Table of contents of the thesis

*** figure in brackets corresponds to the Summary of the PhD Thesis page

*** figure in brackets corresponds to the Summary of the PhD Thesis page

1. Introduction

Mining causes the destruction of natural ecosystems by soil stripping and, along with it, destruction of vegetation and the entire biocenotic complex, but also by the large amounts of wastes stored either as waste heaps or as tailing ponds.

In order to achieve restoration based on long-term affordable ecological principles (Benayas *et al*., 2009), the investigation of various damaged areas is very important in terms of composition and structure of the vegetation patches occurred spontaneously along the vegetation succession (Young, 2000; White *et* Jentsch, 2004; Walker *et* del Moral, 2009). At the same time, investigation of the floristic structure within these pioneer stages is essential for the drawing up and testing of some scientific hypotheses within the theories regarding the mechanisms and factors involved along the succession of the vegetation cover (Cadenasso *et al*., 2009; Walker *et* del Moral, 2009; Pickett *et al*., 2011).

The study of vegetation succession may inform the practice of ecological restoration on the following aspects: improvement of the substrate conditions; development of vegetation communities structure; nutrient dynamics; species life history traits; species interactions and modelling of transition stages succession and of the trajectories pursued along the time (White *et* Jentsch, 2004; Walker *et* del Moral, 2009; Meiners *et* Pickett, 2011).

In this context, the purpose of our research was to examine how spontaneous vegetation colonizes the new substrate (technogenous soils) resulting from the open pit mining of the gold and silver ores in Roşia Montană.

To achieve this purpose we have set the following **main objectives**:

1) assessment of the state-of-the-art regarding the vegetation in the areas damaged by the extractive industry;
2) identification of the structure and composition of the plant communities specific to the various succession stages spontaneously developed on the waste heaps;
3) analysis of the correlation between the floristic composition of the identified communities and some assessed environmental factors;
4) clarification of correlations and main dynamic trends in the phytocenoses of the investigated communities, depending on the spatial configuration of the Roşia Montană landscape;
5) analysis of spatial distribution of the vegetation patches on the waste heaps where the spontaneous succession of plant communities occurs, at landscape level by the use of the GIS technology.

1. The theoretical framework of research

The researches on the vegetation component of the areas damaged by mining activities generally regard the mitigation of the impact induced upon this component by studying the occurrence processes and rehabilitation of the vegetation cover.

The studies regarding the spontaneous vegetation conducted in the mining areas long before the awareness of their ecological restoration necessity (Barnes *et* Stanbury, 1951; Johnoson *et al*., 1977; Game *et al*., 1982), reveals the importance of the **directional dynamic processes** in the occurrence, set up, development and evolution of the vegetation cover. These researches represent the empirical background for the connection between the dynamic changes within the phytocenoses and the ecological restoration (Choi, 2004), therefore, the practical restoration activity begins to consider as well the theoretical aspects regarding **the ecological successions.**

The ecological succession is a basic Ecology concept referring to the changes occurred at biocenoses structure and composition level in an ecosystem, when some groups of organisms are replaced by others along the time as a result of certain disturbances (Wali, 1999). Each of these newly occurred cenotic complexes represent a point of the dynamic trajectory of vegetation evolution in order to ensure the maximum stability and efficiency in the use of resources (Cristea *et al*., 2004). Depending on the factors determining the ceno-structural changes, the successions may be **allogeneic** or **autogenous**. Therefore, in the first case the external factors, as well as the climatic, hydrographical, orographic and edaphic changes, anthropic-zoogenic pressure, etc. play a major role, and in the second case, the internal factors derived from the creation of a specific microclimate through the release of allelopathic compounds, are the cause of the changes induced in the vegetal cenoses.

If the succession process develops starting from a certain pre-existing vegetation group, then **secondary succession** occurs (Borza *et* Boşcaiu, 1965; Cristea *et al*., 2004). **The primary succession** (phytocenogenesis) occurs on bald or outcropped surfaces due to the severe action of disturbing natural (retreat of glaciers, volcanic eruptions) or anthropic (mining operations, landslides) factors. As mining activities often imply the total disappearance of the vegetation and of the seed reserves from the exploited land, the primary succession process initiates, *"phytocenogenesis is in fact a complex process complex conducting all types of successions, rarely addressed comprehensively by phytosociologists, most often rebuilt based on the dynamic stages where the vegetation groups are located within the investigated area"* (Cristea *et al*., 2004, p. 199).

The succession was initially explained by the progressive and gradual change based on facilitating the installation of species in the late stages by the dominant species in the previous species. These expectations were not confirmed by some studies, especially by those where fine scale or long-term investigations were performed (Pickett *et* McDonnell, 1989). There are cases where the communities specific to the final successional stages occur directly on the newly formed substrate, depending on the landscape configuration or species abilities to disperse on large distances (Pickett *et* Cadenasso, 2005).

The modern hypotheses and theories consider that the processes defined by Connel *et* Slayter (1977) are specific mechanisms that may trigger and direct differently the successional trajectories depending on the eco-pedological conditions, availability of seeds and the "abilities" of species within a certain area (Pickett *et al*. 2009).

In the vegetation succession, one can distinguish **initial stages** (colonization or pioneering stage), **transition** and **final,** which link and combine in **successional series,** generally determined by the substrate where the colonization begins.

Depending on the changes trend along the time in terms of floristic composition of the various plant associations, the following successional trajectories were described (Walker *et* del Moral, 2003; del Moral *et al*., 2010): convergent trajectories, divergent trajectories, network trajectories, parallel trajectories, diverted trajectories and cyclic trajectories.

3. Eco-cenotic context and the successional dynamics of the plant communities in the mining area of Roşia Montană

3.1 Introduction

The landscape in the metalliferous mining area of Roşia Montană represents an ideal investigation area for the research of the primary vegetation succession due to the fact that there are numerous areas abandoned at different time intervals where the tailings from two open pits: Cetate and Cârnic were stored, after the mining of gold and silver ores.

The purpose of this study is to identify those plants associations which have spontaneously colonized primary surfaces, as well as the investigation of the process of changing the colonizing communities composition along a 60 years cronosequence in order to reveal the specific causes and mechanisms that imprint the successional trajectories on the waste heaps from Roşia Montană.

In this context, the present research intends to analyze the vegetation in terms of its structure and dynamics, in order to highlight the main processes and mechanisms governing the spontaneous succession of the plant species, i.e. the natural revegetation of the affected areas.

3.2 Materials and methods

The area where the research was conducted is located within the territory of Roşia Montană commune (46°18′0″N, 23°08′0″E), Alba county, at an elevation of approximately 850 m above the sea level, in the Apuseni mountains within the South-Eastern Carpathians (fig. 3.1).

We mention that our studies have been conducted on the dry waste heaps where the tailings and the low-precious metal content rocks are stored, whose transport and processing are not economically viable.

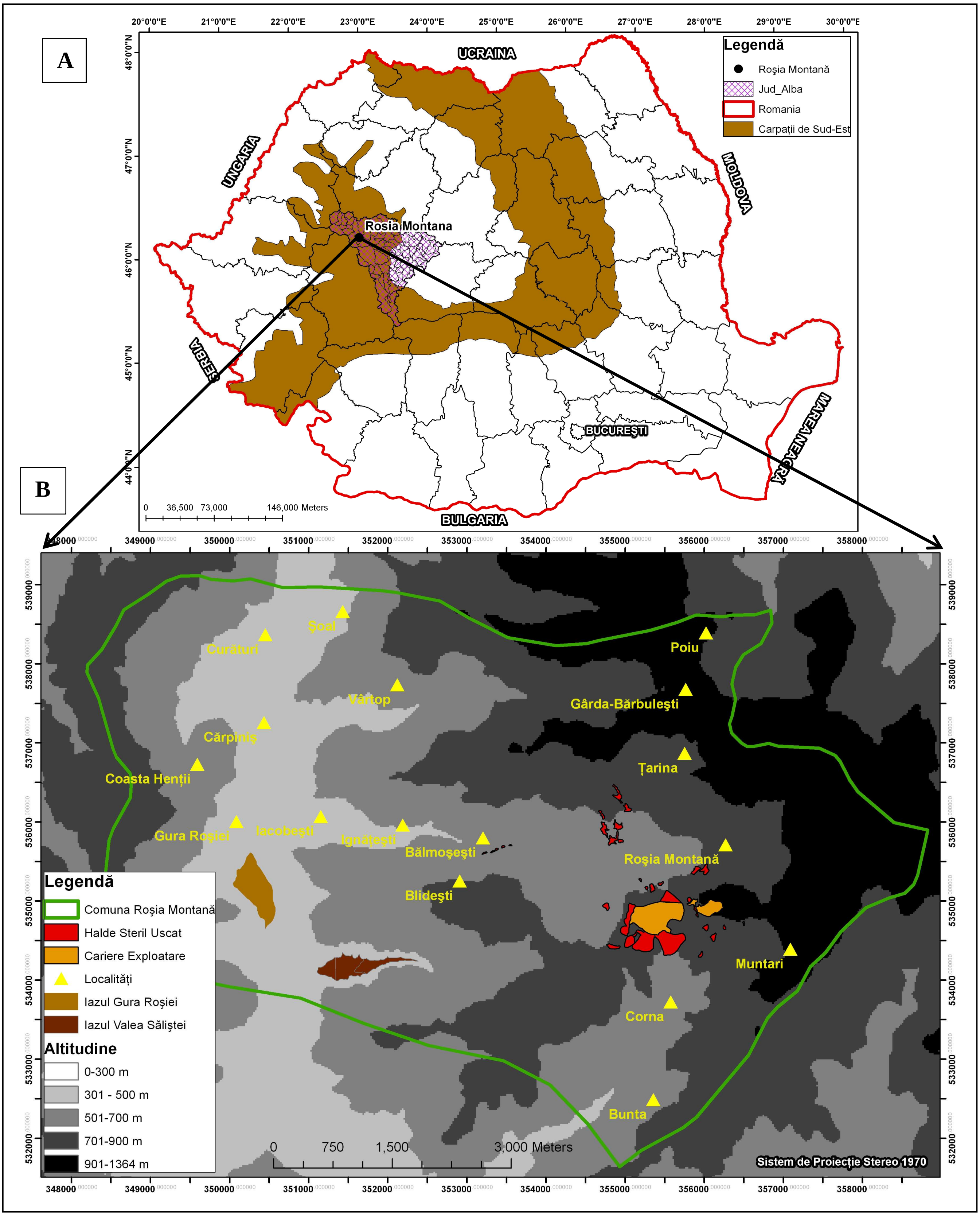


Fig.3.1: Location of the investigated area (A) and the location of waste heaps, tailings ponds and open pits within the relief elevation units (B). The elevation units were extracted from a DEM of pixel resolution of 2 m, provided by RMGC.

