

Vegetation Dynamics Depending on Ecological Particularities of Bozanta Mare (Maramures County-Romania) Tailing Pond: Case Study

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Abstract: The present study followed an ecological demarche of reintegration in the scenery through revegetation of an anthropic ground, consisting in a waste pond formed from the flotation activity of non-ferrous ores. **Problem statement:** To support the formation of a compact vegetal layer, having anti-erosion and a restoration role, a preliminary study was required regarding the spontaneous settlement of different vegetal species. We had followed the specific floristic composition and biodiversity on the waste pond, manner of association of plant species and possible interactions with other species from the biocenosis (microorganisms and fungi). We had studied the pace at which vegetal species settle, as well as the reciprocal influence, from the point of view of vegetation, with the neighboring area, since the desideratum was the settlement of a vegetation similar to the natural one. **Approach:** The aim of the research was to draw a list of the vegetal taxa installed on the pond, as well as to detect some succession stages or some possible vegetal associations. We had established the share of different species in the vegetal layer on the waste pond through an analysis of ecological preferences, of the geographical origin of plant species, of the cariological and bioform profile. All this was done to compare the possible vegetal associations which settle on such anthropic grounds with the neighboring vegetation. The approach used was the classical one in fitosociology, recommended by the central European fit sociological school adapted to the pedo-climatic conditions in Romania. **Results:** Over 50 species of plants and fungi spontaneously settled had been listed and we had followed their association as well as their distribution, compared to the microclimatic conditions of the waste pond. We had distinguished species with a large potential of revegetating highly polluted with heavy metals waste ponds and sites. **Conclusion/Recommendations:** Starting from this study, we may establish a formula of sustaining the vegetation and using the interactions among species in order to stimulate the settlement of dense vegetation, which might ensure anti-erosion protection and landscape integration.

Key words: Tailing ponds vegetation, biological rehabilitation

INTRODUCTION

Non-ferrous minerals represent an important economic resource for most European States. The amount of ore processed by the mining industry each year is about 60 billion tons, of which waste accounts for almost 55%. Disposing of such enormous quantities of waste is a challenge for the mining industry and the issue is of concern to both authorities and citizens. Depending on the nature of the waste generated by mining activities, two methods to dispose of it generally apply. The discharge as tailings waste applies to the coarser particles coming from mine opening activities and they generally have no economic value. The fine

particles resulted from mineral processing are mixed with water and deposited in the form of slurry in tailings ponds. The construction does not always take place in compliance with safety requirements and this poses a high level of risk in countries where safety recommendations are not strictly followed. Tailing ponds are constructed without any impervious core and, as such, process and rainfall water seep through the dam towards its free face. Uncontrolled water flowing through, beneath or - in the worst case - over the dam can lead to a loss of stability. Water management is a key safety factor for the handling of large amounts of heterogeneous wet slurries. One of the main causes of accidents and hazards in tailing facilities is lack of

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water management practices. Failure and collapse of tailings ponds has tremendous consequences including casualties, damage to property and pollution of the environment. Many studies have reported the impacts and risk factors of failure of tailings wastes and tailings ponds on surrounding environment^[1-4].

Study area: In Maramures County, in the hot spot areas of non-ferrous mining industry are located over 20 tailing ponds, many of them still active. We can notice a special situation near Baia Mare city, where, in the same area, there are three tailing ponds (Fig. 1), one of them being under preservation.

The Preserved Tailings Pond is the oldest in the area and has been under preservation for more than 20 years.

The Remin Tailing Pond which was built in 1977 covers 1,050,000 m², is 30 m deep and has an embankment of 18-20°. Hydrocyclones located on the wall of the pond mechanically purify the wastewater collected from the industrial plants of Baia Mare. The pond collects the liquid phase thus spilled and the solid waste is deposited on the wall for reinforcement purposes. A build-up rate of 2 m annum⁻¹ has allowed for over 150,000,000 m³ of tailings to accumulate in the pond. Winds easily transport the dam's fine particles. There were a few attempts to consolidate the pond by planting trees of which bur (*Cirsium lacceolatum*) and acacia (*Robinia pseudacacia*) are best adapted to the site.

