Development of Soil Characteristics and Plant Communities On Reclaimed and Unreclaimed Spoil Heaps After Coal Mining

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Abstract. The aim of this study was to compare soil characteristics, plant communities and the rate of selected ecosystem function performance on reclaimed and unreclaimed plots (left for spontaneous succession) of different age on spoil heaps. Twelve spoil heaps (three circle plots of radius 12.5 m) near the town Kladno in north-west direction from Prague, created after deep coal mining, were compared. Five mixed soil samples from organo-mineral horizons in each plot were analysed for total content of carbon, nitrogen and phosphorus. In addition, active soil pH (pH\textsubscript{H₂O}) was determined. Plant diversity was determined by vegetation relevés. The biodiversity value of the habitat according to the Habitat Valuation Method was assessed and the rate of evapotranspiration function by the Method of Valuation Functions and Services of Ecosystems in the Czech Republic were determined. The higher organo-mineral layers and higher amount of total nitrogen content were found on the older reclaimed and unreclaimed plots than in younger plots. The number of plant species and the total contents of carbon and nitrogen were significantly higher at the unreclaimed plots compared to reclaimed plots. The biodiversity values and evapotranspiration function rate were also higher on unreclaimed plots. From this perspective, it is possible to recommend using of spontaneous succession, together with routine reclamation methods to restore habitats after coal mining. Despite the relatively high age of vegetation in some of selected plots (90 years), both the reclaimed and unreclaimed plots have not reached the stage of potential vegetation near to natural climax. Slow development of vegetation was probably due to unsuitable substrate of spoil heaps and a lack of plant and tree species of natural forest habitats in this area. However, it is probable that vegetation communities on observed spoil heaps in both type of management (reclaimed and unreclaimed) will achieve the stage of natural climax and they will provide ecosystem functions more effectively in the future.

1. Introduction
The current large-scale mining of mineral resources has resulted in the disruption or destruction of the ecosystems and it is in the interest of society change this situation in the present time. The area of 679 km\textsuperscript{2} that represents 1\% of the area of the Czech Republic was affected by mining in the year 2007. According to § 31 Czech Justice Act No. 44/1988 Coll. “On the Protection and Use of Mineral
Resources”, the mining companies must invest and arrange the landscape restoration after the end of mining. They used primarily forestry, agriculture and hydric reclamation. Spontaneous or controlled succession is not allowable according the legislative, [1]. The coal mining activity in Kladno area began in the 18th century and this area was the most important area for coal mining in the Czech Republic until the end of the year 1990. During mining activities, the 37 spoil heaps occupying about 100 km² were created, [2]. Currently, some spoil heaps have been reclaimed and more technical reclaims are planned in the near future. There were some studies on the vegetation succession in Kladno spoil heaps by Dvořáková [3] and plants and invertebrates in reclaimed spoil heaps by Tropek et al. [4]. Development of soil and humus layers is a long process in the spoil heaps, [5], thickness of the fermentation horizon of 4-5 cm was formed after 15 to 22 years and the humus layer occurred as late as 24 years after the spoil heaps were finished, [6]. Gremlica et al. [7] studied intensively the soil, vegetation and state of reclamation but they have not compared conditions between unreclaimed and reclaimed spoil heaps. To assess the value of nature under strong anthropogenic pressures during last decades, the concept of ecosystem services, including supporting, provisioning, regulating, and cultural services, was established [8]. Seják et al. [9] proposed valuation methods for biodiversity of habitats and rate of ecosystem function performance, and ecosystem service provision for the Czech Republic, [10].

The aim of this study was to compare soil characteristics, plant communities and the rate of selected ecosystem functions on reclaimed and unreclaimed plots (left for spontaneous succession) of different age on spoil heaps.

2. Methods

Selected spoil heaps are located near the town Kladno, 15 km North-west from the Prague, capital city of the Czech Republic. Climate of this area is slightly warm up to warm and slightly dry up to dry, altitude is from 250 to 400 meters above the sea level, average annual temperatures range from 7 to 8.7°C and annual precipitation is from 450 to 500 mm. Potential natural vegetation of forests consisted of Quercus robur, Q. petraea and Carpinus betulus, [11], but most of these forests has been replaced by monoculture of Picea abies, [7].

