/ Near-natural restoration vs. technical reclamation of mining sites in the Czech Republic

Editors: Klára Řehounková, Jiří Řehounek & Karel Prach

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University of South Bohemia in České Budějovice
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Preface

/ White-spotted Bluethroat (*Luscinia svecica cyanecula*).
Photo: Lubomír Hlásek

/ Preface

The proceedings you are just opening concern ecological restoration of sites disturbed by mining activities. They summarize current knowledge with an emphasis on near-natural restoration, in light of theoretical aspects of restoration ecology as the young scientific field.

The proceedings are largely based on contributions presented at a workshop organized by the Calla NGO and the Working Group for Restoration Ecology, Faculty of Science, University of South Bohemia in České Budějovice. About 30 specialists, both scientists and practitioners, attended the workshop. This English version emerged from the Czech one published in 2010, adapting the texts to an international readership, reducing local and too specific information. The proceedings are published under the bilateral German-Czech project DBU AZ26858-33/2 (Utilisation of near-natural re-vegetation methods in restoration of surface-mined land – principles and practices of ecological restoration) thus a brief chapter reflecting German experiences is newly included.

Klára Řehounková, Jiří Řehounek & Karel Prach, the editors
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Photo: Jiří Řehounek

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/ Using restoration ecology for the restoration of valuable habitats

Karel Prach

Restoration ecology is a scientific discipline engaged in restoration of ecosystems or their parts, which were degraded, damage or destroyed by humans (Society for Ecological Restoration International, Science & Policy Working Group 2004). Restoration can concern populations, communities, whole ecosystems or landscape. General aims of restoration ecology can be summarized in the following four points (Hobbs and Norton 1996):

- to restore highly degraded or destroyed sites (e.g. after mining)
- to increase productivity of degraded sites designed for production
- to increase natural value of protected sites
- to increase natural value of productive sites.

Restoration ecology exploits theoretical knowledge of ecology as a scientific discipline and provides a scientific basis for practical ecological restoration.

The restoration process can generally include the following seven successive key steps (Hobbs and Norton 1996):

- identification of the processes that led to degradation
- suggesting nomination of procedures to stop degradation
- setting realistic objectives for a restoration project
- to design easily measurable parameters documenting the recovery process
- to design concrete restoration measures
- application of these measures to the project and its practical implementation
- monitoring

For post-mining sites, where degradation has already taken place, the relevant steps are those starting with the third in the sequence.

In practical projects we can (a) completely rely on natural (spontaneous) succession, (b) on natural succession modified in various ways, e.g. sowing of desirable species, targeted elimination of undesirable species, management practices like, for example, mowing of degraded and abandoned meadows, or (c) we can use technical approaches where target vegetation is as a whole planted or sown. The third way is used in technical reclamations. They usually result in a state far from the natural situation and thus are in conflict with more natural approaches.

The important part of any restoration project is definition of the target ecosystem, community or population. A target can be derived from well preserved reference sites with similar environmental conditions. Without detailed knowledge of the reference site it is difficult or imposible to define the target. However, we have to be aware of various limitations. For example, we would not be probably able to restore a climax forest despite its existence in close vicinity of a restored site. In this case, we would probably appreciate another stand resembling at least partly the natural one.

We can ask which communities and species have a chance to establish by spontaneous processes in the current landscape and which not. The following processes mainly operate against spontaneous restoration: large-scale eutrophication, intensive exploitation on one hand and abandonment of some habitats on the other. This situation supports ubiquitous, widely-spread species which are not usually of interest for biodiversity. In current landscape conditions, comunities and species requiring oligotrophic, i.e. nutrient poor, site conditions are the most endangered and thus desirable to be restored.

If we want to maintain or restore species rich communities of plants and animals, we have to restore the traditional management in secondary habitats (secondary meadows and pastures), otherwise, spontaneous processes will lead to their degradation or destruction, and exclude intervention into the preserved primary habitats (e.g. rock steppes, peatlands and some forests with natural species composition).

A different situation exists in highly degraded or even destroyed sites, where succession starts on bare substrate. Here, spontaneous succession usually leads to the restoration of valuable ecosystems by successive establishment of species whose ecological requirements fit the local site conditions. It is desirable if we have at least some knowledge of spontaneous processes. Due to our long term research (the results of which are partly summarized in this work), respective succession can be at least partly predicted.