The newest pond in the area is the Transgold Tailings Pond, where the wastewaters coming from the Transgold Plant (former AURUL) used to be discharged. The pond which is about 3.8 km long and covers 94,0000 m² contains wastewaters with high amounts of heavy metals and cyanide.

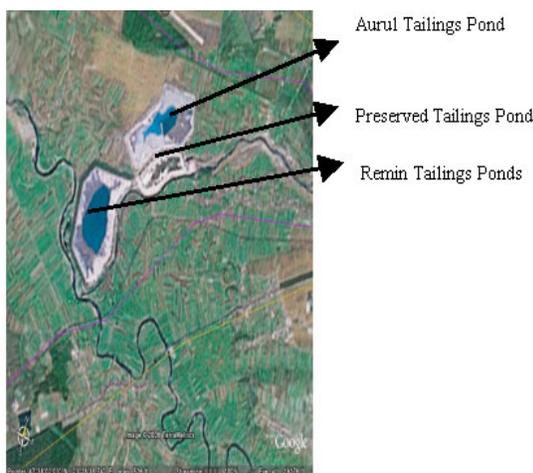


Fig. 1: Overview of tailings ponds in studied area

The study considers preserved tailings pond: The physical stability of dam refers to the collapse of the dam as a consequence of circular sliding, sinking of the foundation and regressive erosion induced by the spilling of the wastewater over the dam. The main factors which influence the physical stability of the dam are the granulometry of the grains, the construction characteristics, the seismic risk of area, the configuration of the tailing's foundation and also its physical, chemical and elastic properties. For the Preserved Tailings Pond, the physical characteristics of the soils are shown in Table 1^[5-8].

Due the fact that the largest part (about 39%) of pond's dam is made by fine particles (under 0.005 mm Table 1), large amounts of fine particles in the sub-layer, strongly polluted with heavy metals, were transported by winds and deposited in the surrounding areas. Large size particles were transported by rains and thus many ravines appeared Fig. 2. This erosion process reduces the physically stability of the pond.

Chemical stability of the tailing pond and the soil around is strongly affected by the potential acidity of the solid waste forming the dam. Pyrite (FeS₂) accounts for the highest proportion of the chemical composition in the above-mentioned tailing ponds with chalcopyrite (CuFeS₂), galena (PbS) and sphalerite (ZnS) being reported as well.

Table 1: Characteristics of soil

Nr. Crt.	Parameter	Value
1	Texture	Sandy clay loam
2	Type	Alluvial
3	Organic matter, g kg ⁻¹	0.57
4	Organic carbon, g kg ⁻¹	0.38
5	Water holding capacity, mm/cm depth of soil	38.7
6	Cationic Exchange Capacity (CEC), cmol kg ⁻¹	12.6
7	Mineralogical composition:	
	Quartzite (sand)	40-45
	Clay	20-25
	Feldspar	15-Oct
	Sulphides	7-8
	Sericite, Carbonates,	23-7
8	Particle composition, %	
	>0.2 mm	3
	0.2÷0.2 mm	4
	0.1÷0.05 mm	18
	0.05÷0.02 mm	10
	0.02÷0.01 mm	15
	0.01÷0.015 mm	11
	<0.005 mm	39
9	Physico-mechanical parameters of sandy clay loam	
	Natural humidity, %	27-37
	Plasticity, %	56-61
	Porosity, %	60-17
	Coativity factor, KPa	22.46
	Specific weigh, KN· m ⁻³	24.13

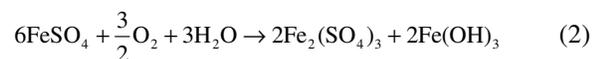


Fig. 2: Ravines in the pond's dam

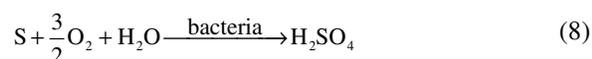
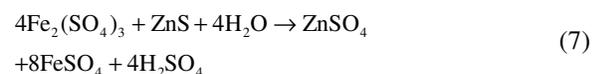
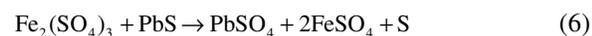
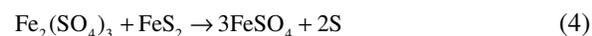
The high specific area of the ore's grains induced by their low granulometry favours oxidation in the presence of air, water and microorganisms. In concentrations of 0.5-1%, pyrite is the main factor that causes acidity. The next chemical reactions occur:



