

RESTORATION OF OPEN PIT COAL MINING DEPOSITS –CASE STUDY FROM KOLUBARA LIGNITE BASIN (SERBIA)

Dragana DRAZIC¹, Milorad VESELINOVIC¹, Ljubinko RAKONJAC¹, Srdjan BOJOVIC², Ljubinko JOVANOVIC³

¹Environmental Protection Department, Institute of Forestry, 11030 Belgrade, Kneza Visislava 3, Serbia, e-mail: drazicd@yubc.net

²Institute for Biological Research “Sinisa Stankovic” – 11000 Belgrade, Bulevar. despota. Stefana. 142, e-mail: bojoss@ptt.yu

³Institute for Multidisciplinary Research – 11030 Belgrade, Kneza Visislava 1, Serbia, e-mail: jovaanko@eunet.yu

Abstract: The paper presents the case-study of successful biological recultivation, landscaping, restoration and revitalization of the huge areas of destroyed or degraded landscapes and ecosystems in Kolubara coal basin (Serbia). The lignite deposits interesting for exploitation in this Basin occupy the area of more than 500 km². The rehabilitated area consists of forests – about 75% and agricultural crops – about 25%. Such initial ratios of different ecosystems are justified if we consider the fact that forest ecosystems are of the highest significance for environmental protection and maintenance.

The first afforestation of minespoil banks was performed in 1957. by planting predominantly black locusts, but the first project of biological rehabilitation by afforestation based on the previous ecological, phytocoenological and pedological researches of deposol, performed in 1977 (Institute of Forestry, Belgrade). Till 1997, the rehabilitated area was 1,306 hectares.

A relatively high number of species is applied in the afforestation of stock piles not only because of the high variability of the micro-ecological conditions over a small area conditioned by the non-selective deposition of waste, but also due to the tendency to enrich the landscape of the created forest ecosystems whose valorisation should be directed towards the post-exploitation land use as a leisure and recreation zone.

Despite the great difficulties caused by non-selective deposition of overburden and by the absence of previous technical rehabilitation and planned shaping of the spaces in some areas planned for forest-biological rehabilitation, excellent results of successful afforestation and the dynamics of development of different broadleaf and coniferous tree species have been achieved.

Extraordinary anthropogenic forest ecosystems have been created, rich in colours, poly-functional values, enriched by aquatic and meadow-grass ecosystems, which make an excellent base for further spontaneous evolution of rich phyto- and zoo- biodiversity, multiply richer than that existing in the pre-mining period.

Key words: open pit coal mining, biological recultivation, landscaping, multifunctional valorization.

Introduction

In Serbia, coal is the major energy raw material and the base of the industrial and economic development. The percentage of coal in the structure or primary energy supplies in Serbia is 83.6%. Low calorie coal - lignite is the most significant. Almost all the lignite supplies are concentrated in several basins, of which the most significant are Kolubara. It is located 50 km southwest of Belgrade. The geological contours of lignite deposits suitable for exploitation occupy the area of more than 500 km². This area is characterized by level and gentle undulated terrain along several rivers. It is mainly covered by agricultural soil and broadleaf forests of lowland and low hills. Important thoroughfares pass through this area, and there are c. 60 settlements within the limits of the productive part of the basin.

Lignite extraction worldwide and in our country is based on large-scale opencast mines, which produce multiple degradation of the environment: occupation of agricultural and forest land, change of surface and underground water regime, broken food chains and other changes of biocoenoses, migrations of population, translocation of settlements, industry, traffic, cultural-historical and other facilities which are situated above coal deposits. A drastic change of the landscape and ecosystems is unavoidable in the course of lignite extraction: artificial sterile minespoil banks, immense holes -craters, areas without vegetation and with destroyed soil cover, formation of lakes, pools and oilier artificial water bodies give a completely new image of the disturbed landscape.

Kolubara lignite basin was formed by the deposition and carbonation of plant materials in the swamps and lakes of the Tertiary. The paleo-palinological research of pollen and spore samples shows the presence of the remnants of numerous species of trees and shrubs, such as: *Abies* sp., *Ginkgo* sp., *Sequoia* sp., *Picea* sp., *Pinus* sp., *Acer* sp., *Alnus* sp., *Carpinus* sp., *Corylus* sp., *Quercus* sp., *Salix* sp., *Tilia* sp. and many other species, which gave a rich material for the formation of lignite. Many of the mentioned families and genera survived, ecologically adapted and, probably, morphologically modified. Some of the above species are applied in the process of recultivation.

In this Basin, coal was extracted by deep mining in the coal mines, but due to adverse hydro geological and other factors, this method of exploitation was abandoned and since 1950, coal has been extracted exclusively by opencast

mining. As the result of different mining activities, especially opencast mining and the development of industries, the whole region has been multiply damaged and transformed, which affected seriously the natural balance and visual characteristics of the landscape. The adverse changes, processes and consequences required the parallel works on rehabilitation, i.e. revitalization, recultivation and, in general, the works on the management of the disturbed natural units.