Spontaneous succession as a tool of restoration of valuable ecosystems has generally a greater chance on sites where nutrient poor conditions are created. On such sites, rare and endangered species participate more in succession. The most extensive human activity creating nutrient poor site conditions is mining.

In the Czech Republic the main topics of restoration ecology are as follows:

- restoration of ecosystems on arable land
- **restoration of post-mining and other industrial sites (considered in this issue)**
- restoration of riverine ecosystems
- restoration of degraded grasslands
- restoration of more natural species composition and structure of forests

We recommend the reader to consult the works of van Andel and Aronson (2006) and Walker et al. (2007) for more detailed information on restoration ecology in general.

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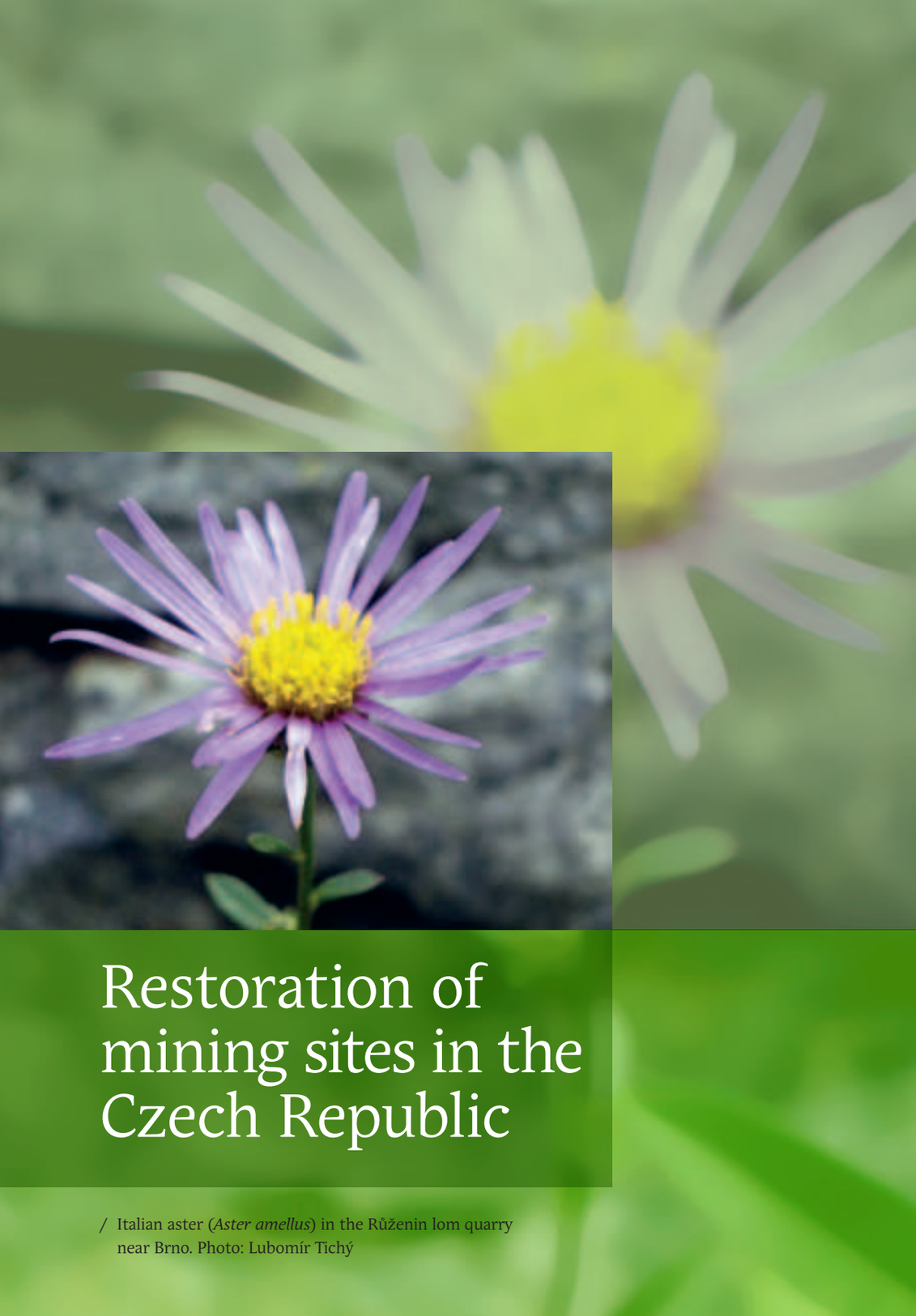