Twelve spoil heaps created during coal mining activities were selected, 6 spoil heaps were reclaimed and 6 spoil heaps were left for spontaneous succession; each type of management was composed of 3 young and 3 old spoil heaps. Three circular plots with a radius of 12.5 m were randomly established on each spoil heap. Plant diversity by fytoecological relevés was investigated in the herb, shrub and tree vegetation floor, [12] and Hill’s diversity index by Hill, [13], was calculated for each plant floor. The soil results represent the average value from three composite samples (mixed from five samples) for each spoil heap. Soil samples were dried and sieved through a sieve with grid of 2 mm for analysis of active soil pH (pHH₂O) by pH meter, total carbon (TC) and total nitrogen (TN) in the CN analyser and the content of phosphorus (P) by the method of Total Phosphorus Spectroscopy. The biodiversity value of the habitat was evaluated by point values (8 characteristics of plant and habitat diversity and their threat, scored from 0 to 6 points) according to the Biotope valuation method (BVM), [9] for 192 biotope (habitat) types in the Czech Republic (138 natures and close to nature biotopes and 54 more anthropically influenced biotopes). The value of evapotranspiration function was estimated on the base of measured micrometeorological and literature data, [10]. The differences between individual characteristics on reclaimed and unreclaimed spoil heaps with different age of vegetation at a significance level α = 0.05 were computed by the unpaired t-test to test in the program R, [14].

3. Results and discussions

There were found 123 species of vascular plants on all spoil heaps (78 species of plants, 12 species of shrubs and 20 species of trees). At average 34 vascular plant species were found on unreclaimed and 27 species on reclaimed spoil heaps. The lowest number of species was found in the reclaimed heap Teplák (17 species) and the highest number of species was on the reclaimed heap Bohumir (41
species). The number of plant species and values of Hill’s diversity indices were higher on the unreclaimed spoil heaps in comparison with reclaimed spoil heaps (Table 1). The exception was reclaimed heap Bohumír, where a higher number of plant species was found than on unreclaimed localities. This result was probably caused by a lower level of shading tree layer, [15] and therefore a higher cover of herb layer.

Soil characteristic, especially the average values of the total carbon and nitrogen, were higher in unreclaimed locality compared with the reclaimed spoil heaps. The concentration of phosphorus, pH and organo-mineral horizons (soil layer) between unreclaimed and reclaimed spoil heaps was not significantly different. Statistically significantly higher values of layers of organo-mineral horizons and Hill’s indices and slightly higher values of total carbon and nitrogen on the border of significance were detected on all older spoil heaps in comparison with young unreclaimed and reclaimed heaps (Table 2). Significantly higher values of total carbon and pH were observed in younger unreclaimed spoil heaps in comparison with younger reclaimed sites (Table 3). The pH values ranged from 5.57 to 7.97, corresponding to slightly acidic mineral composition of spoil heaps occurring in the same area, [7]. According Frouz et al. [6], pH value of soil was usually lower with increasing age of spoil heap, while the values of soil carbon, nitrogen and phosphorus were increasing. Also pH values were decreasing and increasing values of total carbon and nitrogen were recognized with increasing age of spoil heaps. However, slight decline of phosphorus values occurred on some older spoil heaps, especially on 140 years old Josef-Antonín spoil heap, were observed (Table 3). This state could be caused by many factors, e.g. type of substrate, weather, and human activities.

| Table 1. The mean characteristics of plant communities and soil characteristics on reclaimed (R) and unreclaimed (U) spoil heaps |
|---------------------------------------------------------------|
| **Spoil heap; Mngmt** | **No. of species** | **Depth of soil cm** | **Hill’s indices** | **pH** | **P mg/kg** | **TC %** | **TN %** | **C/N** | **BVM points** | **Evptr funct mm** |
| Max, R | 40 | 25 | 14.07 | 1.98 | 5.57 | 395.14 | 14.95 | 0.82 | 18.23 | 20.9 | 500 |
| Teplák, R | 40 | 17 | 14.07 | 1.05 | 7.97 | 1392.71 | 6.21 | 0.43 | 14.45 | 20.9 | 500 |
| Bohumír, R | 50 | 41 | 10.47 | 2.24 | 6.96 | 480.33 | 6.91 | 0.43 | 16.07 | 19 | 500 |
| Ludvík, R | 80 | 28 | 18.07 | 6.87 | 5.15 | 561.8 | 15.2 | 0.65 | 23.51 | 20.9 | 500 |
| Jan Dubí, R | 80 | 26 | 21.2 | 4.68 | 5.41 | 539.82 | 12.5 | 0.6 | 20.72 | 20.9 | 500 |
| Josef Antonín, R | 90 | 26 | 15.73 | 3.76 | 6.87 | 353.39 | 13.23 | 0.8 | 16.54 | 20.9 | 500 |
| Ronna, U | 20 | 38 | 9.53 | 2.14 | 7.2 | 1040.5 | 12 | 0.58 | 20.82 | 24.7 | 700 |
| Prago, U | 25 | 40 | 12.67 | 4.4 | 6.9 | 940.13 | 15.74 | 0.61 | 25.94 | 22.8 | 700 |
| Mayrau, U | 40 | 35 | 8.27 | 2.88 | 5.99 | 416.63 | 17.76 | 0.91 | 19.45 | 24.7 | 700 |
| Jan a, U | 80 | 28 | 16.27 | 3.22 | 6.75 | 416.03 | 16.71 | 0.78 | 21.52 | 24.7 | 700 |
| Jan b, U | 80 | 30 | 17.4 | 2.7 | 6.29 | 1231.63 | 22.83 | 1.05 | 21.74 | 22.8 | 700 |
| Jan c, U | 80 | 30 | 12.4 | 6.16 | 6.54 | 530.46 | 12.69 | 0.75 | 17 | 22.8 | 700 |

