ALTERNATIVE RESTORATION STRATEGIES IN FORMER LIGNITE MINING AREAS OF EASTERN GERMANY

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Summary

Spontaneous vegetation development was studied on more than a hundred sample sites in surface-mined land of Eastern Germany. In contrast to other studies of delayed colonization processes in restoration, more than 50% of the wild plants present within an area radius of 30 km² were able to colonize the investigated mining sites. In the process they formed attractive biotope mosaics of grasslands, heaths, reed, fens and woodlands. Depending on the local landscape structure, up to 40% of the species present in the mining sites have their next occurrences at distances of more than 3 km. High immigration rates over large distances can be explained by the availability of large-scale competition-free space in the mining sites in combination with extraordinary events. The final voids function as enormous seed traps in the landscape.

Our examinations about successional series of woodland in surface-mined land showed that the substrate has a major influence on the development of different woodland

stages. On a hospitable substrate birch pioneer forest is likely to establish within a few years. Intermediate and climax tree species replace *Betula pendula* after 60 to 80 years on these sites. On less hospitable substrates, colonization can be impeded for decades. This delayed development offers a chance for valuable pioneer stages where less competitive and therefore endangered species can find refuges over long periods. General successional mechanisms and pathways in former mining sites of Eastern Germany are summarized.

Furthermore, suitable methods to initiate near-natural vegetation development have been developed for areas where successional processes have to be accelerated to control erosion processes or to avoid dust emissions. The methods described have been adopted on slope sites with quaternary sand, sandy and loamy silt, and loess. The target vegetation was selected according to the site conditions and a prognosis of the spontaneous vegetation. On all study sites both chosen methods—application of fresh, diaspore-rich plant clipping material and mulch seeding with site-specific species—were able to start sustainable vegetation development in towards the chosen target vegetation. These methods are alternatives to traditional recultivation measures. They guarantee effective erosion control and promote the desirable succession, if appropriate donor sites are selected. In combination with the designation of successional areas, sustainable development of valuable biotope mosaics can be supported. These wilderness areas are suitable both for leisure activities and nature conservation objectives in the post mining landscape.

1. Introduction

In the federal states of Saxony, Saxony-Anhalt and Brandenburg (Eastern Germany), open-cast mining has destroyed vast landscapes of extensive close-to-nature floodplain-ecosystems and forests as well as elements of cultural landscapes, or has affected them by lowering of the groundwater table. As a result of the land reclamation process, forests have been considerably extended (in total area), compared to the situation before the open-cast lignite mining, as a result of afforestation of worked-out mine sites. In Saxony and Saxony-Anhalt, for example, the current extent of forests is 63% greater than it was before the open-cast mining. However, afforestation with monocultures of non-native species and low structural diversity has, in general, led to reduced ecological value of these forests.

After the German reunification in 1990, 32 active surface mines were shut down. An area of nearly 1000 km^2 was included in a reclamation process. Since the beginning of this process, scientists and conservationists have demanded a stronger integration of natural processes in the development of post-mining areas. Unfortunately at that time the knowledge about successional processes and near-natural restoration methods was inadequate. In the subsequent years, many research projects have investigated the ecological potential of surface-mined land in the new federal states of Germany. Since the turn of the century, ecologically based restoration concepts have been integrated into conventional recultivation schemes, mainly in areas which were reserved for natural development. Nevertheless, many slopes must be technically recultivated because of erosion risks.

Seeding is most common in recultivation. Standard seed mixtures generally require a considerable change of the given site conditions (e.g. liming, amelioration). They often promote the development of species-poor plant communities with low aesthetic value. The seeding of ecotypes derived from plant-breeding establishments is not in accordance with the need to use indigenous ecotypes. Also, exotic species are frequently found in the seed mixtures (e.g. *Sanguisorba muricata*). The valuable ecological potential of former mining sites can be destroyed by traditional recultivation methods which include leveling of the surface, ameliorating of nutrient-poor substrates and seeding or planting of non-native species or plants not suited to present habitat conditions.

In mining sites where successional processes have been undisturbed for decades, varied grasslands, heaths, reeds and fens, as well as varied woodlands have developed. The stages of development, species composition and stand structure of these biotopes are very different. Such areas can serve as refuges for rare species or plant communities. In general successional stages of post-mining areas are characterized by a high heterogeneity in terms of substrate, soil hydrology and surface topography, often in combination with nutrient deficiency. Therefore, in order to enhance the biological diversity of the affected regions, the valuable ecological potential of the mining areas should be included in future restoration schemes.

But spontaneous succession needs time. A combination of extreme site conditions and increasing distance to appropriate seed sources in the surrounding area delays the colonization of the unvegetated sites. The methods application of diaspore-rich plant clipping material and mulch seeding of autochthonous species are used to initiate or accelerate near-natural vegetation development. They are meant to replace traditional recultivation methods and expensive aftercare. They should promote sustainable development of species-rich plant communities that are optimally adapted to the given site conditions. The use of autochthonous material can prevent adulteration of the local flora and protect the genetic diversity of the regional species pool.