Restoration of mining sites in the Czech Republic

/ Italian aster (*Aster amellus*) in the Růženin lom quarry near Brno. Photo: Lubomír Tichý

/ Restoration of mining sites in the Czech Republic

Jiří Řehounek & Miroslav Hátle

Mining has a long tradition in the Czech Republic and still is an important part of the country's economy, although recently, its economic importance has been decreasing. However, it still has a significant impact on the landscape and nature. Czech legislation distinguishes two types of mining sites regarding their size and importance of the resource. The first type covers larger areas where strategic resources such as coal are extracted. Starting to mine is done according to special mining laws, which desire the building of a financial reserve during the mining process for subsequent reclamation of the site after finishing the mining process. The second type covers smaller mining sites with locally used resources, e.g. sand and stone. For such sites, less strict rules are applied and the building of a financial reserve for reclamation is not required.

In reclamation, it is desired to re-establish the landscape corresponding to that before mining. An exception is for mines scheduled for inundation, where anthropogenic lakes are created. Czech legislation provides relatively powerful laws restricting the loss of land used for agriculture and forestry; hence re-establishment of forest and agricultural land is mainly desired by the authorities. Unfortunately, strict application of these technical reclamations leads in many cases to the destruction of valuable habitats or the eradication of rare and endangered species, which is often in conflict with nature protection laws. Moreover, productivity of such newly created meadows, arable fields, or forests is in most cases low and unimportant.

In the Czech Republic, there is an effort by scientists, non-governmental organizations and occasionally even mining companies themselves to increase the proportion of near-natural restoration measures in post-mining sites, but it is often limited by legislative barriers. Technical approaches lead to establishment of uniform communities with low natural and even economic value. A unique chance to increase the natural value of the landscape is usually missed.

Until recently, it was possible to miss the challenge with the argument that there is not enough scientific knowledge about near-natural restoration. However,

/ A biocentre restored by spontaneous succession in the mining area Cep located in the Třeboňsko Protected Landscape Area. Photo: Jiří Řehounek

the negative role of technical reclamations was recently documented in many scientific studies. On the other hand, near-natural approaches are increasingly and successfully used in various restoration projects. Some of them will be further described as examples of good restoration practices.

Remark: We use here the term technical reclamation for those restoration measures which usually consist of levelling the surface by heavy machines, covering it by some organic material and then creating a monotonous vegetation cover by planting or sowing. We include under the term near-natural restoration those restoration measures which respect natural, spontaneous processes either manipulated or not.

Spoil heaps

/ Common Stonechat (*Saxicola torquata*). Photo: Josef Hlásek

/ Spoil heaps

Editor: Karel Prach

Coauthors: Vladimír Bejček, Petr Bogusch, Helena Dvořáková, Jan Frouz, Markéta Hendrychová, Martin Kabrna, Věra Koutecká, Anna Lepšová, Ondřej Mudrák, Zdeněk Polášek, Ivo Přikryl, Klára Řehounková, Robert Tropek, Ondřej Volf & Vít Zavadil

Spoil heaps after coal mining are an important component of the landscape in several parts of the Czech Republic, especially the Most and Sokolov regions in the western part of the country, where lignite coal is mined in open-cast mines. However, deep mining also had significant impact especially in the black coal rich Kladno and Ostrava regions in the central and northeastern parts of the country, respectively. In addition to coal mining, spoil heaps were also created during uranium mining, but no mine is recently active. Mining of other resources have been rather rare, if we do not consider historical mining. Here, we focus on spoil heaps after coal mining, because they are fairly more extensive and their formation continues until the present. The area of coal spoil heaps is around 270 km^2 and approximately the same area is heavily impacted by mining in other ways.

Some spoil heaps or their parts were left unreclaimed in the past because of the low capacity of reclamation companies, coal reserves underneath the heaps, etc. In addition, these areas are planned to be technically reclaimed in the near future. As far as we know, only 60 ha of the heaps have been recently dedicated for spontaneous succession, while the rest of the area was technically reclaimed or technical reclamation is planned. In 2007, there were 14 084 ha of spoil heaps technically reclaimed and an additional 9 352 ha were under the process of reclamation.

