiza univariată a similarităţii şi testul Kruskal-Wallis).

Din punct de vedere floristic, WD2 este bine individualizată în raport cu WD20; WD20 are o compoziţie asemănătoare, dar în mod evident diferită de WD40, iar WD40 este clar separată de WD60. O specie ruderală (*Tussilago farfara*) şi una subarbustivă (*Vaccinium vitis-idaea*) au fost identificate ca fiind cele mai bune diferenţiale pentru WD2 şi respectiv, WD60 în raport cu celelalte halde. Numărul total de specii de plante creşte continuu şi semnificativ de la o haldă la alta în lungul cronosecvenţei WD2 - WD40, dar scade sensibil pe halda WD60. Diferenţe semnificative în ceea ce priveşte numărul relativ de specii din fiecare grup funcţional de plante au fost detectate cel puţin între două halde de vârstă diferite. În timp ce bogăţia specifică relativă a grupurilor funcţionale distinse după modul de dispersie a polenului/seminţelor nu indică un progres al succesiunii pe WD60 în comparaţie cu haldele mai tinere, proporţia speciilor fixatoare de azot şi distribuţia numărului total de specii sugerează existenţa unui stadiu intermediar al succesiunii pe halda cea mai veche. Această contradicţie ar putea fi un efect al eşantionajului (număr mic şi mărime redusă a suprafeţelor de probă) sau o consecinţă a unor perturbaţii recente, de mică amploare.

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