Materials and methods

In the first part of the paper the site conditions of Kolubara basin has been analyzed, then the development characteristic of planted coniferous and deciduous trees used in the process of biological recultivation by afforestation. Finally, to assess the potential capability of the study sites for recreation, we applied the Method of evaluation of potential natural suitability for recreation, after Cvejic (1989). This method, as the result of the research and detailed comparative analysis of previous methods (Kiemstedt, 1969; Ruppert, 1971, Schaneich, 1972, Turovski, 1972, Mrass, 1974, Harfst, 1975, Kastner et al., 1982, after Cvejic, 1989), has the following advantages. It belongs to a group of quasi-total, quantitative methods, user-independent. The method takes into account the natural characteristics of the region and includes ecological and esthetic-psychological aims, as well as the aim of potential suitability for outdoor recreation, conditioned by the climate.

Results and discussion

Site conditions

The study area is characterized by the temperate continental climate (Kerner), subhumid, moister type (Thornthwaite), with mean annual air temperature 11.0-12.0°C. Annual rainfall ranges between 583.5 and 783.1 mm, with two maxima. The rainiest season is summer, and then spring, autumn and winter. More than 50% of the annual rainfall occurs in the vegetation growth season. Mean annual relative air humidity is 69.0-76.9%. The most frequent winds are in ESE direction, then WNW, W, N and NW, while average frequency of calms is 629‰.

In the course of opencast mining, the previously natural soils (brown forest soil, pseudogley, smonitza, meadow soil, hydromorphic black earth, mineral marsh soil, alluvium, alluvial-deluvial and deluvial deposits), were replaced by mine spoil banks, originating from different geological layers. Pontian sands and heavy Pliocene clay are most often found on the surface of the spoil banks.

The plantations were established on the very heterogeneous substrates, which are in the class of anthropogeneous soil, special class of technogenic soils, type deposols, subtype deposols formed by opencast mining of lignite. The deposols of the study area have very variable properties, which is the consequence of different initial characteristics of the deposited material. Depending on the dominant structure of the profile part where the root system develops most intensively, the deposols were classified according to their textural class into deposols of lighter mechanical composition, and more heavily textured deposols. Chemical properties are characterized by a very low amount of total humus and organic matter and by a weak acid to neutral reaction of the soil solution. The analysis of soil micro-flora in all sample plots shows that the biogenity of the substrates formed by mechanical damage of soil in open-cut coal mining was restituted under the influence of forest plantations.

Tree development

During the process of forest recultivation, numerous species of trees and shrubs were planted, depending on the type of soil and micro-habitat conditions. These plantings, with an extremely wide specter of trees and shrubs, represent an excellent polygon for monitoring the development, vitality and ornamentality, especially taking into account the potential use of the recultivated spaces as recreation spaces.

The largest area is occupied by pure plantations of Austrian pine and Scots pine (27.2%), and by group selection mixtures of broadleaves and conifers (23.2%). The percentage of group mixtures of coniferous plantations is 11.1% of total afforested area, and mixed plantations of broadleaves account for 9.6%. Other broadleaves - lime, alder, Siberian elm, birch, etc., account for 7.9%, black locust 8.4% in total afforested area, while other species account for 1.3% to 3.4% of the total plantation area. Besides the mentioned species, in the process of biological recultivation by afforestation, there have been also planted: **Gymnospermae** - *Pseudotsuga menziesii* Mirbel. Franco., *Picea pungens* Engelm., *Picea abies* L. Karst., *Larix europaea* Lam. et DC, *Pinus wallichiana* A. B. Jacks., *Pinus strobus* L., *Pinus ponderosa* Dougl. et Laws., *Pinus nigra* Arn., *Pinus silvestris* L., *Chamaecyparis lawsoniana* Murr. Parl. and **Angiospermae** - *Liriodendron tulipifera* L., *Ulmus pumila* L., *Quercus borealis* Michx., *Quercus robur* L., *Betula pendula* Roth., *Alnus glutinosa* L. G a e r t n., *Populus x euramericana* Dode. Guinier., *Tilia* sp., *Robinia pseudoacacia* L., *Acer negundo* L., *Acer platanoides* L., *Acer saccharinum* L., *Acer pseudoplatanus* L., *Fraxinus*

excelsior L., *Fraxinus americana* L.

Monitoring of the development and classification of the above species, the assessment of their vitality, ornamentalness and other characteristics is important for the widening of the assortment of species for recultivation. It should be taken into account that the depositing of overburden was non-selective and that the majority of forest recultivation was performed without technical recultivation, and without previous planning documents of the multidisciplinary approach to the integral management and future land use in the post-mining and post-industrial works.

