METHODOLOGY FOR MONITORING LAND RECLAMATION OF COAL MINING DUMPS[1]

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Abstract: The main objective of reclaiming coal mining dumps is to create a stable and self-sustaining land surface that can, in the long term, be put to some productive use. The relationship that is established between the soil and vegetation is the starting point for the newly created ecosystem to enter into a dynamic evolution. In order to know this evolution, it is necessary to develop a methodology for monitoring systematically the reclaimed surfaces. This monitoring methodology should make it feasible to continuously evaluate the obtained results and serve to clarify the potential uses of the reclaimed lands. This paper explains a monitoring methodology implemented at the mining waste dump at the Puentes Mine in Spain. It consists of the selection of 11 plots on the basis of the time the spoils have been exposed to weathering, the type of reconstructed soils, the reclamation system applied, and the revegetation success. Furthermore, an attempt was made to include every possible situation in the dump. Over a period of 3 years, the evolution of the physicochemical conditions of the reconstructed soils, the soil organisms, the herbaceous species, mycorrhizae, tree species, and vertebrates in these plots were studied. The paper also defines the parameters that need to be controlled within each phase of the study. The results obtained reveal the necessity to place the spoils selectively in the dump, the possibilities offered by the ashes as amendments, and the importance of applying organic fertilizers, seeding herbaceous species as a first phase, selecting tree species, and introducing the vertebrates, soil organisms, and mycorrhizae gradually.

Introduction and Objectives

The subject of this paper is the development of a technique to monitor systematically the evolution of a coal mining waste dump that is in the process of land rehabilitation. The work was conducted from 1990 to 1993 and is part of a research project financed partially by the European Económic Community. At the same time, this project forms part of a global program started by the Empresa Nacional de Electricidad S.A. (ENDESA) at the beginning of the 1980's. The objectives of this global program include recuperating the landscape altered by mining operations and establishing a ground cover that controls erosion as well as the quality of the runoff water and favors the creation of productive land. The results presented in this paper encompass conclusions about the analytical techniques and prospecting methods that should be used to correctly monitor the steps taken in land reclamation, the land reclamation techniques that have been the most appropriate for environmental rehabilitation of the dump, the foreseeable evolution of reclaimed surfaces, and their suitability for different land uses.

The site of the project is the Puentes Mine which is located in the municipality of As Pontes in the province of La Coruña in northwestern Spain. At this mine, there is a combination of circumstances that make land reclamation extremely difficult. The most outstanding of these factors are the extreme acidity and toxicity of the spoils, the scarcity of topsoil due to the time lag between entry into operation of the mining activity and land reclamation work, the high rainfall along with consequent erosion and water contamination, and the absence of methodologies in Europe for the reclamation of surface mined land with these characteristics. Finding a method for the reclamation of surface mined lands with these difficulties is a top priority in Spain.

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Background

Description of the Exploitation

ENDESA has been exploiting the Puentes Mine since 1976. The brown lignite from this mining operation supplies a nearby 1,400-Mw powerplant. The deposit is approximately 6 km long and 2 km wide. There is a partial narrowing at the center that divides the exploitation area into two fields: west and east. Owing to the characteristics of the deposit, transfer mining, namely, mining in which the spoils are dumped in the area already exploited, has been impossible.

The basement and edges of the coalfield consist of porphyric schists from the Precambrian period. On top of these are materials from the Ordovician period that are separated by a stratigraphic discontinuity. The series is formed by an alternation of phyllites, quartz phyllites, and quartzites, with a clear predominance of the phyllites. On top of these basement rocks is a series of materials from the Tertiary period in erosional unconformity. The bottom of this series consists of a level of plastic clays that are a result of the complete weathering of the phyllites. Above this level, there is basically an alternation in angular unconformity of clays, carbonaceous clays, and lignites with a total thickness of 400 m.

Currently, the minable reserves total 130 Mt, and the rate of extraction is about 12 Mt of lignite annually. As a result, 42 Mm^3 of spoils is excavated and spread annually.

Seven bucket wheel excavators extract the materials, and five pilers deposit the spoils in the dump. The excavated material is carried by conveyor belt to a transfer point, after which the lignite is sent to the powerplant and the spoils to the pilers. The ashes and slag also arrive at this same transfer point. They are then evacuated by dry method and also deposited in the dump. Consequently, the material dumped is made up of tertiary clays intercalated between the seams of minable coal, slates from the edges of the sedimentary basin, which have to be excavated because of the stability of the final slopes of the mine, and the ashes from the powerplant. Furthermore, the fact that all the materials to be dumped come together at the transfer point makes it possible, within the limitations of the mining operation itself, to mix the materials as well as carry out a certain selection of those that will constitute the final surfaces of the dump.