/ Geology and Geomorphology /

The main materials forming the coal spoil heap are overburden and the surrounding rock of coal layers. They mostly consist of Tertiary sediments (Most and Sokolov districts) or Permo-Carbonian sediments (Kladno and Ostrava districts). In the Most region, heaps are mainly formed by grey Tertiary clay sporadically mixed with sand and volcanic debris. Tertiary clays are typical for the heaps in the Sokolov region. They are named after the crustacean *Cypris angusta*, whose fossils are commonly present in the clay. Heaps after uranium and other ore mining are usually

/ A spontaneously developed part of the Radovesická spoil heap in the Most region aged 15 years. A diverse mosaic of herbal communities, woodlands and wetlands is favourable for biodiversity. Photo: Karel Prach

formed by proterozoic sediments, claystones and sandstones (Chlupáč et al. 2002).

An undulating surface usually develops due to substrate deposition on the heap during open-cast mining. Heaping machines form a system of parallel elevations and depressions of various depth and size. Water often accumulates in the deeper depressions. In this way, heaping forms a large variety of microhabitats, which is beneficial for biodiversity. Unfortunately, recent technologies form more flat surfaces (mainly in the Sokolov region). Leveling of the surface is a regular part of technical reclamation and is highly inconvenient for biodiversity. Heaps after deep mining have a conic or rather irregular shape and the surface is rather homogenous. However, surface erosion often increases surface heterogenity.

Valuable fossils are commonly found on the heaps (Mergl and Vohradský 2000), which further increases their natural value.

/ Technical reclamation /

As mentioned above, most of the heaps area is technically reclaimed. One of the most common procedures is as follows. After stabilization of the spoil substrate, usually after about eight years, the surface is leveled by heavy machinery and depressions with accumulated water are drained. This surface is covered by organic material like milled timber or bark, or a humus layer stripped from mining sites, but sometimes also materials like marlite. When a heap is prepared in this way, trees are planted, usually 1 tree per m^2. Tree species are sometimes indigenous for the area, but sometimes not. Exotic species (including invasives) are also commonly used. In the following years, the area surrounding a tree seedling is then mown to suppress competition from the herb layer, which is usually well developed. The herbaceous layer is commonly formed by common ruderal and weedy species (*Cirsium arvense, Artemisia vulgaris, Calamagrostis epigejos, Elytrigia repens* and others), because of the nutrient rich organic material used. Chemical repellents for deer are often applied on the tree seedlings. Sometimes, rodenticides are used without consideration if they are really needed.

The second most common method of reclamation is directed to agricultural use. The heap surface is prepared similarly as in the previous case (the leveled spoil is covered by a humus layer), but then it is sown with various commercial grass mixtures, usually with a large portion of nitrogen fixing legumes. This develops into a monotonous and species poor grassland community with no conservation potential.

A third common way of reclamation is creation of water bodies. The holes of the already inactive mines are purposely flooded. We will not evaluate this approach here, mainly because it is a new approach in this country and long-term mainly hydrological experiences are needed.

/ Another part of the same spoil heap technically reclaimed. Photo: Karel Prach

Sometimes the heaps are technically reclaimed for the purposes of recreation and sports, which we mostly consider as a suitable use of the post-mining areas.

Over all, in terms of landscape restoration, technical reclamations are a negative and expensive activity in the current scheme except in some sites which are endangered by erosion, close to the vicinity of settlements, and the above mentioned recreation and sport use. In many cases, technical reclamations destroy valuable habitats and negatively impact populations of endangered and rare species.

According to some data, technical reclamation in the Most region costs approximately 2 million CZK (approximately 80 000 Euros) per 1 ha. This cost is about 0.5 million CZK (approximately 20 000 Euros) in the Sokolov region. Here, there is currently about 2000 ha under reclamation and another 3000 ha is planned. This together calculates to 2.5 billion CZK (100 million Euros) of mostly needless costs, which can be spent in another way in restoring the natural values of the landscape in the mining districts.

/ Near-natural restoration /

Most of the heaps have the potential to be reclaimed by spontaneous succession (Prach et al. 2008, 2011). Specialists have estimated the potential extent to which heaps can be overgrown spontaneously in various mining areas: the Most region – up to 100 % (V. Bejček, K. Prach); the Sokolov region – almost 100 % (K. Prach, I. Přikryl), ca. 90 % (A. Lepšová), 30–40 %, but after modification of heaping technology (formation of a more heterogenous surface) around 60 % (J. Frouz, O. Mudrák); Kladno – up to 100 % (K. Prach, R. Tropek); Ostrava – up to 100 % (V. Koutecká). Some lower values in the Sokolov region are presented, because monodominant swards of the expansive and competitively strong grass *Calamagrostis epigejos* is formed especially on the leveled surface.