Legend: Mngmt – type of the management; BVM points – points of biodiversity value of the biotope; Evptr funct–evapotranspiration function

Recorded tree species composition was compared with potential vegetation species on our locality. Mainly pioneer species such as Betula pendula, Populus tremula and non-native species Robinia pseudacacia and only a small percentage species of potential vegetation, e.g. Acer pseudoplatanus, A. platanoides, Quercus petraea, Q. robur, and Carpinus betulus were found on the unreclaimed spoil heaps. Lower percentage of species of potential vegetation was observed on reclaimed spoil heap where economic species, e.g Larix decidua, Pinus sylvestris and Fraxinus excelsior prevailed. Obtained results are consistent with knowledge of Dvořáková [3] and Felinks et al. [16].
Table 2. Comparison of measured parameters for unreclaimed and reclaimed spoil heaps and for all younger and all older spoil heaps with both types of management by t-test

| Variables | Unreclaimed x reclaimed spoil heaps | Young x old spoil heaps |
|-----------|-----------------------------------|------------------------|
|           | t-test p | mean SD n | t-test p | mean SD n |
| P (mg/kg) | 0.65 0.523 762.60 742.46 18 | 0.79 0.438 777.60 738.58 18 |
| TC (%)    | 3.21 0.003 16.29 4.26 18 | -2.03 0.05 15.35 4.90 18 |
| TN (%)    | 2.52 0.017 0.62 0.20 18 | -2.07 0.046 0.73 0.20 18 |
| pH        | 0.95 0.351 6.61 0.53 18 | 2.01 0.053 6.76 1.00 18 |
| depth of soil (cm) | -1.89 0.068 12.76 3.91 18 | -4.12 >0.001 11.51 3.85 18 |
| No. of species | 2.03 0.051 19.50 4.27 18 | 16.28 5.21 18 |
| Hill’s indices | 0.95 0.349 3.58 1.95 18 | 3.43 3.56 18 |

Tab. 3. Comparison of measured parameters for unreclaimed and reclaimed spoil heaps with different age by t-test

| Variables | Young unreclaimed x young reclaimed spoil heaps | Old unreclaimed x old reclaimed spoil heaps |
|-----------|-----------------------------------------------|-------------------------------------------|
|           | t-test p | mean SD n | t-test p | mean SD n |
| P (mg/kg) | 0.03 0.980 799.10 738.11 9 | 0.90 0.392 726.00 789.68 9 |
| TC (%)    | 3.25 0.005 15.17 3.26 9 | 1.90 0.076 17.41 5.01 9 |
| TN (%)    | 1.48 0.159 0.56 0.21 9 | 1.96 0.068 0.86 0.20 9 |
| pH        | -0.27 0.788 6.70 0.72 9 | 2.24 0.051 6.53 0.27 9 |
| depth of soil (cm) | -1.56 0.144 10.16 2.56 9 | -1.70 0.109 15.36 3.28 9 |
| No. of species | 1.78 0.096 20.56 4.64 9 | 16.44 4.77 9 |
| Hill’s indices | 2.32 0.040 3.14 1.61 9 | 5.11 4.48 9 |

Support of spontaneous succession on our studied spoil heaps could help to accelerate the development of functional potential natural vegetation. Slow development of near to climax vegetation was probably due to unsuitable substrate of spoil heaps and a lack of plant and tree species from...
natural forest habitats. Also Dvořáková [3] observed that species of potential vegetation were spreading very slowly unlike the spreading the ruderal and invasive species. In any case, selected unreclaimed spoil heaps achieved the same and sometimes higher values of plant species and soil characteristic as reclaimed localities. In addition, spontaneous succession is an inexpensive and sufficient method, particularly for restoration of a small area with surrounding natural vegetation, [17], [18].