In order to identify the plant species and vegetation groups (cenotic types) located in various succession stages in the Roșia Montană mining area, investigation areas (cronosequences) were selected. These were assigned according to the time period passed from the moment when the technogenous substrate storage was ceased. In addition, for comparison purposes and in order to see if the spontaneous vegetation on the waste heaps tends to evolve in terms of floristic structure towards the types of vegetation surrounding the mining site, a control area not affected by the impact of the ore extraction activities was also analyzed.

To sum up, 5 areas of 25 ha each were investigated and inventoried. In terms of their location, these areas form a cronosequence:

- approximately 60 years old heaps**: the heaps in Orlea; included in the ~ 60 years (**HA60**) age category;
- heaps abandoned 38 – 43 years ago: Iuliana, Aurora and Afiniş heaps; included in the ~ 40 years (**HA40**) age category;
- heaps abandoned 24 – 28 years ago: Cârnicel, Piatra Corbului and Măneşti heaps; included in the ~ 25 years (**HA25**) age category;
- heaps abandoned 5 years ago: Hop, Valea Verde and Rakosi heaps; included in the ~ 5 (**HA5)** age category;
- a control area located in the surroundings of the Roşia Montană locality, South of the Tăul Ţapului pond, where there is no impact of the mining activities **(ZM).**

** The age of the heap was calculated according to the information available in the official documents regarding the year when the tailing substrate storage has ceased, respectively the dates when we conducted the phytosociological surveys (the 2007-2010 period).

The identification of plant species spontaneously colonizing the dry waste heaps, as well as those in the control area, was performed by covering the land during the vegetation seasons in the 2007-2010 period along two transects, located perpendicularly within each investigated perimeter.

The sampling of vegetation was performed in all previously established areas forming the cronosequence (HA60; HA40; HA25; HA5 and ZM). Hence, square shape plots were inventoried (sampling plots) with a 25 m^2 area, pastures, scrubs and other open habitats and respectively 400 m^2 of woods. The plots were located randomly within relatively physiognomically homogenous patches: empty areas with tailings, pastures, scrubs and woods. At each plot level, for each species, the abundance-dominance (AD) was noted, converting it to a central percentage value for data analysis, according to the Braun-Blanquet scale, completed by Tüxen *et* Ellenberg and adapted from Cristea *et al.* (2004). The identification of cenotaxones, respectively of their characteristic species was performed according to Coldea (1991), Sanda (2002) and Coldea *et al.* (2012).

The environmental variables. During the first stage, performed in the field, the following parameters were measured in the centre of each sampling (survey) area by means of a GPS receiver (Garmin 60.S):

- longitude: ***Long*** (metrical units, in Stereo 1970 Projection system);
- latitude: ***Lati*** (metrical units, in Stereo 1970 Projection system);
- altitude: ***Alt*** (meters);

- exposition: ***Ex*** (cardinal point: 23=NNE; 45=NE; 68=EEN; 90=E; 113=EES; 135=SE; 15=SSE; 180=S; 203=SSW; 225=SW; 248= SWW; 270=W; 293=NWW; 315=NW; 338=NNW; 360=N).

Subsequently, in the laboratory, based on a Digital Elevation Model – DEM with a pixel resolution of 2 m, for each phytosociological survey, the following were calculated and extracted:

- medium slope: ***Pa*** (degrees);
- total curvature of the area: ***Cb*** (concave: negative values, convex: positive values, flat: value 0);
- the potentially received radiant energy: ***En*** (kilowatt-hour/m^2).

In order to estimate the values of the geomorphologic (Pa, Ex, Cb), respectively climatic (En) parameters of the sampling areas inventoried from DEM, from the *ArcToolbox* menu of the ArcGIS 9.3.2 programme (ESRI, 1999-2009) we used the functions: *Slope, Curvature* and *Points Solar Radiation*.

The distinction between the relatively homogenous “vegetation groups” in terms of floristic composition, as well as the identification of the main ecological factors which contributed to their differentiation, a multivariate analysis of the gathered phytosociological data was performed. In this regard, we used a non-hierarchical cluster analysis method: *Fuzzy c-Means* (FCM, Bezdek, 1981). The optimum number of groups (clusters) was chosen and their subsequent validation was performed by using both internal and external assessment criteria, according to recommendations available in the literature (Cristea *et al*., 2004; De Cáceres *et al*., 2009; Tichý *et al*., 2011). For this purpose, we calculated various indices and we performed a series of numerical analyses: clusters separation indexes, species indicator value (IndVal) for the identified survey groups, analysis of the floristic similarity between clusters (ANOSIM) and the non-metrical multidimensional scaling (NMDS) of the surveys (internal validation criteria), as well as the assessment of the ecological differentiation of the identified vegetation groups (external validation criteria), by making multiple comparisons in terms of the habitat age, of some cenotic parameters and abiotic factors (the exact Savage test).

The most probable successional trajectories from the individualized vegetation groups were deducted by building the Minimum Extension Graph (MEG) for the synthetic surveys corresponding to each cluster. The distance between the nodes of the graph or, in other terms, the length of the segments composing the graph is proportionate to the Bray-Curtis floristic distance between the synthetic surveys characterizing the identified vegetation groups (Podani, 2001). All the tests were considered statistically significant to 5 % transgression alpha probability threshold.

3.3 Results and discussions

3.3.1 Classification of surveys

On the dry waste heaps and in the control area, a number of 150 surveys were conducted (which sum up 259 cormophite species), phytosociological data gathered in a unique matrix which set the basis of the FCM partitioning.

The variation of the partitioning coefficients of the clusters according to their number reveals the fact that the optimum solution is that with **8 clusters** (groups), as in this case, a maximum value of the Dunn coefficient and of the medium Silhouette is reached, as well as a minimum value of the entropy partitioning (fig. 3.2).

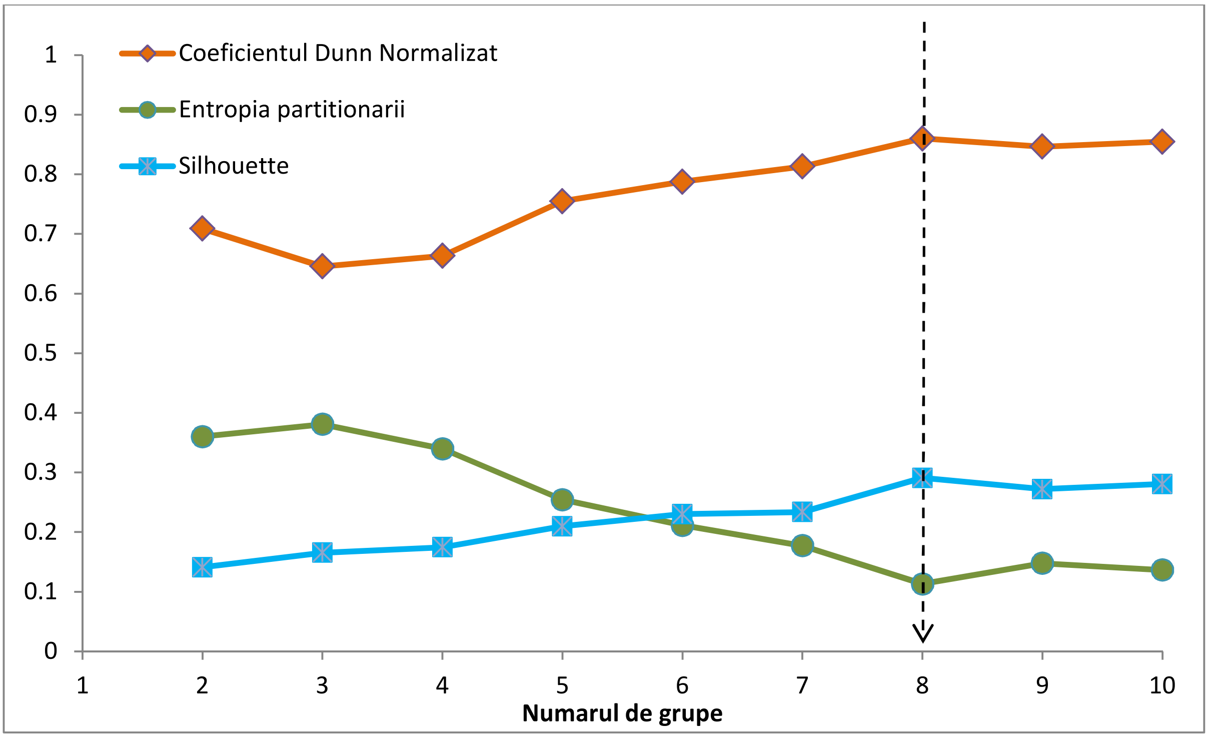


Fig.3.2: Determining the optimum number of groups by FCM partitioning of the vegetation

Classification of surveys by the FCM *portioning* reveals the affiliation degree of each survey to one of the 8 clusters: CL1-CL8. On the other hand, the positive values close to zero (≤ 0.05) and the negative ones of the Silhouette coefficient have highlighted 18 transition surveys or outliers, which have been eliminated from all the following analyses and tables. Of the 150 initial surveys, **132** (with 244 sp.) were left, assigned to the 8 clusters as follows: 25 surveys in CL1, 14 surveys in CL2, 16 surveys in CL3, 14 surveys in CL4, 15 surveys in CL5, 17 surveys in CL6, 13 surveys in CL7 and 18 surveys in CL8.