/ Sparse steppe-like grasslands in the spoil heaps are crucial for arthropod diversity for the whole Kladno region. Photo: Robert Tropek

The easiest and cheapest mean of reclamation is obviously spontaneous succession, similarly as in other areas destroyed by mining activities. In certain cases, we can direct succession towards the desirable pathways, arrest or even reverse it. Here, we consider an ideal situation in which spontaneous succession is included into the restoration scheme and site conditions facilitating its progress are prepared during the mining process, e. g. formation of a heterogenous surface with inundated depressions. During the mining process, it is desirable to leave untouched semi-natural communities in the close surrounding of the heaps which can later serve as sources of desirable species. The already running succession can be directed, for example, by sowing of desirable species or suppression of undesirable (invasive) species. In addition, arresting or even delaying succession by cutting trees or even by more destructive methods, such as disturbing the surface by heavy machinery is necessary for maintaining its conservation potential for endangered arthropods. Such measures increase the diversity of habitats forming a mosaic of different successional stages. However, a complex biological evaluation is necessary prior to such management.

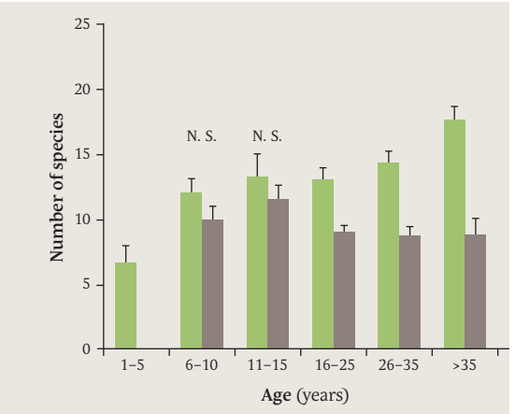
Because the individual mining districts are considerably distinct, they will be discussed separately.

/ Most region /

There are about 150 km^2 of heaps in the Most region with another 100 km^2 degraded by mining activities. The largest is Radovesická spoil heap, which has been heaped since the end of the 1970s and filled a whole valley including several villages. In total, over 60 villages or towns were destroyed in the Most region due to coal excavation, including the historically important town of Most.

The heaps in this region are commonly known as a “moon landscape” due to their appearance just shortly after heaping. However, the appearance of the heaps is dramatically changed immediately after the start of primary succession processes (Prach 1987, 1989, Hodačová and Prach 2003). Seeds of plants are spread into the heaps by wind, animals and sometimes also by man during the heaping. Annual plant species, e.g. *Atriplex sagittata, A. prostrata, Chenopodium* spp. (mainly *Chenopodium strictum*), *Persicaria lapathifolia, Polygonum arenastrum* and *Senecio viscosus* and biennials, e. g., *Carduus acanthoides* dominate in the first few years.

Total cover in this stage, which lasts about five years after heaping, is relatively low, usually less than 30 %. Apart from the mentioned common species, there are some which are rare (*Atriplex rosea*). These sparse habitats are crucial also for many threatened arthropods which colonise the heaps from the first years after heaping and persist mainly in habitats with long-term blocked succession. This early stage attracts also birds such as *Anthus campestris, Oenanthe oenanthe* and *Emberiza hortulana* (Bejček and Tyrner 1977). Between the 5th and 15th years of succession, broad-leaved herbs prevail such as *Tanacetum vulgare*, *Artemisia vulgaris* and *Cirsium arvense.* They are, followed by grasses, mainly *Elytrigia repens*, *Calamagrostis epigejos* and *Arrhenatherum elatius*, and together form the next successional stage where the cover of ruderal species decreases and cover of meadow species increases. With increasing vegetation cover, arthropods of early successional habitats are also replaced by meadow species. The majority of the most endangered species decrease and occur just in smaller sites in which succession is blocked by abiotic conditions or disturbances. Because the Most region has relatively warm and dry climate, woody species have a rather low cover (up to 30 %), even in late successional stages. However, the cover of woody species is much higher on wetter sites and in close vicinity of forest stands. After around 20 years of succession, anthropogenic or semi-natural forest steppe is formed, which obviously persists for a relatively long period. This can be seen on the oldest unreclaimed Albrechtická spoil heap which is more than 50 years old. This very sparse woodland habitat is a refuge for a large variety of forest-steppe arthropods, e. g. *Proserpinus proserpina*. Most of the area of the heaps develops in this way with exceptions of wet depressions (see below).