The system for depositing the spoils involves producing final surfaces in the dump at intervals and at an average rate of 60 ha per year. The pilers dump by levels with a height of approximately 20 m, depending on the projected geometry of the dump. Each level consists of a slope with a 20% gradient and a horizontal berm that both constitute the final surfaces of the dump. Once the dump is finished, it will contain 750 Mm^3 of spoils, cover an area of 1,400 ha, and have a maximum height of 200 m.

The mining operation affects several tributaries of the Eume River, which flows in the immediate area, since perimetric channels that flow directly to the waters outside the mining operation have been constructed. Likewise, all the waters from the mine and the dump are canalized to the treatment plant, located near the powerplant, for purification.

Characteristics of the Environment

Surrounding Area

The natural terrain surrounding the mining operation has a curve-backed aspect with elevations between 330 and 540 m. There is a strong anthropic influence. The pasture predominates and is divided into small plots for exploitation, which are demarcated by lined trees and look like a vegetable mosaic. In the areas with steep gradients, shrubs predominate. The different species of *Ulex*, *Cytisus*, and *Erica* predominate. Along the river bank, there is a thickly wooded area with prevalence of *Betula pubescens*, *Salix atrocinera*, and *Alnus glutinosa*.

In addition, there are are small areas with arboreal species characteristic of the region: *Betula pubescens* and *Quercus robur*. Likewise, small reforestations of *Pinus pinaster*, *Pinus insignis*, and *Eucaliptus ssp* can be found.

The geological material of this area is formed mainly by slates and phyllites. The soils developed on top of these materials are characterized by little geochemical evolution due to the high degree of stability of the material. With regard to fertility, these soils have high content of organic matter with an amount of organic carbon between 4.2% and 12.1%, very acidic pH (the most frequent values for pH in water are between 4.1 and 4.6 and never higher than 5.5), predominance of variable charges in the cationic exchange capacity, frequent alic nature (> 60 % saturation of aluminum in the cationic exchange capacity), frequent shortages of Ca and Mg, and low levels of P and K.

Climate

Some of the most outstanding climatic parameters of the area are summarized in table 1.

The extreme monthly thermal amplitude is relatively high throughout the year. The smallest difference is in December (7.5 °C) and the greatest in August (10.9 °C).

The average annual accumulated precipitation is 1,678 mm (table 1). The extreme values were registered in 1951 with a maximum of 2,516 mm and in 1973 with a minimum of 1,178 mm. With regard to its distribution during the year, a marked seasonality has been observed and the following periods are distinguished:

- Period with high precipitation: The rainfall is normally greater than 150 mm per month, and values up to 130 mm/day and 30 mm/h are reached. This period extends from October to March and, as a whole, represents 70% of the average annual accumulated precipitation.
- Period with medium precipitation: This includes September, April, and May and accounts for 20% of the annual total amount.
- Period with low precipitation: During this period, from June to August, the rainfall is less than 100 mm per month and its portion of the average annual accumulated precipitation is 10%.

Table 1. Average monthly values for climatic parameters at the As Pontes weather station.

	Months												
	J	F	M	A	M	J	J	A	S	O	N	D	Annual
T	6.7	6.8	8.5	9.7	12.1	14.9	17.1	17.3	16.1	13.1	9.2	7.3	11.6
MT	10.6	11.2	13.5	14.3	16.8	20.1	22.2	22.7	21.5	18.1	13.6	10.9	16.3
mT	2.7	2.7	3.6	5.1	7.3	10.0	12.1	11.9	10.6	8.2	5.1	3.8	6.9
maxT	16.3	17.9	21.3	22.5	25.7	29.0	31.2	30.8	30.3	25.9	19.4	16.2	23.9
minT	-3.6	-3.7	-2.4	-0.8	1.6	4.6	6.0	6.2	4.2	1.6	-1.1	-3.2	0.9
P	228	188	160	119	112	72	39	51	101	157	200	251	1,678
PET	16	23	47	69	97	108	122	101	58	39	17	15	713
RH	84.3	82.2	79.4	78.5	77.7	77.7	77.7	78.3	79.4	82.3	83.1	84.5	80.0

[1] T=average temperature (°C); MT=average maximum temperature; mT=average minimum temperature; maxT=average absolute maximum temperature; minT=average absolute minimum temperature; P=precipitation (mm); PET=potential evapotranspiration (mm); RH=relative humidity (%).