One needs to mention that within CL1, most of the surveys conducted in the control area were grouped, except 4 surveys performed on the oldest waste heaps (3 surveys of HA60 and 1 survey of HA40). In CL2 and CL6, surveys conducted on older waste heaps (HA60 and HA40) were grouped, surveys performed on the waste heaps HA40 and HA25 gathered in CL3, most of the surveys in CL4 belong to HA40, those in CL5 are all from the recently abandoned waste heaps (HA5), and those from CL7 and CL8 are from HA60 and ZM (in CL7: 10 surveys belong to HA60 and 3 are from ZM; in CL8: 1 survey is from HA40, 5 surveys from HA60 and 12 surveys from ZM).

The analysis of similarities (ANOSIM) indicates that the floristic differences from all the 8 clusters identified by the FCM partitioning are statistically significant, and the value of the differentiation coefficient ($R = 0.9305$; $p \leq 0.0001$) is higher than those achieved when randomly assigning surveys to the identified groups. Therefore, there are significant floristic differences between all clusters, the smallest ranging between CL2 and CL6 ($R = 0.7144$), respectively between CL2 and CL3 ($R = 0.7418$).

At the same time, the analysis of *species differential values* has generated statistically significant IndVal values for 7 of the 8 identified clusters, as CL6 did not have any statistically significant differential species compared to other groups. The species with the highest IndVal values are used to **generically name** and **subsequently interpret the obtained clusters.**

As the research approached mainly the spontaneous vegetation in successional and intermediary stages which occur in low-extension isolated plots without a well defined cenotic nucleus, the cenotaxonomic framing of the surveys is very difficult. Therefore, the mapped phytocenoses (except those in the control area) represents various dynamic transitory stages which converge floristically towards the indicated cenotaxones.

Considering that a series of species revealing statistically significant IndVal values ($p \leq 0.05$) are included in the specific species category, some mapped phytocenoses converge floristically towards the cenotaxones already described in literature (Coldea, 1991; Sanda, 2002; Coldea *et al.*, 2012). Three clusters (CL2, CL3 and CL6) are exempted from this situation, as the literature does not mention any corresponding cenotaxone for these clusters, which represent transition stages most probably towards *Populo tremulae-Betuletum pendulae* Coldea 1972.

Depending on the discriminant value of the species, the achieved clusters were named as follows:

- CL1: *Festuco rubrae-Agrostietum capillaris* Horv. 1951 (**FA**)
- CL2: *Deschampsietum flexuosae* sensu lato(**FD**)
- CL3: *Pinetum sylvestris* sensu lato (**PI**)
- CL4: *Festuco rubrae-Genistetum sagittalis* Issler 1927 (**FG**)
- CL5: *Poo compresae-Tussilaginetum farfarae* R. Tx. 1931 (**PT**)
- CL6: Poorly colonized tailings (**SC**)
- CL7: *Vaccinio-Callunetum vulgaris* Bük. 1942 (**VC**)
- CL8: *Carpino-Fagetum* Paucă 1941 (**CF**)

3.3.2 The floristic composition of the phytocenoses in the defined clusters

CL1: *Festuco rubrae-Agrostietum capillaris* Horv. 1951 (FA)

In this cluster, 25 surveys (totalling 148 sp.; the average number of sp. per survey is 33.7) were included, whose floristic composition is very similar to the *Festuco rubrae-Agrostietum capillaries* association from the alliance *Cynosurion*, *Arrhenatheretalia* order, vegetation class *Molinio-Arrhenatheretea*. Most of its phytocenoses are found in the control area, where the soil is weakly acid towards acid, but also on the dry waste heaps older than 40 years, where they cover small areas. The general cover of the species within the mapped phytocenoses ranges within the 49 – 96.5% interval. The species that assert both quantitatively and by occurrence (K) are: *Agrostis capillaris, Festuca rubra*, *Anthoxanthum odoratum* and *Achillea millefolium*. The species *Briza media, Centaurea phrygia, Hypericum maculatum, Leucanthemum vulgare*, *Lotus corniculatus*, *Potentilla erecta*, *Polygala vulgaris* and *Trifolium pratensese* also assert by their constant occurrence in the sampled areas (61 – 80%).

The FCM partitioning algorithm has grouped in this cluster all the cenoses in the control area located at a medium altitude of 885 m together with the cenoses from HA40 (1 survey), respectively HA60 (3 surveys) located at an altitude higher than 789 m. At the same time one may notice that both the cenoses on the waste heaps and those in the control area are found on slopes ranging in the 0 – 26^0 interval on the mainly concave and flat surfaces, except the grasslands in HA40 and HA60, which were not formed on flat surfaces. Regarding the location on slopes, one may notice that within the cluster there is a slight tendency to colonize mainly the SW to NW slopes, and the potential radiant energy received by the phytocenoses within the cluster is 1114.2 KWh/m².

CL2:***Deschampsietum flexuosae* s. l. (FD)**

This cluster was assigned 14 surveys (with 39 sp. in all and 9 sp. on average per survey), which may represent an incipient transitional stage towards *Festuco-Genistetum* or *Pinetum sylvestris* and, subsequently, probably towards *Populo tremulae-Betuletum pendulae*. The communities dominated by *Deschampsia flexuosa* are located on the dry waste heaps from the HA40 and HA60 years cronosequences, as plots between the *Festuco rubrae-Genistetum* (on HA40) and *Vaccinio-Callunetum vulgaris* (on HA60) phytocenoses. The general cover of vegetation is low (7 – 28%), and the barren rock is often exposed. This cluster is dominated by the species *Deschampsia flexuosa*, but the species *Calluna vulgaris, Betula pendula, Pinus sylvestris, Salix capraea, Luzula luzuloides* and *Populus tremula* also asserting from the constancy point of view. There are no floristic differenced determined by altitude, slope, exposition, surface curvature or potential radiant energy, on the heaps belonging to the two age groups (HA40 and HA60). We consider that the skeletal soil and the higher acidity represent the main factors in strengthening this cenotic ambiance.

CL3:***Pinetum sylvestris*s. l. (PI)**

This cluster gathers 16 surveys grouping 62 sp. in all (average no. of 12.6 sp./survey.). The small size (smaller than 3 m high) pine tree open woods are found on the heaps HA25 and HA40, as patches between the surfaces colonized with *Festuco rubrae-Genistetum sagittalis* communities. Within the entire cluster, the average general vegetation cover is 36.75%. However, depending on the age one may notice that this is significantly lower on the younger heaps. Beside the substrate age, the factor responsible for this difference might be the average potential radiant energy received by HA25 which equals 1047.7 KWh/m², as compared to that in HA40 which is 791.7 KWh/m². This pattern cannot be observed if we analyze the average number of species from the surveys corresponding to the two age groups. Hence, the HA25 heaps gather on an average 13 sp., while the HA40 heaps gather 12 sp. In addition, there are no floristic differences within the PI phytocenoses from the 2 age categories mentioned above, the surveys are located on an average at 873 m, on sloped ranging between 5 – 35^0, mainly on the N, NE and NW slopes. *Pinus sylvestris* asserts quantitatively and the species that occur more constantly (constancy classes III-V) are: *Pinus sylvestris, Betula pendula, Calluna vulgaris, Populus tremula* and *Picea abies* reg., suggesting a dynamics towards *Populo-Betuletum*.

CL4:***Festuco rubrae-Genistetum sagittalis***Issler 1927 **(FG)**

In this cluster, 14 surveys (with 102 sp. in all, on an average 28 sp./survey) have been separated. All phytocenoses mapped are found on HA40 heaps. Within these phytocenoses, the average general vegetation cover is 57.9 %. The species *Chamaespartium sagittale, Festuca rubra* and *Poa pratensis* assert in terms of constancy (class V) and high specific cover and the species *Agrostis capillaris, Achillea millefolium, Polygala vulgaris, Campanula patula, Galium verum, Luzula campestris, Cruciata glabra, Deschampsia flexuosa, Plantago lanceolata* and *Pinus sylvestris,* also occur at high constancy (class IV). The proximity of the pine open woods and assertion of this species in some phytocenoses may suggest a possible dynamics of the *Chamaespartium sagittale* shrubs towards pinery. Generally, these cenoses occur at a medium altitude of 817 m, on the slopes with N, W and E exposition, on slopes ranging between 14^0 – 43^0 mainly on flat or convex surfaces, with average potential radiant energy of 866.4 KWh/m^2.

CL5:***Poo compresae-Tussilaginetum farfarae*** R. Tx. 1931 **(PT)**

The FCM partitioning algorithm has separated 15 surveys with only 22 sp. in all and 5 sp. on the average per survey. These pioneer vegetation groups are found exclusively on the most recently abandoned heap (HA5). In the mapped sampling areas, the average general vegetation cover is very low (5.2%), the barren rock outcrops. The surveys from this pioneer vegetation group were formed at an medium altitude of 863.5 m, on slopes with a declivity ranging between 14 – 55^0, with predominant exposition W, S and E, on various levels of the surface curvature (concave, flat and convex), where the average potential radiant energy is 1023.7 KWh/m^2. The constantly present species are *Tussilago farfara* and *Poa compressa*, as well as a few sporadic specimens of a wood species, such as *Betula pendula, Salix capraea* and *Pinus sylvestris*. Therefore, considering the installation of these pioneer wood species, as well as the location of HA5 which presents a common ecotone with a hornbeam populated area, is it possible that in the successional dynamics, wood phytocenoses may be formed in a shorter time than necessary for the Orlea heaps.

CL6: **Poorly colonized tailings (SC)**

In this cluster, 17 surveys were grouped, including 29 sp. with 7.2 sp. on and average per survey. This type of habitat is found on old heaps (HA40 and HA60) as isolated spots of quasi-bald tailings, covering 25 m^2 – 10000 m^2 areas. These tailing spots are still in the incipient colonization stage, on the respective heaps, most probably because initially, spontaneous colonization has started from certain points where some plant species have succeed to fix and improve gradually the local substrate conditions. After that they slowly extended, and currently there are only several quasi-bald patches.