/ Comparison of the average number of species (vascular plants) in vegetation samples (each 25 m²) recorded in spontaneously developed (green) and technically reclaimed (brown) spoil heaps in the Most region (according to Hodačová and Prach 2003).

Sites without vegetation are quite rare; mostly they are formed by acid sands (with pH below 3.5). However, even such habitats have their value. They are important for some groups of invertebrates, mainly soil-dwelling bees and wasps, butterflies and neuropteran insects, which retreat from the surrounding monotonous landscape.

Wetlands are very valuable; these form quickly in depressions inside or along the edges of the heaps. The wetlands are dominated mostly by *Typha latifolia* and *Phragmites australis*, but rare plants also occur there. Charophytes (genus *Chara*) and other interesting species of algae occur in pools. On the heaps with rugged topography there is usually a large number of small pools which are crucial for amphibians, and aquatic and semiaquatic arthropods. Spoil heaps are highly important for amphibians and dragonflies even in the context of the whole Czech Republic (e. g. Vojar 2006).

/ A steppe-woodland stage spontaneously developed in the Albrechtická spoil heap after 50 years, the Most region. Photo: Karel Prach

Unfortunately, in the time when the valuable habitats are formed, the heaps are leveled by heavy machinery. The technically reclaimed heaps host a much lower number of species than those spontaneously overgrown, as shown for higher plants by Hodačová and Prach (2003). In total, about 400 species of vascular plants were found on spoil heaps of the Most region which represents approximately 15 % of the Czech flora.

More or less continuous vegetation cover is formed around the 15th year of spontaneous succession. Around the 20th year, the vegetation is relatively well stabilized and includes also trees and shrubs, mainly *Sambucus nigra, Salix caprea, Populus* spec. div. and especially *Betula pendula*, occasionally *Acer pseudoplatanus, Fraxinus excelsior, Rosa canina, Crataegus* spp. and others. Considering the fact that technical reclamation can start usually after 8 years since heaping, the use of spontaneous succession for the restoration of heaps in the Most region is quite convenient. When we take into account that the planted trees needs some time to be grown,

it is obvious that spontaneous succession is comparably as fast or even faster than technical reclamation.

Directing of succession has not been used until now. In the near future, active management should be practiced for re-creation of early successional habitats, in order to maintain the high conservation potential of the areas for arthropods, and creation of new small lakes in areas with a dense occurrence of amphibians.

/ A case study /

In a recent study by Málková (2011), species diversity of higher plants in spontaneously re-vegetated and technically reclaimed spoil heaps were compared in the Most region. It was demonstrated that the number of species along 100 m sampling transects was largest on spontaneously re-vegetated spoil heaps, followed by afforested spoil heaps, while the lowest number of species was recorded on spoil heaps reclaimed as agricultural land (grassland). Spontaneously re-vegetated spoil heaps also exhibited the highest beta-diversity meaning that vegetation was the most heterogenous in the studied scale.