This chapter summarizes the results of several studies on spontaneous and initiated development on more than a hundred sites in former lignite mining areas of Eastern Germany (e.g.Tischew and Kirmer 2003, Tischew 2004, Tischew and Lorenz 2005). The aim was to determine opportunities for the integration of spontaneous colonization processes into restoration schemes of former mining sites. The following outlines the most important issues of our research:

- analyses of immigration processes and impact of isolation effects,
- overview of general successional processes of post-mining landscapes,
- analyses of site conditions and successional series of pioneer woodlands, depending on site conditions,
- development of near-natural restoration methods to accelerate vegetation development on sites endangered by erosion, and
- determination of opportunities and perspectives for the integration of natural potentials in the reclamation of post-mining landscapes

2. General site characteristics

Lignite has been mined in surface mines in Eastern Germany since the beginning of the twentieth century. To this end overburden layers 40 to 120 m thick above the lignite seams had to be excavated and dumped, therefore forming very large spoil dumps. This process can be compared with the mass turnover of the last glacial epoch. The groundwater level had to be lowered extensively. Overburden layers consist of Tertiary and Quaternary substrates that were often mixed during the dumping processes. Quaternary substrates are usually more suitable for plant colonization. They are composed of boulder clay, sand and loess. Tertiary substrates consisting of sand, clay and silt often contain fine coal and sulphur. Due to the oxidation of the sulphuric compounds they contain (iron pyrite, marcasite), Tertiary substrates tend to acidify over a long period of time as well as to release high levels of phytotoxic Al^{3+}-ions. Tertiary substrates additionally show high bulk density and low macropore volume. High levels of finely distributed coal-containing admixtures can also influence substrate qualities negatively by their hydrophobic characteristics.

In the investigated mining area the topsoil, which contained humus, was often not separated when dumped. Dumped substrates, therefore, show mostly low biological activity and low levels of available plant nutrients at the beginning of their development. Handmade dumps of the early mining phases (up to the 1920s and '30s) are exceptional, because here topsoil-containing humus was selectively put on the spoil dumps as the uppermost layer.

The area investigated has a mean annual temperature of 8.0 - 9.5 °C and an annual precipitation of 450 to 650 mm. Due to industrial mining, vast surface mines have been created where isolating effects relating to colonization processes must be expected. Remnants of natural woodland vegetation (oak-hornbeam forests, beech forests, birch-oak forests, pine-oak forests, floodplain forests) have remained only rarely around spoil dumps.

3. Investigation methods

3.1. Colonization processes

Special aspects of colonization processes were analyzed in ten former open-cast lignite mining sites in Saxony-Anhalt. These sites were mostly re-vegetated by spontaneous succession and consist of different successional stages dependent on age and substrates with biotope mosaics of pioneer vegetation, psammophytic or calcareous grasslands, pioneer forests and, related to water availability, reed or initial fen vegetation. The examined mining sites in the northern part of Saxony-Anhalt are surrounded by forests, floodplain grasslands of the river Mulde and a small amount of arable land. Eutric Cambisols and sandy loess represent the typical soils of this region. The surrounding area of the southern mining sites are characterised by large and fertile farmlands according to extensive layers of loess and boulder clay.

Bitterfelder/Gräfenhainicher region (northern region)

- Golpa-Nord/Bachaue: approx. 2-14 years; approx. 1 km²
- Goitsche/Holzweißig-West: approx. 4-30 years; approx. 1.8 km²
- Goitsche/Halde 1035: approx. 3-40 years; approx. 0.6 km²

- Muldenstein/NSG Schlauch Burgkemnitz: approx. 38 years; approx. 0.8 km²
- Golpa III: approx. 6-50 years; approx. 2.5 km²

Bitterfelder/Gräfenhainicher region (southern region)

- Kayna-Süd/Süd: approx. 3-34 years; approx. 1.8 km²
- Roßbach: approx. 1-23 years; approx. 2.3 km²
- Mücheln/Innenkippe: approx. 1-41 years; approx. 2.6 km²
- Nordfeld Jaucha: approx. 26-55 years; approx. 1 km²
- Domsen/Nordost: approx. 27-41 years; approx. 1 km²

Complete species composition was identified on sample sites (each about 2 km^2) by several mappings from 1998 to 2002. The investigated sample sites were characterized by open-land and woodland stages. About 1100 relevés were included which were made in several research projects. To determine the regional species pool we used the dataset of the flora mapping of the states Saxony-Anhalt and Saxony which was done in grid cells (5.5 x 5.5 km = 30.25 km²). Detailed descriptions of the method can be found in Tischew and Kirmer (2003).

3.2. Woodland development

The investigations on woodland development were carried out in nearly all lignite mining districts in Saxony, Saxony-Anhalt and Brandenburg and show spontaneous succession at least in some parts. Details are provided in Tischew and Lorenz (2005). Forty-four former mining sites were included in the investigations. Large areas with spontaneous succession were divided into smaller sites with relatively homogeneous site conditions. The time span after disuse of the investigated mines ranges from one to 98 years.