This colonization manner has also been noticed by Game *et al.* (1982) and in the case of heaps resulted after coal extraction where the spatial dynamics of small vegetation patches was recorded in time and their gradual expansion, until all spots of tailings have been vegetated. In these tailings patches, where the vegetation succession seems to be "arrested", the most frequent species are *Deschampsia flexuosa, Calluna vulgaris* and *Betula pendula.* The average general vegetation cover is very low (5%) and one notices no other floristic differences induced by the analyzed factors: medium altitude of the surveys grouped in this cluster is 819.7 m, the slope ranges from 0^0 to 42^0, also, the tailings spots have remained regardless of the exposition, the surface curvature or the potential radiant energy. The poor colonization within these spots could also be determined by other factors, among which tailings granulometry or more better washings, may contribute to the difficulty of grass cover fixation.

CL7:***Vaccinio-Callunetum vulgaris*** Bük. 1942 **(VC)**

In this cluster, 13 surveys have been grouped, including 76 sp. and 16.3 sp. on an average per each survey. These shrubs, of the moorland type with young isolated specimens of birch and poplar cover relatively large and compact areas on the oldest heap (HA60). Such communities have been identified also in the control area (3 surveys), where their dynamics towards a *Betula pendula* and *Populus tremula* pioneer forest vegetation is relevant. In these phytocenoses, the average vegetation cover is 78.2%, and the following species have a significant contribution: *Calluna vulgaris, Vaccinium myrtillus*, *Vaccinium vitis-idaea, Betula pendula,Populus tremula* and *Carpinus betulus*, and in the control area, the *Deschampsia caespitose* asserts. Besides the above mentioned species, *Deschampsia flexuosa* also occurs constantly. In terms of the altitude, the phytocenoses are located between 804 – 894 m, on 11^0 and 24^0 slopes, on S, SW and SE expositions in the case of those on the heaps, respectively NV in the case of those from the control area, preferring generally the convex shapes and the areas with a potential radiant energy higher than that of the vegetation groups from the clusters SC and FD from HA60 or the FA group from ZM.

CL8:***Carpino-Fagetum*** Paucă 1941 **(CF)**

In the hornbeam and beechwood cluster 18 surveys were separated, with a total floristic suite of 81 sp. and average of 17.2 sp. per survey. The hornbeam and beech forests occur also in the control area, but also as clumps in the upper third of the oldest heaps (HA60: 5 survey; HA40: 1 survey). This is reflected clearly in the dynamic tendency of the vegetal communities towards the bordering areas vegetation not affected by the mining operations. The average general vegetation cover within the cluster is 58%, the largest contribution in this percentage is that of the wood species *Carpinus betulus* and *Fagus sylvatica*, mentioning that in the control area there have been recent disturbances (during the last 2-3 years), in consequence of the retrocessions of various areas.

Other species occurring constantly within this cluster are: *Anemone nemorosa, Aposeris foetida, Acer pseudoplatanus, Cardamine bulbifera, Polygonatum odoratum* and *Corylus avellana.* The first 6 phytocenoses are more acidophile by the occurrence and cover of the following species: *Vaccinium myrtillus, Vaccinium vitis-idaea, Luzula luzuloides* and *Calluna vulgaris*, as the surveys are performed on the technogenous substrate of the heaps in Orlea, which is obviously more acid than that in the control area. Another difference between the phytocenoses in the control area and those on the old waste heaps is the absence from the heaps of the *Aposeris foetida* species, common for beechwood.

Attitudinally, the phytocenoses are located at elevations included between 836 – 888 m, where the average potential radiant energy is 1036.4 KWh/m^2 on slopes between 5^0 and 32^0, on various expositions, preferring generally the concave curvatures.

3.3.3 Ordering of the phytocenoses

All the 8 clusters may be identified in the area determined by the three NMDS axes (fig. 3.3). From the analysis of the NMDS ordering, it clearly emerges that the best separation belongs to the FA cluster, followed by the FG group, both located towards the positive end of Axis 1, while the clusters with the phytocenoses in CF, PI and VC are grouped towards the negative end of the same axis. This distribution indicates a clear floristic gradient from the predominantly grass vegetation towards the wood vegetation. The clusters SC and FD are partially overlain in the positive part of the Axis 2, thus reflecting the great floristic affinity between them. The PT cluster is well highlighted at the positive extremity of the third NMDS axis.

The correlation between Axis 1 and the relative cover of the species suggests the fact that this may be associated to a floristic gradient developed from the wood vegetation communities (*Fagus sylvatica, Carpinus betulus, Picea abies, Betula pendula, Populus tremula, Pinus sylvestris, Vacciunium myrtillus, V. vitis-idaea, Frangula alnus, Sorbus aucuparia*) to the grass vegetations (*Agrostis capillaris, Festuca rubra, Poa pratensis, Galium verum, Chamaespartium sagittale, Trifolium pratense, Lotus corniculatus, Arrhenatherum elatius, Anthoxantum odoratum, Plantago media*). At the same time, Axis 1 may be associated to a relative cover gradient developed by the nitrogen-fixing species and implicitly by the soil fertility, which, in its turn promotes the specific richness. The correlation between the occurrence and abundance of the nitrogen-fixing species and fertility, respectively the specific abundance was identified also by other researchers (van der Heijden *et al*., 1998; Klironomos *et al*., 2000; van der Heijden *et* Horton, 2009; Gómez-Aparicio, 2009).

The negatively significant *correlation between Axis 2 and the relative coverage* developed by the species that prefer weakly acid soils such as, *Acer pseudoplatanus, Aposeris foetida, Cardamine bulbifera, Carpinus betulus* and *Corylus avellan*a, on the one hand and the positive correlation with highly acidophile species (*Deschampsia flexuosa* şi *Calluna vulgaris*), on the other hand, indicates the fact that this axis reflects a soil acidity gradient. Among the abiotic factors, altitude is best correlated (negatively) with Axis 2, which suggests that towards the top and on the plateaus in the upper third of the slopes, the acidophile species occur, while the basis of slopes (where the nutrients washed by the surface seepage events) is mainly covered by weakly acidophile species.

Axis 3 NMDS is negatively correlated with the relative cover of species generally found in intermediary successional stages and more dynamically advanced (*Carpinus betulus, Vaccinium myrtillus, V. vitis-idaea*), and positively with species present in the initial stages (*Poa compressa, Polygonum aviculare, Populus tremula, Solidago virgaurea* and *Tussilago farfara*). The gradients associated to this axis are the land slope, the age of the heap and the total vegetation cover. While the positive correlation between the age of the heap and the vegetation cover is easily understood, the negative correlation between the land slope and the age of the heap could be the consequence of surface erosion of slopes, which causes in time the attenuation of slopes by the deposits at the heap base. All these considerations support the association of a successional maturity gradient to Axis 3.

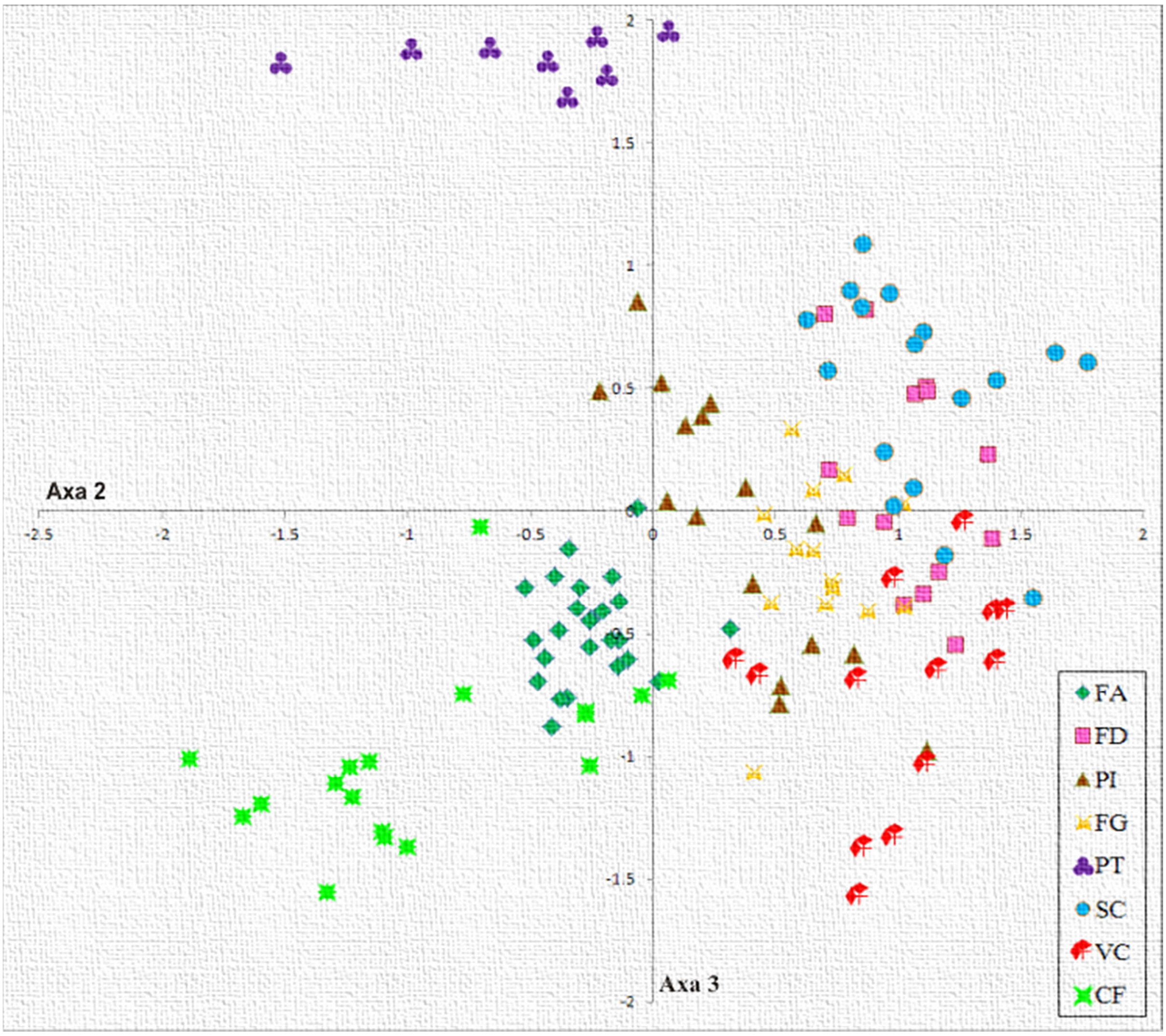


Fig. 3.3: NMDS Ordering of the surveys in the area determined by Axes 2 and 3. FA-*Festuco rubrae-Agrostietum capillaris*; FD-*Deschampsietum flexuosae* sensu lato; PI-*Pinetum sylvestris* sensu lato; FG-*Festuco rubrae-Genistetum sagittalis*; PT-*Poo compresae-Tussilaginetum farfarae*; SC-Poorly colonized tailings; VC-*Vaccinio-Callunetum vulgaris*; CF-*Carpino-Fagetum*.