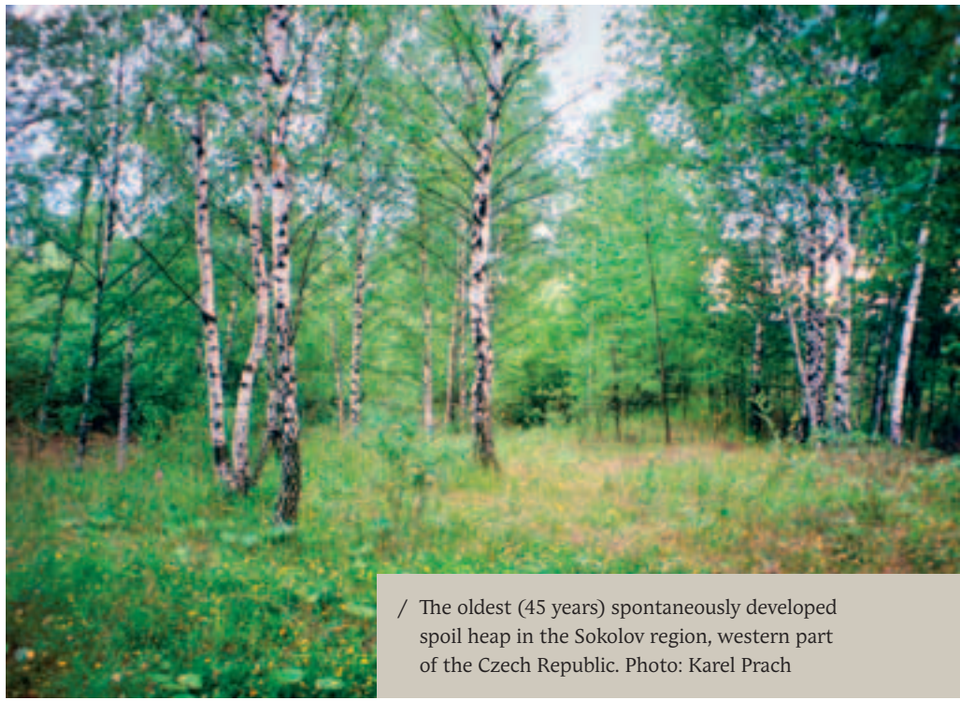
/ Examples of good and bad practices /

We consider as positive that 60 ha of the Radovesická spoil heap were intentionally left to spontaneous development, but until now it has not been officially approved. Moreover, such an area is negligible when compared to the whole area of the heap (1250 ha). On the other hand, we have a recent negative experience from the same heap. In 2009, the sites already well developed by spontaneous succession were bulldozed and technically reclaimed. This is unsuitable not only for nature conservation, but also economically, it is an irrational waste of money. The technical reclamation of this spoil heap cost around 750 million Czech Crowns (approximately 30 million Euros). Of all of the mining districts, the willingness to accept ecological approaches in the restoration of post-mining sites is the lowest in the Most region. We can hope the situation improves in the future.

/ Sokolov region /

Recently, 90 km^2 of spoil heaps were formed in the Sokolov coal mining district, represented neraly solely by the Velká podkrušnohorská spoil heap. About 55 km^2 of that area has been already reclaimed or is currently under reclamation. Further reclamations are planned. However, large parts are left unreclaimed and are being successfully overgrown by spontaneous succession. Exceptions are represented by some toxic substrates (for example, some parts of the Lítovská spoil heap have a pH of about 2), but these sites also have their ecological and conservation value, as was mentioned in the Most region.

Succession in the Sokolov region is different from that in the Most region because of the wetter and colder climate (Frouz et al. 2008). Annual plant species are much less important. Since the beginning of succession, the heaps are colonized rather by perennial species such as *Tussilago farfara* and *Calamagrostis epigejos*. Woody species, mainly *Betula pendula*, *Salix caprea* and *Populus tremula*, easily establish. This successional pathway is running mainly on sites with undulating topography. Recently, the heaping technology forms a rather flat surface which supports expansion of the competitively strong species *C. epigejos*. It forms dense growths and can even arrest succession. If the succession is not arrested, the plant community markedly changes 25 years after the heaping. Ruderal species cover decreases in that time, but the cover of meadow and forest species increases. The increase of non-ruderal species is connected with pedogenic processes, which are caused by the activity of soil macrofauna, mainly earthworms. Their activity is conditioned by the presence of litter produced mainly by the woody species. Macrofauna mix the litter with the mineral substrate, thereby forming a humus layer in the soil profile. Such sites provide more favorable conditions for the establishment of meadow and forest species (Frouz et al. 2008). Other woody species, such as *Picea abies, Pinus sylvestris, Quercus robur* and even *Fagus sylvatica*, may establish beneath the pioneer trees. However, the tree seedlings are significantly harmed by deer, which are present in large quantities on the heaps. Fencing of some unreclaimed parts of spoil heaps would probably speed up succession towards woodland.



/ The oldest (45 years) spontaneously developed spoil heap in the Sokolov region, western part of the Czech Republic. Photo: Karel Prach

The oldest successional stage (at about 50 years) is dominated by birch (*B. pendula*) woodland with species rich understory.

Similarly as in the Most region, valuable wetlands are formed in the wet depressions. They host a large variety of endangered species of animals, mainly amphibians, small crustaceans Copepods, diving beetles, rotifers and others. Some of the species were recorded there for the first time in the Czech Republic. More than 450 species of fungi (macromycetes) were recorded on the spoil heaps of Sokolov district (A. Lepšová).