When the periods with minimum rainfall and the maximum values for evapotranspiration coincide, there is a period with a shortage of humidity that begins in May and extends through September.

With regard to the wind, the prevalent components on a yearly basis are northeast and southwest. In the fall and winter, the southern components (south, southeast, and southwest) prevail and in the summer the eastern components (northeast and east) prevail. The average monthly wind rate ranges from 8 to 11 km/h.

Methodology

This consists of the working method followed for the reclamation of the dump surfaces whose evolution is the object of monitoring, as well as the methodology that has been developed to carry out this monitoring.

Reclamation Methodology

In 1980, ENDESA prepared a Land Reclamation Plan (Val et al. 1989) whose aim was to recuperate the surfaces affected by the mining operation, namely, the dump and the edge of the mine, which total 1,800 ha. Upon completion of the mining operation, a large lake will cover the cavity of the excavated mine. Until 1992, 350 ha of final surfaces were generated.

As a step prior to the undertaking of the specific work of revegetation in these surfaces, a series of criteria concerning the course of action to be followed was adopted. Chronologically, they were:

- Integration of the reclamation activity in the normal development of the mine.
- Awareness of the entire mine work force with regard to this new activity.
- Exploitation of all the possibilities of the deposit and work to improve the quality of the substrate of the final surfaces of the dump.
- Preparation of development projects as well as detailed ones for the dump.
- Project for and the carrying out of the infrastructure works needed (accesses and water evacuation and drainage systems).
- Determination of the uses of the land to be achieved in the different surfaces to be reclaimed, namely, forest land and pastureland.

The specific land rehabilitation stage includes the following:

Study of the Spoils at the Mining Faces. Physicochemical analysis (Guitian and Carballas 1975) is conducted of the seams of spoil in the coal deposit to select the most suitable as topsoil substitute material, on the basis of their agricultural capacity, which are deposited later in the final surfaces of the dump. Analysis is also conducted of the series of slates, that crop out above the coalbed and are excavated due to geotechnical requirements, and the series of spoils from the coal deposit.

Analysis of the Final Dump Surface Materials. There are two reasons for taking a second sample and analyzing it. One is the possibility of the final surface being formed by spoils that have not been selected for this purpose; and the other is to know the real quality of the surfaces to be reclaimed. The number of samples per hectare is 8, with a repetition. The following are analyzed according to the methods described by Peech et al. (1947), Gil et al. (1990), and Urrutia et al. (1992): pH, pH oxidation, total S, cationic exchange capacity (exchange capacity, H+, Al, K, Ca, Mg, Na) and Al saturation. The nutrient elements have not been analyzed, since although the spoils have some nutrients, especially assimilable phosphorus content, they have been fertilized as if they did not have any nutrients.

For orientational purposes, table 2 shows some representative results from the analyses of nonselected spoils from the final surfaces of the dump.

Table 2. Chemical analyses in the final surfaces of the dump.

Samples	pH H_2O	% Total S	pH Oxidation	Exchange Cations (mg/100 gr)					% Al Saturation
				Al	Ca	Mg	Na	K	
1	5.30	0.41	2.76	3.44	1.1	3.17	0.25	0.01	43.22
2	6.25	1.69	2.48	3.66	0.7	2.13	0.16	0.02	54.95
3	5.57	0.40	2.55	0.01	3.9	2.09	0.24	0.03	0.16
4	4.60	1.62	2.50	0.33	0.2	1.38	0.20	0.06	15.21
5	6.01	0.27	3.67	0.10	1.6	1.56	0.03	0.22	2.85
6	6.90	0.31	4.34	1.95	2.4	2.26	0.38	-	27.90

Soil Amendments and Topsoil Worth Replacing. Since it is impossible to replace the layer of topsoil on the entire surface of the dump, calcium carbonate and ashes from the powerplant have been applied as modifiers of the acidity in the spoils. On the basis of the tests performed, the following strategy has been established in general:

pH < 3.5: addition of ashes.
$5 >$ pH > 3.5: addition of calcium carbonate in doses of 5-15 t/ha.
pH > 5: addition of calcium carbonate in doses of < 5 t/ha.

The dose of ash has fluctuated between 500 and 1,000 m^3/ha, depending on the acidity and the type of agricultural work that is foreseen.