The rate of the reaction increases 10^4 - 10^6 times in the presence of the ferroxidans bacteria^[2]. Ferrous sulphate (II) is oxidised to ferric sulphate (III):



The ferric sulphate (III) attacks the other compounds presented in the solide waste, as follows:



The oxidation-hydrolysis reactions are very intense at high levels of precipitations. In their absence, the oxygen in the air will oxidize the sulphide to sulphates. As the chemical reactions 1-7 indicate, the result

consists in soluble (FeSO_4 , CuSO_4 , ZnSO_4) and insoluble (PbSO_4) sulphates. During rains, the acidity of waters increases following the dissolution of soluble sulphates, that are subsequently transported in the soil. Chemical reactions 1, 7 and 8 indicate that large amounts of sulphuric acid are generated. If alkaline substances are present in the area (such as wastewaters coming from flotation plants, cyanuric wastewaters), partial or complete neutralization of the acidity resulting from the oxidation of the ore would occur. If the quantity of acid exceeds the quantity of alkaline substances, acidic drainage is released resulting in dissolution of heavy metals and subsequent pollution of the environment. Considering that average annual precipitation in the area (996 mm) exceeds evaporation (720 mm), the acid exfiltrations appear following pond's washing by rains. Due to the low permeability of soil as the presence of sandy clay loam in the structure (Table 1), acid wastewaters accumulation is favored at the pond's base.

Considering the above presented elements, we can conclude that, even if the active tailing ponds wouldn't be present in the studied area, the pond under the preservation is itself a threat to the environment due to its pollutant potential. Knowing that, there were some attempts to stabilized and integrate the ponds in environment, trying to cover it in vegetation, which assures inclusion of the pond in the landscape and the estetic repair of degraded land, but, the most important element is represented by covering and settling of toxic soils and thus avoiding their transportation by winds and their deposition over the fertile soils and human habitats in the proximity. Appearance of spontaneous vegetation on pond's dam is a long term process, the conditions of this topos, which cannot be named biotop, are extreme, the high concentrations of toxic substances (especially heavy metals) being the most drastically and limiting factor. That is why, ecological reconstruction is the only chance for greening tailing ponds.

Up to now, there were a few attempts to cover in vegetation the studied pond. Some effects are visible, but they are not enough, because the actions were focused only on one component of the ecosystem: Re-built of trees layer, without paying much attention to the microbiota and grass layers, the elements which are the most efficient in surface's cover and avoiding of powders mobility.

MATERIALS AND METHODS

Data regarding flora from the mining ponds from Bozanta Mare represent the results of our investigations made during 2007. The study started with a preably

reconnaissance of territory and of the chemical characteristics of the soil. For each identified species we had in attention the following features: Biological form, floristic element, number of chromosomes and the ecological indices that are characterizing them. The biological forms, number of chromosomes and floristic elements for each species are those that have been given by V. Ciocarlan and the values for ecological indices (T-temperature, U-humidity, R-soil pH) have been established by V. Sanda, A. Popescu, M. Doltu and N. Donita. The used nomenclature is that adopted by Ciocarlan. For the study of vegetation we used the method of the phyto-coenological school in Zurich-Montpellier, perfected by Braun-Blanquet and J. Pavillard.

RESULTS

This study means to observe the specific diversity of cormphytes and fungi spontaneously installed on Bozanta pond twenty years after the attempts to revegetate the area.

Twenty years ago, on the pond dam there were planted black pine (*Pinus nigra*) and acacia (*Robinia pseudacacia*). Actual analysis of the area indicates that only a small part of them rezisted and grew (about 10-20%), only a few have 5-10 m in height and they did not cover more than 10% of pond's surface. In this situation we cannot speak about a unitary crowning as is normal in a plantation. On the E mountainside of the pond there are not significant differences regarding the vegetation comparing with the reference hight. Some bigger *Pinus nigra* and *Robinia pseudacacia* (5-10 m in height) are presented, but their crowning projection on soil do not cover more than 5%. Besides the ligneous species planted on the slopes of this pond, other vegetal individuals belonging to ligneous and herbaceous species have spontaneously installed there, species presented in the synthetic charts.