Table 1. Diameter (cm) and height (m) of planted coniferous and deciduous tree species

Species at the age of 10 years	Type of deposol			
	Lighter mechanical composition		More heavily textured deposol	
	Diameter (cm)	Height (m)	Diameter (cm)	Height (m)
Coniferous trees				
<i>Abies nordmanianna</i>	4.8	3.00	-	-
<i>Cedrus atlantica</i>	7.3	6.00	-	-
<i>Chamaecyparis lawsoniana</i>	6.9	5.67	-	-
<i>Libocedrus decurrens</i>	6.3	4.03	-	-
<i>Larix europaea</i>	11.7	10.80	8.6	10.00
<i>Pinus nigra</i>	7.3	4.60	6.7	4.85
<i>Pinus ponderosa</i>	9.4	4.00	-	-
<i>Pinus griffitii</i>	10.4	5.07	-	-
<i>Pinus strobus</i>	8.6	6.85	9.2	8.00
<i>Pinus sylvestris</i>	8.3	7.10	6.7	4.50
<i>Pseudotsuga menziesii</i>	8.6	6.50	9.1	6.55
<i>Sequoiadendron giganteum</i>	10.7	5.00	-	-
Mean values for coniferous	8.5	5.72	8.1	6.78
Deciduous trees				
<i>Alnus glutinosa</i>	12.3	10.00	10.0	10.00
<i>Betula verrucosa</i>	11.9	9.40	-	-
<i>Liriodendron tulipifera</i>	4.4	4.42	-	-
<i>Quercus borealis</i>	5.1	5.50	-	-
<i>Ulmus sibirica</i>	11.5	6.33	-	-
Mean values for deciduous trees	9.0	7.13	10.0	10.00

All the implemented tree species in afforestation have a high degree of survival after planting, very good dynamics of diameter, height and volume development, but there are differences between the species on the same (identical) deposols, and differences in the development of each species on different deposols. The majority of species showed considerably better results on deposols of lighter mechanical composition.

Monitoring of the development of planted dendroflora makes it possible for each type of deposol to make the optimal selection of species for afforestation, to achieve the highest development-productivity effects, vitality, decorativeness and other functional values. In general, all the study tree species used in the biological recultivation of deposols formed by opencast mining of lignite in the Kolubara-Tamnava Basin, show high development results, even if they are compared with the development of the same species in forest plantations on various natural, anthropogenically undamaged soils. From this aspect, all the study tree species can be implemented in further works of minespoil bank recultivation after opencast mining. Consequently, the soil mapping of lighter and more heavily textured deposols is recommended in the works on biological recultivation by afforestation. The soil maps would ensure the planned planting of those species which show the best development effects on the concrete site. Altitude, exposure, moisture availability and other relevant factors should also be taken into account.

Potential use of reclaimed lignite strip mine areas for recreation

To determine the potential suitability of the study area for recreation, we applied **The method of assessment of potential natural suitability for recreation** (Cvejic, J., 1989). This method evaluates comprehensively the most essential features of the region, taking into account the final objective, i.e. the land use for recreation in landscape. The assessment is based on the detailed aerial photographs, scale 1:10,000. The unit of assessment is a square - raster 0.25 x 0.25 km. The procedure includes three phases: I - elimination of assessment units based on elimination

features, II - designation of the potential recreation zones for all aspects of recreation, and III - assessment of suitability for recreation activities: water and recreation in the landscape. In each raster, 13 features and 21 sub-features were evaluated: relief, forests, water, banks, meadows, presence of individual trees, hedges, orchards-vineyards, fields - ploughland, agricultural, forest roads and walking paths, cultural and natural monuments, settlements, infrastructure, competitive land uses and accessibility of the above main features. The applied scale consists of four degrees of suitability.

Of the evaluated area (1.143 ha) divided into 183 rasters, 31% belong to the first category of suitability for recreation, 56% is in the second category of suitability for recreation. Only 13% is in the third category of suitability for recreation. There are no recorded areas in the fourth category. This means that 87% of the evaluated area belongs to I and II categories of suitability for recreation in the landscape, which is an extraordinary quality.

Based on the above, it can be concluded that the study area has an excellent potential suitability for recreation, because of the significant presence of forests, water bodies (lakes, rivers and marshes), areas of meadow type, terrain configuration is expressive although at a relatively lower altitude. On the other hand, the percentage of arable fields, settlements, infrastructure and competitive uses is low. Water bodies are located in 25% of the evaluated units with excellent potentials for water recreation.

Conclusions

The study of potential uses of newly created landscapes and ecosystems after coal extraction by opencast mining and after the technical and biological recultivation by afforestation, confirms the thesis on the feasibility of sustainable development, because it is not unavoidable that the spaces degraded by modern man in satisfying his demands, are irreversibly lost. On the contrary, with correct and uncompromising legal regulations based on the implementation of scientific results, the degraded space can be enhanced and used for multiple benefits. It is possible to create extraordinary anthropogenic forest ecosystems, of rich colours, multi-functional values, enriched by aquatic and meadow-grassland ecosystems, which make an excellent base of further spontaneous evolution of the wealth of plant and animal biodiversity, multiply richer than that existing in the pre-mining period.

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