As an alternative to the contribution of the soil amendments, the spoils are covered with a layer of topsoil whenever it is available. This layer is 10 to 40 cm thick and sometimes has to be treated with small doses of calcium carbonate (3 t/ha).

Chemical and Organic Fertilizers. Once the acidity of the reconstructed soil is controlled, fertilization through pre- and postseeding fertilizers occurs. Initially, the following rates of fertilizers (fertilizer units) have been applied as a nutrient reservoir prior to seeding:

- N: 50-60 fertilizer units (F.U.)
- P: 150-160 F.U.
- K: 110-120 F.U.

starting from complex 8.24.16.

As a postseeding fertilizer, basically nitrogen has been added with a dose of 40-50 F.U. per hectare, starting from nitramon or with the addition of 15.15.15.

The use of organic fertilizers has had excellent results in the pastureland. The following doses of hen droppings have been applied:

- 30 m^3/ha (in the form of liquid manure)
- 20 t/ha (in the form of solid manure).

Likewise, municipal sewage sludge in doses of 50 t/ha has been applied.

Seeding. Irrespective of the land use that has been determined previously, the seeding of pasture species on all the surfaces occurs with the aim of obtaining a rapid vegetation cover. The mixture of species and doses depends on the land use assigned to each surface (50 to 100 kg per hectare). The species used are *Holcus lanatus*, *Agrostis tennuis*, *Festuca arundinacea*, *Dactylis glomerata*, *Lolium perenne*,and *Trifolium repens*. Occasionally, the shrubs *Cytisus scoparius* and *Ulex europaeus* are incorporated into the mixtures (Jones et al. 1975).

Plantings. Tree species are introduced in the majority of the dump surfaces, fundamentally on the slopes. The distance between trees is 2 x 2 m in quincunx, and there are 3-m-wide pathways every 8 m of separation according to the level lines.

The following species have been planted: *Betula pubescens*, *Alnus glutinosa*, *Pinus insignis*, *Pinus pinaster*, *Eucaliptus ssp.*, *Salix atrocinerea*, *Robinia pseudoacacia*, *Acacia melanoxilon*, *Pseudotsuga douglasii*. In specific dump surfaces, *Castanea sativa* and *Quercus rubra* have been introduced.

Initially, the leafy species were planted with the root exposed and two saps and the coniferous species with a root ball and one to two saps. As a mineral fertilizer, acid calcium phosphate and potassium sulphate in doses of 80 and 50 g per plant, respectively, were applied.

Maintenance Work. Soil analysis campaigns are conducted during the years following the first agricultural year in order to know the chemical evolution of the reclaimed surfaces. On the basis of these analyses, the corresponding amendments and fertilizers are applied to ensure that the soil surface remains in a stable state and there is revegetation success.

Methodology for Monitoring

The results obtained with the application of this line of work are considered important, especially in light of the initial constraints that come together in the land reclamation of this mine. However, due to the quality of the spoils and the limited experience at a national level concerning land reclamation, it was advisable to conduct a detailed monitoring of the behavior as well as the evolution of the reclaimed surfaces. To do this, 11 plots have been selected on the basis of the time the reconstructed soils have been exposed to weathering, the type of reconstructed soils, the handling and the revegetation success. Furthermore, an attempt was made to include every possible situation existing in the dump.

The methodology to evaluate the results and evolution of each of these plots included the study of:

- Physicochemical conditions of the reconstructed soil
- Soil organisms (invertebrates and microorganisms)
- Herbaceous species
- Mycorrhizae (ectomycorrhizal fungus)
- Forest species (trees)
- Vertebrates

Physicochemical Conditions of the Reconstructed Soil. The following have been studied according to the methods mentioned previously:

- The physical properties of the soil: texture, structure, water-holding capacity, hydric balance, and moisture regime of the soil.
- Mineralogy of the clay fraction.
- Chemical properties and fertility: organic matter and C/N ratio, present and potential acidity, base cationic exchange capacity, phosphorus, and heavy metals.
- Composition of the liquid phase of the soil: pH, electrical conductivity and redox potential, anions, basic cations, Si, Al, Fe, and trace elements (Calvo et al. 1987, Kabata-Pendias and Pendias 1984).

Soil Organisms. With special attention paid to the most important groups with regard to the N, C, and S cycles, the microbial populations have been characterized (Jurgensen 1978). On the other hand, the natural colonization of earthworms under different conditions of pH, texture, organic matter, moisture content, and land reclamation activities has been monitored.