Table 2 shows some characteristic of vegetation presented on E mountainside.

The study analyzed the flora and vegetation presented on investigated tailing ponds and in the vicinity, to show the floristic differences which appear and the possible negative influences of the pond on phytocoenosis in the area. Only 11 species are present and the surface they cover is not enough. Due to the lack of the vegetal layer, ravines appear on the slopes, thus leading to the erosion of the dam under the influence of rain. The presence of ravines indicate that a great amount of soil was transported at the pond's base. In the case of E and S-E mountainsides, beyond the

layer charged with heavy metals, insulation acts as a high level limiting factor making harder the development of grassy species which exploit the superficial horizon of sub-layer as water source. On S and N-W mountainsides the situation is positively different. We appreciate a lower insulation on these sides, a lower dehydration level which allows the development of a larger number of species. Some characteristics of vegetation presented on N-W mountainsides are shown in Table 3.

Raunkiaer's life forms analyses: The structure of Raunkiaer's life forms: Mega Phanerophytes (from a past forestation trying) prevail with 54.54%, followed by hemicryptophytes 18.18% and the other life forms are in smaller proportions (Fig. 3).

Table 2: Characteristics of vegetation presented on E and S-E mountainsides

Survey number	1	2	3	4
Direction	E	E	SE	SE
Altitude	Base	Base	The first	The first
	of dump	of dump	v	terrace
Trees' hight	5-10 m	5-10 m	3-4 m	3-5 m
Unity of crowning (degrees)	0.6	0.6	0.4	0.3
General cover (%)	20	20	15	10
<i>Pinus nigra</i>	1	1	-	+
<i>Robinia pseudacacia</i>	+	+	1	+
<i>Betula pendula</i>	+	-	+	+
<i>Frangula alnus</i>	-	-	+	-
<i>Rubus sulcatus</i>	-	-	+	+
<i>Agrostis capillaris</i>	+1	+	+	1
<i>Equisetum arvense</i>	+	-	-	-
<i>Juncus effusus</i>	+	+	-	-
<i>Cardaminopsis arenosa</i>	+	+	-	-
<i>Phragmites australis</i>	-	-	+	-
<i>Reinouttria japonica</i>	+1	-	1	+

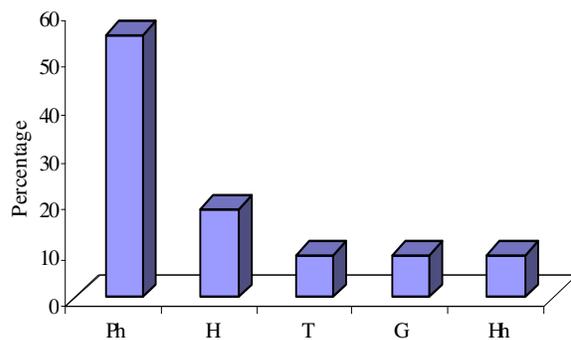


Fig. 3: Raunkiaer's life forms: PhM mega phanerophytes, Phm meso-phanerophytes, Phn nano phanerophytes, H-hemicryptophytes, G-geophytes, Hh-helohydatophytes, ch-chamephytes