3.3.4 The ecological differentiation of the cenotic types highlighted by clusters

The Savage test for the entire model reveals the fact that there are significant differences from the statistic point of view regarding all the measured parameters (the age of the heaps - V, the species richness – Nr-Sp, the total vegetation cover - Ac, the relative cover of the N-fixing species – N-fix, the altitude - Alt, the slope - Pa, the curvature of the surface - Cb, and the radiant energy - En) or indirectly estimated (ecological indexes for the edaphic humidity - U, soil reaction - R and nitrogen - N) between at least two of the 8 cenotic types identified (tab. 3.1).

The results achieved based on the multiple comparisons between all the identified clusters, depending on the indirectly assessed and/or measured factors reveals the fact that the largest differences are determined by the *age of the habitat (heap), the slope and altitude* and, respectively, *by substrate acidity.* In addition, there are also smaller, yet significant differences determined by the *land curvature* and by the *potential radiant energy*. On the other hand, the abiotic differences primordial to the formation of the vegetation communities (age of the heaps, chemical reaction of the substrate, the land slope, heaps elevation) have subsequently induced also a structural differentiation of the vegetation groups belonging to the 8 cenotic types, in terms of *species richness, total vegetation cover* and *relative cover of the nitrogen-fixing species.*

Conclusively, some disparities between the conventional indices and the real measured values of certain ecological parameters make us propose the existence of some various ecotypes within one and the same species, but also establish the necessity of some ecological studies, mainly of modern demecology.

***Table 3.1*: Multiple comparisons between the cenotic types, identified based on the 8 clusters, in terms of the measured or estimated factors.** Only the factors significant at a 5% transgression probability are presented. The correspondence between the two colours (red and blue) indicates the cenotic type with upper values of the tested factor. The abbreviations are those presented in the texts.

	FD	**PI**	**FG**	**PT**	**SC**	**VC**	**CF**
FA	V; Nr-sp; Ac; Pa; U; R; N	V; Nr-sp; Ac; N-fix;Pa	V; Nr-sp; Ac; N-fix; Alt; Pa; En; U; R	V; Nr-sp; Ac; Pa; Cb; R; N	V; Nr-sp; Ac; Alt; Pa; U; R; N	V; Nr-sp; Ac; N-fix; Alt; Cb; En; N	Nr-sp; N-fix; Alt; Pa; R; N
FD		V; Ac; Alt; R	V; Nr-sp; Ac; N-fix; En; U; R	V; Nr-sp; Ac; Cb; R; N	V; Nr-sp; Ac	V; Nr-sp; Ac; Pa	V; Nr-sp; Ac; N-fix; Pa; U; R; N
PI			V; Nr-sp; N-fix; Alt; U	V; Nr-sp; Ac; R; N	V; Nr-sp; Ac; Alt; U; R; N	V; Nr-sp; Ac; Alt; Pa; En; N	V; Nr-sp; Pa; Cb; En; R
FG				V; Nr-sp; Ac; N-fix; Alt; En; R; N	V; Nr-sp; Ac; N-fix; En; R; N	V; Nr-sp; Ac; N-fix; Pa; En; N	V; Nr-sp; N-fix; Alt; Pa; En; U; R; N
PT					V; Alt; Cb; U; R; N	V; Nr-sp; Ac; Pa; R; N	V; Nr-sp; Ac; Pa; Cb; R
SC						V; Nr-sp; Ac; Pa; Cb	V; Nr-sp; Ac; Alt; Pa; U; R; N
VC							V; Ac; Cb; N

3.3.5 The successional dynamics of the differentiated communities

The Minimum Extension Graph (MEG; fig. 3.4) suggests the probable successional trajectories based on the smallest floristic distances between the identified cenotic types. Therefore, the vegetation succession may begin with SC where more frequently species like *Calluna vulgaris, Betula pendula, Populus tremula*, are found, representing **the initial stage** of colonization (the pioneer stage). Depending on the age of the heap where the SC type vegetation groups are found, one notices that in some areas the natural colonization may be a long process, this stage maintaining (on small areas) also on the 40 and 60 years heaps. According to MEG, from the SC stage, the successional dynamics may follow two main directions most probably determined by the mitigation in time of the substrate acidity under the influence of the abiotic and biotic factors. Therefore, the existence of the two dynamic series is revealed: **the weakly acidophile dynamic series,** which includes the communities from PT, FA and CF, respectively, **the acidophile dynamic series,** including the vegetation groups from FD, PI, FG and VC. The comparisons performed by the *Savage test*, between the surveys grouped in the two dynamic series (acidophile and weakly acidophile), indicates that these differentiate in terms of the heap age, altitude and slope. The attitude difference between the two series is not an ecological determinant, but only an artefact caused by the fact that most of the surveys in the control area, included in the weakly acidophile series, were performed on slopes, at upper hypsometry levels (the medium altitude for the surveys in the weakly acidophile series is 864 m, and 839 m for the acidophile series). Consequently, on the tailings surfaces located on smaller slopes, vegetation communities belonging to the weakly acidophile series will be formed most probably.

Within the weakly acidophile series, on HA5 the succession proceeds from SC to PT, along an altitude gradient, i.e. the PT covers the upper third and the high plateaus of the slopes. After this, depending on the availability of the seed sources, grass vegetation communities from FA may install, or wood vegetation communities from CF. Within the acidophyle series the vegetation evolves from the SC stage, depending on the slope and curvature of the surface, towards VC or FD. Therefore, the communities in the VC stage have resulted in the SC incipient stage, where the slope is lower, respectively where the curvature of the surface is higher, and a higher degree of water and organic substances accumulation is implicitly allowed. In the SC incipient colonization stage also, by means of the FD stage currently dominated by *Deschampsia flexuosa*, where *Betula pendula* and *Populus tremula* seedlings frequently occur, vegetation may evolve towards other two transition stages: FG and PI, most probably depending on the availability of seeds.

Considering the ecological and structural properties of the researched communities, the description of the eco-cenotic conditions where the associations described by literature develop, as well as the existing vegetation in the surrounding areas of the Roşia Montană commune, besides the successional trajectories suggested by the MEG itself, we have illustrated in the same figure (fig. 3.4) the possible future trajectories that the vegetation groups on the dry waste heaps may follow. The successional dynamics of the vegetation from the acidophile series towards *Populo-Betuletum pendulae* Coldea 1972 is supported by the floristic composition of the SC clusters (incipient stage towards *Populo-Betuletum pendulae*), FD (incipient transition stage towards *Populo-Betuletum pendulae*), PI (intermediary transition stage towards *Populo-Betuletum pendulae*) and VC (final transition stage towards *Populo-Betuletum pendulae*).

The classification algorithm has identified 8 groups of plant species associations in various successional stages, which follow different future trajectories, depending on the mechanisms that may act at a given moment. The facilitation mechanisms along the trajectory towards advanced successional stages (*Populo-Betuletum* or *Querco-Betuletum*) are dominated and obvious in case of the 25 and 60 years old waste heaps. A final *Querco-Betuletum* stage derived probably from *Populo-Betuletum* was found also on the heaps resulting from the uranium exploitation in Germany (Sänger, 1995; Sänger *et* Jetschke, 2004).

Regarding the recently abandoned heaps, the successional trajectory is rather difficult to foresee, but, considering the fact that after only five years since the abandonment one may find *Pinus, Salix and Betula* seedlings, correlated with the fact that the heap has a common ecotone with the forest habitats of *Carpino-Fagetum*, it is possible that the tolerance mechanisms govern the succession towards the late stages with forest vegetation in a shorter time than that necessary for the Orlea heaps. The 40 years old heaps seem to be dominated also by the facilitation mechanisms in terms of previous installation of a nitrogen-fixing species, such as *Chamaespartium sagittale* which might have facilitated the presence of the intermediary stages species.