The biodiversity value and evapotranspiration functions of the habitats achieved similar and sometimes higher values on the unreclaimed spoil heaps compared with reclaimed spoil heaps (Table 1). The value of habitat biodiversity was similar on some reclaimed spoil heaps as on the unreclaimed localities due to the occurrence of potential vegetation species. Evapotranspiration function rate was higher on unreclaimed heaps, because there were prevailing deciduous forests compared to monoculture deciduous and coniferous forests on reclaimed sites. Unreclaimed spoil heaps are used by local people for mushroom picking, shooting range or mining museum. It would be beneficial to eliminate illegal dumping of waste on the spoil heaps and mark hiking and educational trails, [7].

4. Conclusions

Obtained results indicate that the unreclaimed localities achieved the same or closer status of vegetation to climate stage and soil characteristics near to natural soil and they perform two selected regulation services at similar and sometimes higher level than the reclaimed spoil heaps. From this perspective, it is possible to recommend the use of spontaneous succession to restore habitats after deep coal mining. Vegetation communities have not achieved the climax state yet, but the vegetation communities on observed spoil heaps in both types of management (reclaimed and unreclaimed) will probably achieve the climax stage and they will perform more effective ecosystem functions in the future.

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References

[1] Hodačová D, Prach K. Spoil heaps from brown coal mining: Technical reclamation vs. spontaneous re-vegetation. Restor Ecol 2003; 11:385–391.
[2] Čepelová B, Münzbergová Z. Factors determining the plant species diversity and species composition in a suburban landscape. Landscape Urban Plan 2012; 106:336–346.
[3] Dvořáková, H. Vliv okolní vegetace na průběh sukcese na kladenských haldách [The influence of surrounding vegetation on the progress of the succession in Kladno spoil heaps]. DP Thesis, Faculty of Science, University of South Bohemia in České Budějovice, 2011, [in Czech].
[4] Tropek R, Kadlec T, Hejda M, et al. Technical reclamations are wasting the conservation potential of post-mining sites. A case study of black coal spoil dumps. Ecol Eng 2012; 43:13–18.
[5] Ponge JF. Humus form in terrestrial ecosystem: a framework to biodiversity. Soil Biol Biochem 2003; 35:935–945.
[6] Frouz J, Prach K, Pižl V, et. al. Interactions between soil development, vegetation and soil fauna during spontaneous succession in post mining sites. Eur J Soil Biol 2008; 44:109–121.
[7] Gremlica T, et al. Analytická studie stavu krajiny Kladenska v částech narušených těžbou černého uhlí [Analytical study of state of the landscape parts disturbed by coal mining in the Kladno area]. VaV 640/10/03 Obnova krajiny Kladenska narušené dobýváním [Restoration of Kladno landscape disrupted by mining]. The Institute for Environmental
Policy, o.p.s., 2005, [in Czech].
[8] MEA. *Millennium Ecosystem Assessment, Ecosystems and Human Well-being: Synthesis.* Washington, D.C., Island Press, 2005.
[9] Seják J, Dejmal I, Petřiček V, et al. *Hodnocení a oceňování biotopů České republiky [Valuation of habitats of the Czech Republic].* Czech Environmental Institute, Praha, Czech Republic, 2003, [in Czech].
[10] Seják J, Cudlin P, Pokorný J, et al. *Hodnocení funkcí a služeb ekosystémů České republiky [Valuation of ecosystem functions and services in the Czech Republic].* Faculty of Environment, Jan Evangelista Purkyně in Ústí nad Labem, 2010, [in Czech].
[11] Neuháuslová Z. *Mapa potenciální přirozené vegetace České republiky [The map of potential vegetation of the Czech Republic].* Academia, Praha, 1998 [in Czech].
[12] Moravec J, et al. *Phytocenologie [Phytocenology].* Academia, Praha, 1994, [in Czech].
[13] Hill M. Diversity and evenness: a unifying notation and its consequences. *Ecology* 1973; 54:427–432.
[14] R Development Core Team. *A language and environment for statistical computing, R Foundation for Statistical Computing,* Vienna, 2007.
[15] Tydlitátová K. *Diverzita lesní vegetace Českého středohoří [Diversity of forest vegetation in Bohemian Central Highlands].* DP Thesis, Faculty of Science, Charles University in Praha, 2010, [in Czech].
[16] Felinks B, Pilarksi M, and Wiegleb G. Vegetation survey in the former brown coal mining area of eastern Germany by integrating remote sensing and ground based methods. *Appl Veg Sci* 1998; 1:233–240.
[17] Prach K, Pyšek P. Using spontaneous succession for restoration of human-disturbed habitats: experience from Central Europe. *Ecol Eng* 2001; 17:55–62.
[18] Řehounek J, Řehounková K, and Prach K, (eds.). *Ekologická obnova území narušených těžbou nerostných surovin a průmyslovými deponiemi (Ecological restoration of area disrupted by mining and industrial depositions),* Calla, České Budějovice, [in Czech].