Table 3: Characteristics of vegetation presented on N-W mountainsides

Survey No.	1	2	3	4	5	6	7
Altitude	Base	Base	Terracy I at half pond	Terracy I at half pond	Terracy II clos	Terracy II clos to upper part	On upper part of pond
Direction	N	N	N	N-W	N	N-W	-
Slope, degree	30-40°	20°	0°	0°	0°	5°	0°
Crowning of trees	0,3	0,3	0,3	0,2	-	-	-
Covering of grassy layer %	60	50	10	5-10	5	20	1-2
<i>Robinia pseudacacia</i>	1-2	+1	+1	+	-	-	-
<i>Populus tremula</i>	+	+	+	+	-	-	-
<i>Quercus robur</i>	+	+	-	-	+	-	-
<i>Betula pendula</i>	+	+	+	+	+	-	-
<i>Prunus serotina</i>	+	-	+	-	-	+	-
<i>Agrostis capillaris</i>	4	2	+1	+	+2	+1	-
<i>Carex hirta</i>	+	-	+	2	+	1	-
<i>Juncus effusus</i>	+	-	-	-	-	-	-
<i>Juncus conglomeratus</i>	+	-	-	-	-	-	-
<i>Tussilago farfara</i>	+	+	-	-	-	-	-
<i>Phragmites australis</i>	+	+	-	-	-	+	+
<i>Festuca rubra</i>	+	-	-	-	-	-	-
<i>Holcus lanatus</i>	+	+	-	-	+	+	-
<i>Solanum dulcamara</i>	+	-	-	-	-	-	-
<i>Cichorium intybus</i>	+	-	-	-	-	-	-
<i>Galium cruciata</i>	+	-	-	-	-	-	-
<i>Lythrum salicaria</i>	+	-	-	-	-	-	-
<i>Melilotus albus</i>	+	-	-	-	-	-	-
<i>Verbascum phlomoides</i>	+	-	-	-	-	-	-
<i>Rumex acetosa</i>	+	-	-	+	+	-	-
<i>Erigeron annuus</i>	-	-	+	+	-	+	-
<i>Frangula alnus</i>	-	+	-	+	-	-	-
<i>Poa pratensis</i>	-	+	-	-	-	-	-
<i>Crepis biennis</i>	-	-	+	-	-	-	-
<i>Rubus sulcatus</i>	-	-	-	+	+	-	-
<i>Rumex acetosella</i>	-	-	1	+	+	+	+
<i>Hieracium pilosella</i>	-	-	-	1	+	+	-
<i>Setaria glauca</i>	-	-	-	-	+	+	-
<i>Calamagrostis epigeios</i>	-	-	-	-	-	+	-
<i>Convolvulus arvensis</i>	-	-	-	-	-	+	-
<i>Rosa canina</i>	-	-	+	+	-	+	-
<i>Polygonum aviculare</i>	-	+	-	-	+	+	-
<i>Rumex crispus</i>	-	-	-	-	-	-	+

In the floristic elements spectrum, prevail the Adventive species (27.27%), followed by the cosmopolite species and the eurasiatic species, central European species, circumpolar species and cosmopolites. The diploidy index (DI = D/P×100) has a value of 37.5%.

Humidity indices spectrum Fig. 5 reveals the presence and preponderance of mesophytes species (37.5%), followed by hygromesophytes (25%). The xeromesophytes (12.5%) and euryhygrous have both the same percentage.

Temperature indices spectrum Fig. 6 demonstrates the prevalence of mesothermophilous (37.5%), followed by eurythermic (25%) species and microthermophilous species (12.5%).

Soil pH spectrum (Fig. 7) reveals the most of cormophytes species indentified on these sterile deposits tolerate varied values of this indicator.

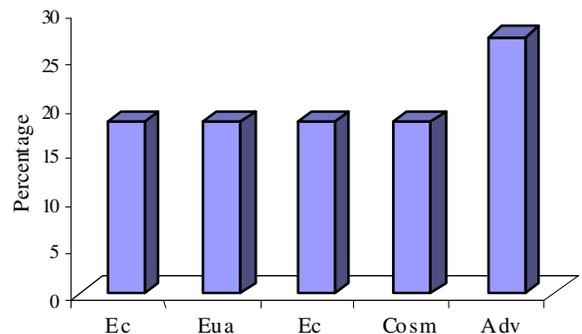


Fig. 4: Floristic elements spectrum

Prevailing of the acido-neutrophilous species (37.5%), euriionics species (25%) and the low acido-neutrophilous species (25%) followed by the acidophilous species (12.5%).