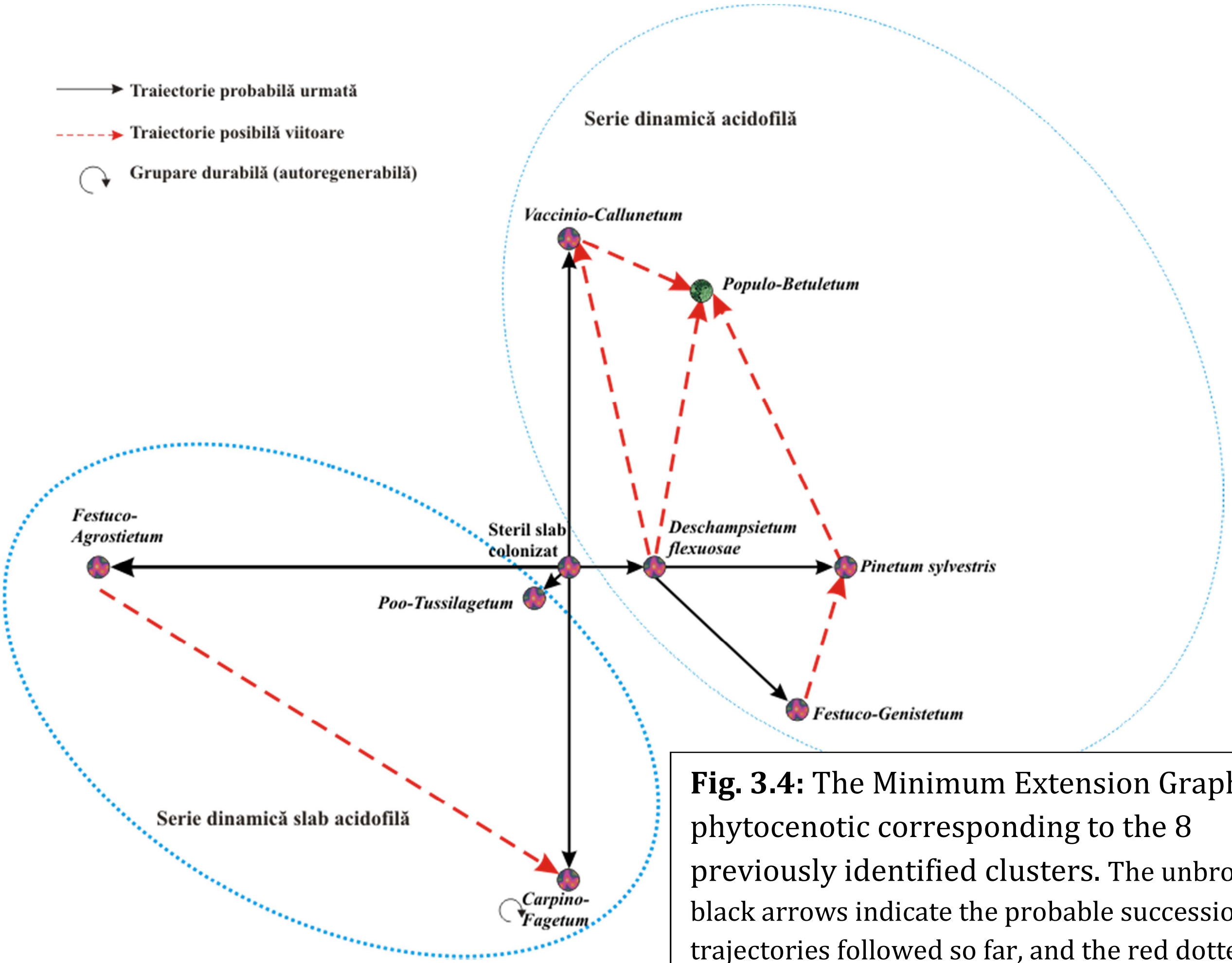


Fig. 3.4: The Minimum Extension Graph of the phytocenotic corresponding to the 8 previously identified clusters. The unbroken black arrows indicate the probable successional trajectories followed so far, and the red dotted line arrows represent the possible future trajectories.

4.Studies regarding the functional dynamics and the influence of the spatial landscape configuration on the identified plant communities

Within the highly disturbed areas, the most relevant functional plant groups in terms of practical ecological restoration are those that may provide information related mainly to the damaged structure and functions remediation processes. In this regard, the functional plant groups related to the dispersion manner of the seeds and/or pollen, respectively to the ecological strategies of the plants (Grime, 1977) are among the best indicators (Tilman *et al*., 1997; Alday *et al*., 2011; Grime *et* Pierce, 2012; Sterk *et al*., 2013). The species belonging to the functional group of the nitrogen-fixing species play an important role, by the fact that through their activity they facilitate the subsequent installation of the species specific to other types of transition stages, along the vegetation succession (van der Heijden *et* Horton, 2009; Gómez-Aparicio, 2009).

The CSR model regarding the type of ecological strategy of the plant species, developed by Grime (1977, 2001) is probably the most frequently used and relevant GFP for the analysis of functional dynamics of the disturbed ecosystems as it incorporates the species response to the stress level developed in time (factors that restrict the production), as well as the response of the species to disturbances (factors destroying the production). These selective forces have shaped three types of main strategies: competitive(C), stress-tolerant (S) and ruderal (R) species.

The spatial dynamics at the level of some plant communities is most often highlighted by studies regarding the proximity and isolation towards the colonization source and reveals generally a connexion between the composition and configuration context of landscape and phytodiversity. These aspects are still intensely debated as some researches have shown that the various spatial contexts have a weak effect as compared to the local environmental factors (Dupré *et* Ehrlén 2002; Öster *et al.* 2007; Marini *et al*. 2008), while others have concluded that space distribution is much more important (Cook *et al*. 2005; Novák *et* Konvička 2006; del Moral *et al*. 2009).

Therefore, one of the specific objectives of our research was that of highlighting the differences between the various ages heaps in terms of species richness and composition, as well as in terms of the relative number of species from various functional plant groups, differentiated by the type of pollen and seeds dispersion, their nitrogen-fixing capacity and the vegetative reproduction, aiming at elucidating the relations and main dynamic trends in the phytocenoses of the studies communities (Article 1).

For the analysis of the spatial distribution of the vegetation patches and species, we issued the hypothesis that for the floristic patterns identified within some poorly colonized tailings areas on the Orlea heaps, the relative location of the surrounding vegetation is determinant. Therefore, the specific objective pursued was to assess to what extent is the floristic structure (species richness, vegetation cover, the number of species with a certain type of dispersion and the number of species with a certain ecological strategy) within the tailing spots spatially related to the vegetation in more advanced successional stages (Article 2).

4.3 Small-scale structure change in plant assamblages on abandoned gold mining dumps (Roşia Montană, România) (Article 1; Roman A., Gafta D., Cristea V., Mihuţ S., 2009, Small-scale structure change in plant assamblages on abandoned gold mining dumps (Roşia Montană, România), *Contribuţii Botanice*, **XLIV**: 83-91.)

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 m2 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. (tab. 4.1).

***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

One ruderal species (Tussilago farfara) and one dwarf shrub (Vaccinium vitis-idaea) are the best discriminators of WD2 and WD60, respectively. (tab. 4.2).

The total number of plant species increased steadily and significantly from WD2 to WD40 but declined on WD60. (fig. 4.1).

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. (fig. 4.2). This inconsistency may be a sampling effect (small number and size of quadrats) or the consequence of small, recent disturbances.

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

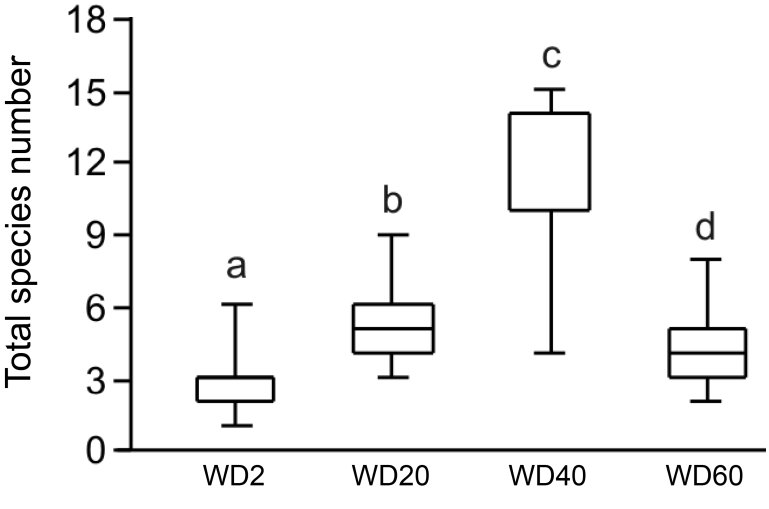


Fig. 4.1: Distribution of plant species number at a 1m^2 scale by cronosequence-ordered waste dump (different letters indicate statistically significant differences between mining waste dumps based on the Kruskal-Wallis test).

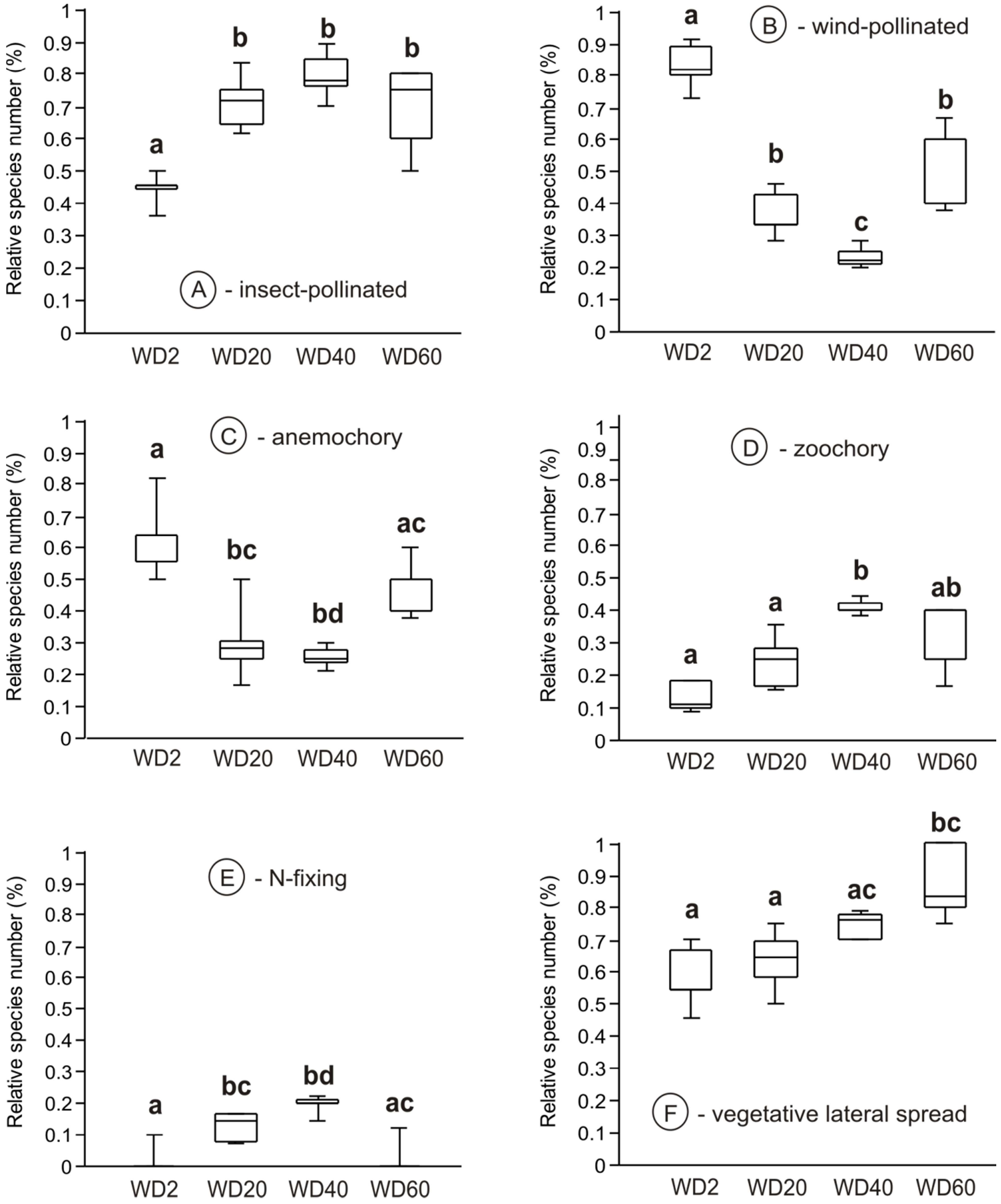


Fig. 4.2: Distribution of the relative number of species in each plant functional group by cronosequence-ordered waste dump (different and same letters indicate statistically significant and non-significant differences, respectively between mining waste dumps).