The investigation of woodland development was carried out on 104 sample sites for the classification and description of chronologically and spatially differentiated successional series. Abundance and species cover percentage of vascular plant species in all vegetation layers were estimated (modified Braun-Blanquet scale). In order to assess stand structure, all trees from 1 cm diameter upwards were measured in plots that ranged from 400 to 2000 m^2. Further investigations were carried out with respect to selected site factors, e.g. soil acidity, soil texture, nutrient availability, cation exchange capacity, lignite content, humus and fly ash coating. (For detailed methods see Tischew and Lorenz (2005). The classification of successional stages in space and time was carried out by using hierarchical and non-hierarchical cluster analysis as well as multivariate ordination methods. The bioindicative parameters (1) percentage of vegetation layers, (2) weighed percentage of ecological groups (e.g. dry psammophytic grasslands, mesic grasslands, woodlands), (3) stand density per hectare of pioneer, intermediate and climax tree species as well as (4) stand basal area of all trees per hectare were included for every plot.

3.3. Near-natural restoration methods

Alternative restoration methods were realized in three former mining sites in Saxony-Anhalt: final void Holzweißig-West (mining area Goitzsche), mining site Mücheln

(Innenkippe) and mining site Roßbach. The selection of the target plant communities for our case studies was based on analyses of the site conditions and a prognosis of the spontaneous vegetation development on the unvegetated sites (for site parameters see Table 1). The success of the methods used was assessed by the average and total transmission or establishing rates of the species brought in by the different methods and by the quantitative similarity to the target vegetation.

Mining site	**Goitzsche (Holzweißig-West)**	**Mücheln (Innenkippe)**	**Roßbach**
Aspect	north	south	west
Geological origin of substrate	quaternary	tertiary	quaternary
Inclination	approx. 15°	approx. 15°	approx. 8°
Soil	pure sand	sandy and loamy silt	loess
average pH value ($KCl/CaCl_2$)	4.4 (±0.2)	5.5 (± 0.7)	7.5 (± 0.1)
N_t (%)	no data	0.13	no data
S_t (%)	no data	0.82	no data
P_2O_2 (mg per 100 g soil)	0.2	11	no data
CaO (mg per 100 g soil)	0	980	no data
K_2O (mg per 100 g soil)	no data	86	no data
MgO (mg per 100 g soil)	2.6	no data	no data

Source: Kirmer A. (2004b). Beschleunige Entwicklung von Offenlandbiotopen auf erosionsgefährdeten Böschungsstandorten. *Renaturierung nach dem Braunkohleabbau* (ed. S. Tischew), 234-248. Stuttgart Leipzig Wiesbaden: B.G. Teubner Verlag.

Table 1. Site parameters of study sites for near-natural vegetation development.

In addition, the total number of species differentiated from the material brought in, and from seed rain, as well as the average coverage of the herb and moss/lichen layer was listed. All vascular plant species recorded in the study sites were classified according to Frank, Klotz and Westhus (1990): (1) psammophytic grassland species (Corynephoretalia, Festuco-Sedetalia), (2) dry grassland species (Festuco-Brometea), (3) species of ecotonal communities (Trifolio-Geranietea), (4) grassland species (Molinio-Arrhenatheretea), (5) ruderal species (e.g. Artemisietea, Sisymbrietea, Stellarietea), (6) other species (species of other plant communities with very low abundance). Shrub and tree species were put in a group called “woody species”. Bryophytes and lichens were recorded separately.

The following methods to initiate or accelerate near-natural vegetation development were used:

- Application of fresh, diaspore-rich plant clipping material. The spreading of hay for the restoration of grasslands has been employed since the Middle Ages. Then, farmers used the seed-rich material accumulated from hay storage in barns to establish new grasslands. Nowadays, fresh material mown at an optimal time for fructification of the chosen target species is used, as well as dry material mown at different times. In recent years this method has become more widespread (e.g. Molder 1995, Pywell et al. 1995, Kirmer and Mahn 2001).

- Mulch seeding with autochthonous species. Seeding is the most common method in the recultivation of sites endangered by erosion. Some authors (e.g.Wathern and Gilbert 1978, Keller and Kollmann 1998) emphasize the importance of regional origins of the seed mixtures used, and warned against adulteration of the local flora and a possible loss of the genetic diversity of the regions. The coverage of the seeds with different mulching material enhances germination and establishment, and promotes water retention. Mulch layers with organic material should reduce erosion and create better growing conditions.

3.4. General methods and data analysis

Vegetation development in general was analyzed by the following methods (for detailed descriptions see the research projects mentioned in the Acknowledgements):

- space for time substitution (chronosequences)
- permanent plots

Vascular plant nomenclature follows that of Wisskirchen and Haeupler (1998).

Statistical tests and cluster analysis were carried out using SPSS 10.0 and PCORD 4.0. Multivariate statistics were carried out using CANOCO 4.5.

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