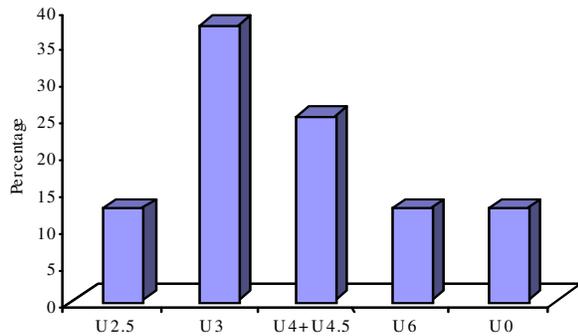


Fig. 5: Humidity indices spectrum

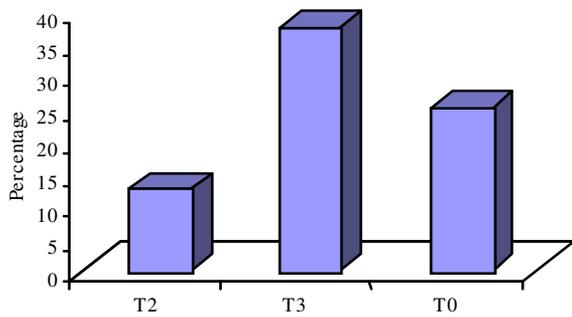


Fig. 6: Temperature indices spectrum

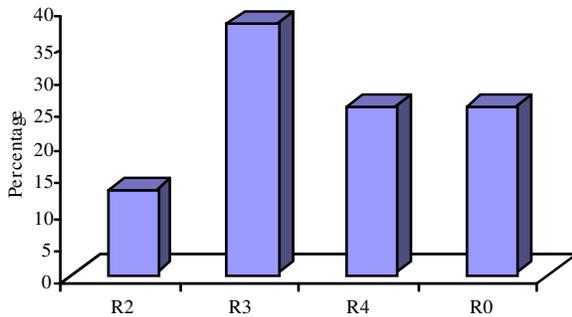


Fig. 7: Soil pH spectrum

It is obvious that on less exposed to the sun mountainsides, the number of species is higher, which proves that a limiting factor (as important as the sublayer) is lack of water. Also, we can notice that the surveys located at the pond's base, being in a kind of ecoton, with a soil un-washed by rains, present considerably much more species than the mountainsides areas.

The upper part of pond's crowning is almost entirely without vegetation. The planted trees in this area are completely dried and the grassy layer is not settled. The exception is represented by the water evaporation surface, with a high level of humidity where a reed (*Phragmites communis*) compact association is developing.

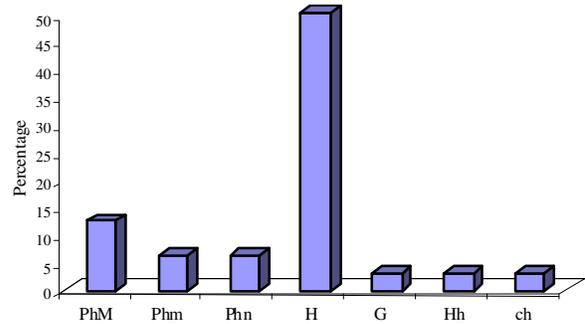


Fig. 8: Raunkiaer's life forms: PhM mega phanerophytes, Phm meso-phanerophytes, Phn-nano phanerophytes, H-hemicryptophytes, G-geophytes, Hh-helohydatophytes, ch-chamephytes

On the first terrace, at half pond and on the top some species of mushrooms like: *Laccaria laccata*, *Scleroderma citrinum*, *Inocybe lacera*, *Xylaria hypoxylon*, *Suillus bovinus*, *Calvatia excipuliformis*, *Pisolithus tinctorus*, *Telephora terrestris*, *Amanita muscaria*, *Rusula emetica*, *Paxillus involutus*, *Lactarius glycosmus*, *Russula vesca* were identified. We consider that mushroom diversity is considerable for this restrictive conditions. This great number of species of fungi indicate a mychorrizing maintenances with the cormophyte plants installed in such restrictive conditions.

Raunkiaer's life forms analyses: The structure of Raunkiaer's life forms: Hemicryptophytes prevail with 50 and 12.5% represent Mega Phanerophytes (from a past forestation trying) and the other life forms are in smaller proportions Fig. 8. The great number of hemicryptophytes demonstrates the tendency of colonization of tailings by perennial herbaceous species.