4.4 Proximity to successionally advanced vegetation patches can make all the difference to plant community assembly (Article 2; Roman A., Gafta D., 2013, Proximity to successionally advanced vegetation patches can make all the difference to plant community assembly, *Plant Ecology and Diversity*, **6** (2): 269-278.)

The shape and spatial arrangement of habitat patches in terms of their connectivity, neighbourhood and isolation have been emphasised as playing an important role in vascular plant species richness and abundance at community level (Sarlöv Herlin and Fry 2000; Petit et al. 2004; Piessens et al. 2004).

However, the overall importance of landscape context on plant species diversity and composition is still debated because some studies have demonstrated that landscape features had no, or weak, effects compared with local environmental factors (Dupré and Ehrlén 2002; Öster et al. 2007; Marini et al. 2008). Conversely, other authors have reported that the surrounding landscape features was important (Cook et al. 2005; Novák and Konvička 2006; del Moral et al. 2009).

We hypothesised that the relative position of surrounding vegetation patches would account for most floristic patterns observed in patches of exposed gold mine spoil (EMS) scattered over a 60-year old, abandoned waste heap.

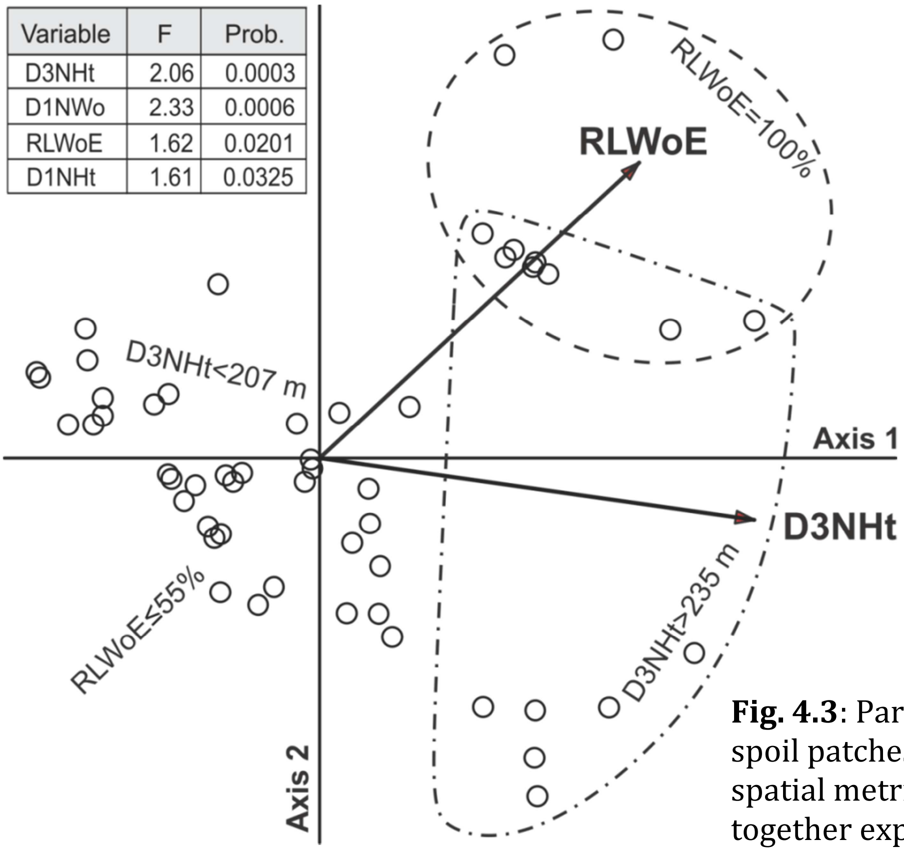
We assessed the extent to which the structure of plant species assemblages (species richness, total vegetation cover, the number of species of a given dispersal type and the number of species of a given ecological strategy - Grime, 2001; Grime *et* Pierce, 2012) from 53 EMS patches was related to distance from woodlands, heathlands and grasslands by controlling for the effect of spatial autocorrelation, patch size, slope and aspect.

The most discrepant in terms of species composition were the EMS patches located farthest away from heathlands and those embedded in woodlands. (tab. 4.3; fig. 4.3). Zoochorous species richness declined with distance from the nearest heathland. Anemochorous, competitive-stress tolerant and total species richness increased with proximity to the nearest woodland. Conversely, competitive species richness and total species cover were larger in EMS patches that were farther away from the nearest woodland, but closer to grasslands. Depending on the identity of colonising species, the woodland stands could act as propagule source, ecological filters or seed dispersal amplifiers.

The relative importance of proximity to source habitats for plant community assembly can change dramatically under the confounding or contrasting effects of 'third-party' habitat patches, which are interposed in the landscape.

***Tabel 4.3:* Forward selection of the most important spatial metrics in terms of their effects on the species composition of EMS patches by controlling for the effect of patch area, slope and aspect.** The selection procedure stopped at exceeding the entry probability level of 5% (last, grey-filled row).

Spatial metric	F	*P*	Cumulative variance explained (%)	Variance inflation factor
Mean distance to the three-nearest heathland patches (D3NHt)	2.06	0.0003	0.15	1.906
Distance to the nearest woodland patch (D1NWd)	2.33	0.0006	0.32	3.258
Relative length of woodland ecotone (RLWdE)	1.62	0.0201	0.43	1.707
Distance to the nearest heathland patch (D1NHt)	1.61	0.0325	0.55	3.909
Distance to the nearest exposed spoil patch (D1NSp)	1.47	0.0647	0.65	1.501



Variable	F	Prob.
D3NHt	2.06	0.0003
D1NWo	2.33	0.0006
RLWoE	1.62	0.0201
D1NHt	1.61	0.0325

Fig. 4.3: Partial CCA biplot of the exposed spoil patches and the best explanatory spatial metrics (the first two axes together explained 29.1% of the variance in species data). Patch area, aspect and slope were considered as covariables. Abbreviations as in Tab. 4.3

General conclusions

Considering that the spontaneous vegetation on the gold and silver ore waste heaps from Roşia Montană was not exclusively addressed in any scientific paper in our country, our researches may be appreciated as original. At the same time, the identification of structure and composition of the plant communities specific to the various successional stages occurred spontaneously in these areas represents a priority in the context of their ecological and economically viable restoration within their surrounding landscape. Therefore, based on the initially proposed objectives and depending on the achieved outcomes, we can outline the following conclusions:

- the vegetation communities occurred spontaneously on the waste heaps in Roşia Montană are found in terms of their dynamics, in various successional stages: pioneer stages: the poorly colonized tailings (SC) and *Poo compresae-Tussilagetum farfarae* (PT); transition stages: *Deschampsietum flexuosae*, *Pinetum sylvestris* (PI) and *Festuco rubrae-Genistetum sagittalis* (FG); medium stages towards the late ones: *Festuco rubrae-Agrostetum capillaris* (FA), *Vaccinio-Callunetum vulgaris* (VC) and *Carpino-Fagetum* (CF). The possible future trajectories that the plant communities from the dry waste heaps may follow within the late successional dynamic stages may include cenoses of *Populo-Betuletum* towards the forming of some beech forests (for example, *Hieracio rotundati-Fagetum*) or durmast (for example, *Querco petraeae-Betuletum*), according to the stationary conditions, the edaphic factors and seeds availability, thus shaping the convergence towards the surrounding vegetation types;
- the analysis of the correlation between the floristic composition of the dynamic stages and some assessed factors reveals the fact that the succession is governed mainly by: the age of the habitat (heap), the slope and the altitude, and respectively the substrate acidity. Also, there are smaller, yet significant differences determined by the land curvature and by the potential radiant energy. On the other hand, the abiotic differences primordial to the formation of the vegetation communities (age of the heaps, chemical reaction of the substrate, the land slope, heaps elevation) have subsequently induced also a structural differentiation of the vegetation groups belonging to the 8 cenotic types, in terms of species richness, total vegetation cover and relative cover of the nitrogen-fixing species;
- Depending on the combination of successional mechanisms and on some particular elements of the landscape (altitude, slope, surface curvature, related potential radiant energy), the successional trajectory follows two min directions: the weakly acidophile dynamic series, on the older tailings areas located on lower slopes where the tolerance mechanisms prevail and respectively, a dynamic acidophile series, where the facilitation alternates with inhibition. The location of the Orlea heaps in relation to the spatial configuration of the landscape (proximity and length of the ecotones with habitats in various more advanced

successional stages) determines a floristic diversity higher in the tailings patches with a longer ecotone with the forest habitats, while the vegetation cover is better in the tailings fragments located closer to the grassland habitats;

- The results achieved at 1 m^2 scale confirm the theoretical hypotheses related to the significance of the species succession in the various functional categories for the ecological restoration of the damaged areas. The total number of plant species increases continuously and significantly from one heap to another along the cronosequence, but decreases on the oldest heap. While the specific relative abundance of the functional groups identified by pollen/seeds distribution does not indicate a progress of the succession on the Orlea heaps, as compared to the newer heaps, the percentage of the nitrogen-fixing species and the distribution of the total species number suggests the existence of an intermediate stage of the succession on the oldest heap. This contradiction might be an effect of the sampling (small number and size of the sampling areas) or a consequence of recent slight disturbances;
- In the particular case of Roșia Montană, for the heaps older than 40 years, the maintenance and use of the vegetation resulting from the spontaneous succession represents a viable solution that needs to be considered throughout the general restoration strategy;
- As for the newer heaps, handling of the facilitation, tolerance and inhibition mechanisms within the identified spontaneous cenoses might contribute to the ecological restoration of these areas, according to the objectives referring to the time, costs and long-term self-maintenance, provided within the general restoration strategy.