Herbaceous Species. With the aim of knowing the potential capacity for pastureland, the number of cuts per year that the corresponding grass cover is capable of tolerating has been estimated. With each cut this production, in green as well as dry material, has been controlled on the basis of the different doses of postseeding fertilizers: without fertilization, 40 F.U. of N, 60 F.U. of N, 40 F.U. of N + 60 F.U. of P. Additionally, analytical determinations have been performed on the samples of the species that have been seeded. The purpose has been to know the assimilation of the soil elements available to the plants and their suitability for consumption by cattle.

Mycorrhizae. An initial prospection has been conducted in the natural zones near the dump and in the monitored plots in order to know the fungus-tree correspondence. Thus, the most adequate ectomycorrhizal fungi for reproduction for each species has been identified. Furthermore, the real spontaneous colonization produced in the existing tree species in the surfaces already reclaimed has been evaluated on the basis of the time elapsed since their planting (Marx 1980).

Tree Species. There has been monitoring and control of a set number of tree species that were selected on the basis of the different types of reconstructed soils, and the relationship with the degree of mycorrhization produced has been determined.

The following parameters have been studied: survival, height growth, diameter, and diagnosis of deficiencies and diseases (Ashby et al. 1988). The tree species studied include: *Pinus pinaster* and *Pinus radiata*, *Betula pubescens*, *Alnus glutinosa*, and *Castanea sativa*. Furthermore, with some specimens the above-mentioned parameters have been monitored on the basis of the application of the different doses of fertilizers.

Vertebrates. Faunistic inventories and censuses, which have coincided with the breeding seasons for the different species of birds and mammals, have been conducted (Majer 1989).

Results

Physicochemical Conditions of the Reconstructed Soils

The obtained results reflect a wide range of variation in all the analyses among the different monitored plots as well as the samples within each of these plots. This is attributed to the heterogeneity of the spoils in the mining face and the additional variability produced when they are spread in the dump. This heterogeneity makes it very difficult to compare the results obtained in the different monitored plots and limits the use of the average values as representative data.

The parameters that have been identified as essential to manage the different dump surfaces are: pH in water and ph oxidation, percentage of S, C, and N, exchange capacity, and available metals.

Soil Organisms

The figures for bacteria, actinomicetos, and fungi reach normal values in undisturbed soils and are similar to those found in other soils from mining operations. The groups that intervene in the carbon and nitrogen cycles show levels similar to those found in the natural soils of the area in which the absence or scarcity of *Nitrobacter spp.*, *Nitrosomonas spp.* and *Azotobacter spp.*, probably related to a low pH (lower than 6.0), is also habitual.

However, there is a small number of species and specimens of earthworms. Only 131 specimens belonging to 4 species, *Allolobophora caliginosa* (8 specimens), *Dendrobaena madeirensis* (2 specimens), *Dendrobaena octaedra* (120 specimens) and *Lumbricus friendi* (1 specimen), were captured. This reveals that the conditions of the plots are unfavorable to the natural invasion of these species. Only two plots have shown a certain diversity and abundance (92.36% of the total of individuals). The most abundant species throughout the dump is *Dendrobaena octaedra* although it is an epigeal species that lives on organic horizons of the soil.

Herbaceous Species

The amounts produced on the surfaces without topsoil and organic fertilization have been acceptable (30 t/ha/year of green material) even though they have been lower than the optimum production for the pastureland in the region. The relationship between fertilization and production is clearly revealed on these surfaces. The surfaces with topsoil have produced amounts that have been uniform, very good, and close to the optimum for the region (40 t/ha/year of green material). The surfaces with ashes have produced much lower amounts than the optimum for the region, especially when they receive only mineral fertilization (20 t/ha/year of green material). The amounts produced on the surfaces with mixtures of spoils selected from the upper levels of the excavation have been very good and equivalent to those obtained on topsoil.

The heavy metal contents of the vegetation are within the habitual range for species developed in natural soils. The mineral composition varies according to the species considered. The concentration of the macronutrients, K, Ca, P, and Mg, are normal in all the species and plots studied. On the basis of the obtained productions of herbaceous species, the N content is low although it does not limit vegetal growth.

Mycorrhizae

The specific composition of the fungi associated with each tree species is different. Although some species, such as *Paxillus involutus*, are present in all the plots, others are found only in specific tree species. For example, *Suillus luteus* appears only in the plots with *P. radiata* and *Krombholziella scabra* only below *B. celtiberica*. The younger trees show less diversity and abundance of fungi than the older trees. Species such as *Amanita muscaria* or *Lactarius spp.* are representative of a more evolved state of the fungi succession that occurs below *B. celtiberica*. For *P. radiata*, this state is characterized by species such as *Amanita muscaria*, *Laccaria bicolor*, or *Scleroderma citrinum*.