In the floristic elements spectrum, prevail the Eurasiatic species (37.5%), followed by the cosmopolite species (21.8%) and the alien species (9.375) (Fig. 9).

The eurasiatic and circumpolar elements represents the native species background and also the main source of colonizer species.

The diploidy index ($DI = D/P \times 100$) has a value of 33.33% reflected general ecological conditions and the pressure generated by human activities.

Humidity indices spectrum (Fig. 10) reveals the presence and preponderance of mesophytes species (33.33%) and xeromesophytes (30%), followed by mesohydrophilous (20%) and euryhygrous (3.33%).

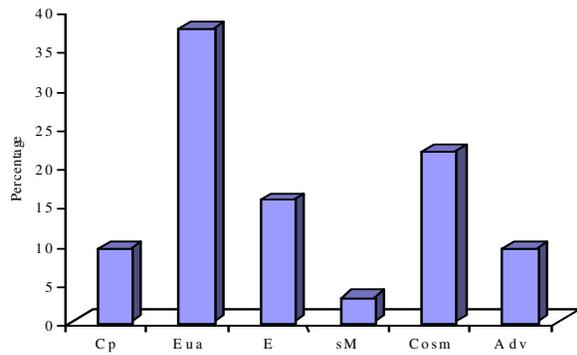


Fig. 9: Floristic elements spectrum

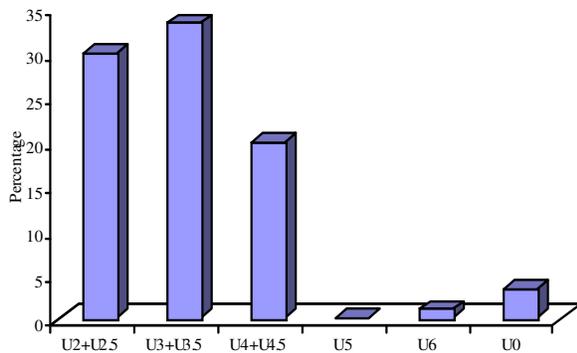


Fig. 10: Humidity indices spectrum

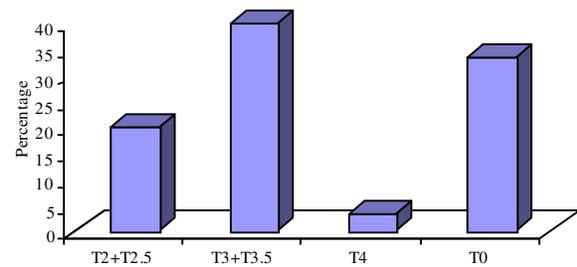


Fig. 11: Temperature indices spectrum

Temperature indices spectrum (Fig. 11) demonstrates the prevalence of mesothermophilous (36.66%), followed by eurythermic (33.33%) species and microthermophilous species (16.66%).

Soil pH spectrum (Fig. 12) reveals that most of cormophytes species indentified on these sterile deposits tolerate varied values of this indicator.

Euriionics species prevail (43.33%) and the acido-neutrophilous species have a significant proportion (23.43%), followed by the low acido-neutrophilous species (20%) and by the acidophilous species (16.66%).