References

1. Alday J.G., Pallavicini Y., Marrs R.H., Martínez-Ruiz C., 2011, Functional groups and dispersal strategies as guides for predicting vegetation dynamics on reclaimed mines, *Plant Ecology*, **212**: 1759-1775.
2. Barnes H., Stanbury T.A., 1951, A statistical study of plant distribution during the colonization and early development of vegetation on China clay residues, *Journal of Ecology*, **39**: 171-181.
3. Benayas J.M.R., Newton A.C., Diaz A., Bullock J.M., 2009, Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis, *Science*, **325**: 1121-1124.
4. Bezdek J.C., 1981, *Pattern recognition with fuzzy objective functions*, Plenum Press, New York.
5. Borza A., Boşcaiu N., 1965, *Introducere în studiul covorului vegetal*, Edit. Academiei RPR, Bucureşti.
6. Cadenasso M.L., Meiners, S.J., Pickett S.T.A., 2009, The success of succession: a symposium commemorating the 50th anniversary of the Buell-Small Succession Study, *Applied Vegetation Science*, **12**: 3-8.
7. Choi Y.D., 2004, Theories for ecological restoration in changing environment: Toward 'futuristic' restoration, *Ecological Research*, **19**: 75-81.
8. Coldea G. (ed.), Oprea A., Sârbu I., Sîrbu C., Ştefan N., 2012, *Les associations végétales de Roumanie.. Les associations anthropogènes,* **2**, Edit. Presa Universitară Clujeană, Cluj-Napoca.
9. Coldea G., 1991, Prodrome des associations végétales des Carpates du sud-est (Carpates Roumaines), *Documents Phytosociologiques*, **13**: 326-522.
10. Connell J.H., Slayter R.O., 1977, Mechanisms of succession in natural communities and their role in community stability and organization, *American Naturalist*, **111**: 1119-1144.
11. Cook W.M., Yao J., Foster B.L., Holt R.D., Patrick L.B., 2005, Secondary succession in an experimentally fragmented landscape: community patterns across space and time, Ecology, **86**: 1267-1279.
12. Cristea V., Gafta D., Pedrotti F., 2004, *Fitosociologie*, Edit. Presa Universitară Clujeană, Cluj-Napoca.
13. De Cáceres M., Font X., Vicente P., Oliva F., 2009, Numerical reproduction of traditional classifications and automated vegetation identification, *Journal of Vegetation Science*, **20**: 620-628.
14. del Moral R., Sandler J.E., Muerdter C.P., 2009, Spatial factors affect primary succession on the Muddy River Lahar, Mount St.Helens, Washington, *Plant Ecology*, **201**:177-190.

15. del Moral R., Saura J.M., Emenegger J.N., 2010, Primary succession trajectories on a barren plain, Mount St. Helens, Washington, *Journal of Vegetation Science*, **21**: 1-11.
16. Dupré C., Ehrlén J., 2002, Habitat configuration, species traits and plant distributions, *Journal of Ecology*, **90**: 796-805.
17. ESRI, 1999-2009, ArcGIS 9.3.1, Environmental Systems Research Institute, Redlands.
18. Game M., Carrel J.E., Hotrabhavandra T., 1982, Patch dynamics of plant succession on abandoned surface coal mines: a case history approach, *Journal of Ecology*, **70**: 707-720.
19. Gómez-Aparicio L., 2009, The role of plant interactions in the restoration of degraded ecosystems: a meta-analysis across life-forms and ecosystems, *Journal of Ecology*, **97**: 1202-1214.
20. Grime J.P., 1977, Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory, *American Naturalist*, **111:** 1169-1194.
21. Grime J.P., 2001*, Plant strategies, vegetation processes, and ecosystem properties*, Wiley-Blackwell, Chichester.
22. Grime J.P., Pierce S., 2012, *The evolutionary strategies that shape ecosystems*, Wiley-Blackwell, Chichester.
23. Marini L., Scotton M., Klimek S., Pecile A., 2008, Patterns of plant species richness in alpine hay meadows: local vs. landscape controls, *Basic and Applied Ecology*, **9**: 365-372.
24. Meiners S.J., Pickett S.T.A., 2011, Succession, in: *Encyclopedia of biological invasions*, eds.: Simberloff D., Rejmanek M., University of California Press, Berkeley- Los Angeles.
25. Novák J., Konvička M., 2006, Proximity of valuable habitats affects succession patterns in abandoned quarries, *Ecological Engineering*, **26**: 113-122.
26. Öster M., Cousins S.A., Eriksson O., 2007, Size and heterogeneity rather than landscape context determine plant species richness in semi-natural grasslands, *Journal of Vegetation Science*, **18**: 859-868.
27. Petit S., Griffiths L., Smart S.S., Smith G.M., Stuart R.C., Wright S.M, 2004, Effects of area and isolation of woodland patches on herbaceous plant species richness across Great Britain, *Landscape Ecology*, **19**: 463-471.
28. Pickett S.T.A., Cadenasso M.L., 2005, Vegetation succession, in: *Vegetation ecology*, ed.: van der Maarel, E., Blackwell Publishing, Oxford-Malden-Carlton.
29. Pickett S.T.A., Cadenasso M.L., Meiners S.J., 2009, Ever since Clements: from succession to vegetation dynamics and understanding to intervention, *Applied Vegetation Science*, **12**: 9-21.
30. Pickett S.T.A., McDonnell M.J., 1989, Changing perspectives in community dynamics: a theory of successional forces, *Trends in Ecology and Evolution*, **4**: 241-245.

31. Pickett S.T.A., Meiners S.J., Cadenasso M.L., 2011, Domain and propositions of succession theory, in: *The theory of ecology*, eds.: Scheiner S.M., Willig M.R., University of Chicago Press, Berkeley-Los Angeles.
32. Piessens K., Honnay O., Nackaerts K., Hermy M., 2004, Plant species richness and composition of heathland relics in north-western Belgium: evidence for a rescue-effect?, *Journal of Biogeography*, **31**: 1683-1692.
33. Podani J., 2001, *SYN-TAX 2000 – Computer Program for data analysis in ecology systematics. User's Manual*, Scientia Publishing, Budapest.
34. Roman A., Gafta D., Cristea V., Mihuţ S., 2009, Small-scale structure change in plant assamblages on abandoned gold mining dumps (Roşia Montană, România), *Contribuţii Botanice*, **XLIV**: 83-91.
35. Roman A., Gafta D., 2013, Proximity to successionally advanced vegetation patches can make all the difference to plant community assembly, *Plant Ecology and Diversity*, 10.1080/17550874.2013.771222.
36. Sanda V., 2002, *Vademecum ceno-structural privind covorul vegetal din România*, Edit. Vergiliu, Bucureşti.
37. Sänger H., 1995, Flora and vegetation on dumps of uranium mining in the southern part of the former GDR, *Acta Socientatis Botanicorum Poloniae*, **64**: 409-418.
38. Sänger H., Jetschke G., 2004, Are assembly rules apparent in the regeneration of a former uranium mining site?, in: *Assembly rules and restauration ecology-Bridging the gap between theory and practice*, eds.: Temperton V.M., Hobbs R.J., Nuttle T., Halle S., Island Press, Washington DC.
39. Sarlöv Herlin I.L., Fry G.L.A., 2000, Dispersal of woody plants in forest edges and hedgerows in a Southern Swedish agricultural area: the role of site and landscape structure, *Landscape Ecology*, **15**: 229-242.
40. Sterk M., Gortb G., Klimkowskac A., van Ruijvend J., van Teeffelene A.J.A., Wamelinkh G.W.W., 2013, Assess ecosystem resilience: linking response and effect traits to environmental variability, *Ecological Indicators*, **30**: 21-27.
41. Tichý L., Chytrý M., Šmarda P., 2011, Evaluating the stability of the classification of community data, *Ecography*, **34**: 807-813.
42. Tilman D., Knops J., Weldin D., Reich P., Ritchie M., Siemann E., 1997, The influence of functional diversity and composition on ecosystem processes, *Science*, **277**: 1300-1302.
43. van der Heijden M.G.A., Horton T.R., 2009, Socialism in soil? The importance of mycorrhizal fungal networks for facilitation in natural ecosystems, *Journal of Ecology*, **97**: 1139-1150.

44. van der Heijden M.G.A., Klironomos J.N., Ursic M., Moutoglis P., Streitwolf-Engel R., Boller, T., 1998, Mycorrhizal fungal diversity determines plant biodiversity, ecosystem variability and productivity, *Nature*, **396**: 72-75.
45. Wali M.K., 1999, Ecological succession and the rehabilitation of disturbed terrestrial ecosystems, *Plant and Soil*, **213**: 195-220.
46. Walker L.R., del Moral R., 2003, *Primary succession and ecosystem rehabilitation*, Cambridge University Press, Cambridge.
47. Walker L.R., del Moral R., 2009, Lessons from primary succession for restoration of severely damaged habitats, *Applied Vegetation Science*, **12**: 57-67.
48. White P.S., Jentsch A., 2004, Disturbance, succession and community assembly in terrestrial plant communities, in: *Assembly rules and restoration ecology: Bridging the gap between theory and practice*, eds.: Temperton V.K., Hobbs R.J., Nuttle T., Halle S., Island Press, Washington DC.
49. Young T.P., 2000, Restoration ecology and conservation biology, *Biological Conservation*, **92**: 73-83.

Keywords:

- mining impact
- metalliferous waste heaps
- primary succession
- cronosequences
- vegetation structure
- spatial, functional and temporal dynamics of vegetation
- composition and configuration context of landscape
- Roşia Montană
- Romania