The considerable abundance of fungi associated with the trees studied could be an important piece of information with regard to the explanation of the adaptation and development of the tree species planted in the environment in question.

Tree Species

- *Betula pubescens*: It has been confirmed that it adapts well to the reconstructed soils of the dump including the acidic, poor, and compacted ones. It shows abundant mycorrhization in the substrates with topsoil.
- *Alnus glutinosa*: It has shown good adaptation to any substrate not excessively acidic (pH $\geq$ 4). It tolerates drought conditions when it is already established.
- *Pinus insignis*: Its development in uncompacted materials has been good, although it is very sensitive to diseases that are common in the region. It shows good mycorrhization.
- *Pinus pinaster*: Its initial development has been mediocre, but it is very well adapted in the region.
- *Castanea sativa*: Its development has been good in adequate substrates and locations.

In general, the growth curves for the species studied have a uniform, upward line. This is a clear symptom that the trees are reaching an important degree of maturity and stability in the dump.

The application of high doses of nitrogen in young trees can lead to a high level of mortality if there is continuous rainfall and the N reaches the roots massively .On the other hand, the effect of the application of different doses of fertilizers in big trees is practically not reflected in their development, especially when they are planted on topsoil. Neither is there a clear response to the application of potassium.

Vertebrates

A positive response of the bird communities to the land reclamation work conducted has been clearly revealed at two levels. On the one hand, it is observed that the oldest land reclaimed surface, where there is already a well-developed vegetation cover and structure (trees, shrubs, and herbaceous cover), is the richest in fauna. Furthermore, the evolution in diversity over the 2 years of the study has shown a considerable increase associated with the changes in the vegetal composition and structure, basically due to the presence of species from the *Cytisus sp.* and tree species. The number of vertebrates found in each sampling totaled 42 species (4 amphibian, 1 reptile, 29 birds, and 7 mammals). This figure can be considered equivalent to that found in the forests in the region.

General Conclusions

- The usefulness of systematically monitoring the evolution of surfaces undergoing reclamation in mining operations in which, like this one, there are serious obstacles to land reclamation and limited availability of topsoil, has been confirmed.
- Under these conditions, the key to obtaining the most adequate technicoeconomic results is to focus on the study of the spoils from the excavation and on their selection for disposal on the final surfaces of the dump as topsoil substitute material.
- The addition of basic amendments is essential. Apart from the classical contributions of calcium carbonate, it has been verified that the use of ashes from the combustion of lignite is appropriate for the reclamation of these surfaces, given the results obtained for the quality of the soil as well as the vegetation.
- The contribution of organic fertilization (manures, composts, municipal sewage sludge, etc.) is decisive in these substrates, which are extremely poor and have very low levels of organic matter.
- Seeding all the reconstructed soils with herbaceous species to control erosion is considered very useful as a first phase of revegetation. Furthermore, it speeds up the natural invasion and succession of the other species of the area, fundamentally the shrubs.
- In very adverse soil quality conditions, the principal effort should be directed toward planting tree species, which, once settled down, show an outstanding capacity for survival, since, even naturally, they have good mycorrhization.
- The species that are considered the most suitable for the conditions of these reconstructed soils are *Betula pubescens*, *Alnus glutinosa*, and the *Pinus sp.* conifers existing in the area of the mining operation. The trees should be planted with a root-ball.
- A variety of habitats (trees, scrub, pasture) should be maintained to increase the possibilities of invasion by wildlife. It is extremely important to keep to a minimum the presence of physical barriers that impede the entry of species from neighboring areas that are rich in fauna.
- The following steps taken in representative plots are considered appropriate for conducting the monitoring:
    - Sampling: eight per hectare in heterogeneous substrates and two per hectare on the topsoil.
    - Analysis of the soil samples: pH in water and pH oxidation, percentage of S, C, and N, exchange capacity and available metals once annually.
    - Analysis of the vegetation samples: observation of any deficiencies of metals and nutrients once annually on the same dates (identical physiological state).
    - Study of the soil organisms and mycorrhizae every 2 years.
    - Study of the vertebrate community every 2 years.

A multidisciplinary team should conduct the monitoring, and the participation of universities and research institutes is also considered very useful.

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