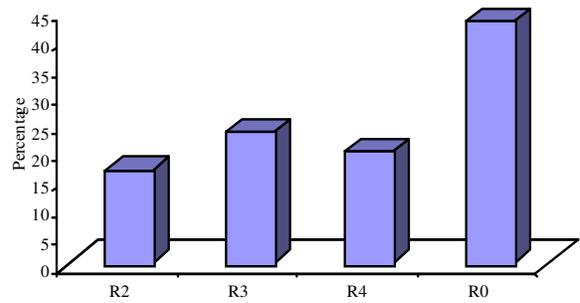


Fig. 12: Soil pH spectrum

The vegetation around the pond is entirely ruderal, installed along the access roads to the pond. It is obvious that high concentrations of heavy metals in soil are lower, many species being present: *Daucus carota*, *Cichorium intybus*, *Trifolium pratense*, *Taraxacum officinale*, *Galium verum*, *Tussilago farfara*, *Achillea millefolium*, *Campanula patula*, *Rumex acetosella*, *Galium pseudoaristatum*, *Eupatorium cannabinum*, *Equisetum arvense*, *Melilotus albus*, *Cirsium rvense*, *Lythrum salicaria*, *Ranunculus repens*, *Festuca gigantea*, *Dactylis glomerata*, *Lotus corniculatus*, *Abutilon theophrasti*, *Convolvulus arvensis*, *Galium molugo*, *Salix viminalis*, *Erigeron canadensis*, *Matricaria recutita*, *Artemisia vulgaris*, *Centaurea austriaca*, *Chrysanthemum leucanthemum*, *Lactuca saligna*, *Salix alba*, *Plantago lanceolata*, *Trifolium medium*, *Inula britannica*, *Linaria vulgaris*, *Lathyrus tuberosus*, *Thypha latifolia*, *Silene alba*, *Prunus spinosa*, *Populus nigra*.

We have noticed a low number of leguminous species whose roots could establish symbiotic relationships with settling nitrogen bacteria, meaning that the soil structure could not be improved.

DISCUSSION

The present study case catches a certain aspect of a primary sequence of vegetation, on the one hand stimulated by planting some ligneous species in order to rehabilitate the area and, on the other hand, greatly slowed down by the substratum's restrictive conditions.

We ascertain that on various slopes of the pond, the sequence of vegetation is at different stages, although the stratum is the same, thus proving that alongside the restrictive polluting influence of the stratum, physical agents, such as external display, insolation, erosion exert significant external influences on consolidating the vegetal layer. On the eastern slope, which is exposed to insolation and erosion, the vegetation has been in a colonisation process for over twenty years and still the number of vegetal species is small and the layer discontinuous.



Fig. 13. Mycorrhizal roots of *Quercus petraea*

On the slope with a west-north-west orientation we can distinguish and determine the precise class of certain vegetal associations, the vegetal layer being in a strengthening stage. The number of species is higher, for species like: *Agrostis capillaris*, *Carex hirta*, *Rumex acetosella*, *Hieracium pilosella*, *Polygonum aviculare* which have more numerous and compact populations.

Moreover, many of the installed species, through planting or spontaneous reproduce vegetatively and sexed, fructifying and disseminating. Thus, we can notice fructifying and regenerating from seedling at *Pinus nigra*, *Prunus serotina*, *Quercus petraea* an regeneration by vegetative means at *Rubus hirtus*, *Hieracium pilosella*.

The large number of species of mycorrhizal fungi identified on the pond indicate a maintenance of ligneous vegetation. There have also been noticed mycorrhizals at the root level of *Betula verrucosa*, *Populus tremula*, *Quercus petraea* (Fig. 13).

At the level of vegetation dynamics, these observations indicate a slow passage from the colonization process towards one of consolidation. Taking into consideration the restrictive conditions, this stage is a long term one and slowed down by the high concentrations of pollutants in this anthropic layer.

Stimulating the sequence stages of vegetation which condition the ecological rehabilitation of such ponds, depends on abiotic factors and on the sublayer, external display, insolation, on the dip of the slopes, but also on the development and maintenance of the other categories of micro-organisms and fungi.

Starting from the case study presented above, we consider that the ecological reconstruction by trees planting is not enough and on long term proves incapacity for covering the degraded surface with a continuous vegetation layer. Cover in vegetation of ponds should consider beyond of cover with a continuous fertile soil layer and immediately cover with vegetation resisting to extreme conditions of dry and high level of contaminants. The studies and

rehabilitation should be also oriented to improvement of microbiota (fungus, microorganisms) of which development is directly conditioned by the vegetation layer.

CONCLUSION

Finally, we can conclude that the tailing ponds under preservation still remain threats to the environment, due to their physical and chemical instability. One of the most important problems that must be solved concerns avoiding of soil mobility. In this respect, biological rehabilitation of the pond should be considered in all ecosystem's elements: trees and grasslayers and microbiota of soil. Symbiotic relationships settled among all these contribute not only to stop the mobility of soil, but also to improve the soil structure.

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