Parts reclaimed by forest planting have lower biodiversity than spontaneously overgrown parts of the heap. This is not true for some groups of soil organisms, which desire a large quantity of high quality litter (Frouz et al. 2008). For soil formation, the most favorable stands from plantings are lime (*Tilia cordata*) and alders (*Alnus glutinosa* and *A. incana*); coniferous species (*Picea* sp. div.; *Larix europaea*) are less favorable. Spontaneous colonization by invasive species is insignificant.

/ Examples of good and bad practices /

The acceptance of near-natural approaches (including spontaneous succession) by the mining company in the Sokolov region is higher than in the Most region. We appreciate that spontaneously overgrown areas are not further reclaimed and are officially scheduled for spontaneous succession. However, an area of 3 000 ha is still scheduled for technical reclamation, which appears to us to be mostly needless.

One example of site assisted recovery was done on the Velká podkrušnohorská spoil heap near Sokolov (50º 13’ 49” N, 12º 38’ 24” E). The aim of this trial was to accelerate and direct succession using transplanted grassland turfs and diaspore-rich mown vegetation spreaded on a spoil heap (Matoušů 2010).

Altogether, six monoliths (3 × 10 m each) were taken away by excavator up to a depth of 40 cm below the surface on a mown mesophilous grassland near the spoil heap. Then the monoliths were placed on a four years old spoil heap that was formed by a varied mixture of clay materials. Moreover, mown biomass was applied on a non-reclamated spoil heap in appropriately experimentally designed blocks (Matoušů 2010).

The observation time of the experiment (5 years) was too short to analyze the effect of the treatment during a full succesional sere, however some trends in the early stage can be recognized. The transfer of turfs’ monoliths and fresh mown biomass led to accelerated colonization of the spoil heap by grassland species. The most successful method seems to be monolith translocation combined with a suitable treatment such as mowing and mulching. These methods suppressed strong competititors (namely *Calamagrostis epigejos*), which can block succession for many years, and supported the spread of some rhizomatous and stoloniferous grassland species from the transferred monoliths (*Fragaria vesca*, *Galium mollugo*, *Hypericum perforatum*, *Luzula campestris*, *Poa compressa*, *Pimpinella saxifraga*, *Ranunculus repens, Trifolium repens*) to the spoil heap (Matoušů 2010). The costs and technical implementation of these restoration methods together with future management measures (e. g. mowing) were rather expensive in comparison to spontaneous succession (Hodačová and Prach 2003). Therefore, application on a large scale seems to be unprofitable.

/ Kladno region /

Around 30 spoil heaps in the Kladno region remained after coal mining. Apart from the spoil substrate (mostly Permo-Carbonian sediments), various rubbish material from industrial and building activities is also common. Moreover, building and other rubbish is commonly deposited on the heaps. The heaps range in age from 12 to more than 100 years. Because the mining has finished, initial stages are not present. As in the other localities, succession starts with various annual plants (Dvořáková 2008). Among the interesting species of this stage is, for example, *Chenopodium botrys*. Sometimes, the older spoil heaps are disturbed and initial stages are re-established. Later, perennial species, such as *Tussilago farfara* and *Tanacetum vulgare*, dominate. Woody species establish relatively

/ Spoil heaps in the Kladno region near Prague are easily colonized by woody species. Photo: Robert Tropek

easily. Because the individual heaps are rather small (compared to those in the previously mentioned districts) and have relatively favorable substrate, *Betula pendula, Populus tremula, Salix caprea* and *Acer pseudoplatanus* are most common. Unfortunately, the invasive tree *Robinia pseudacacia* is very common in the whole district and often easily establishes on the spoil heaps. Occassionally, the heaps are dominated by the shrubs *Prunus spinosa* and *Crataegus* sp. div. on drier sites or *Sambucus nigra* on wetter nutrient rich sites. The grassland stages are rarely formed and usually persist only briefly. Inside the forest stands, we can sporadically see small areas with a dominance of grasses, such as *Arrhenatherum elatius* or *Calamagrostis epigejos*. Sparse growths of *Poa compressa* sporadically persist on substrate compressed by heavy machinery. These non-forest stages are very valuable for the occurrence of invertebrates. Many of their species are extinct in the surrounding landscape and many of them are rare also in the context of the whole Czech Republic. It would be desirable to maintain these stages or sporadically disturb the heap to move succession to an earlier state. Some non-traditional ways of management (motocross, paint-ball pitch, camping etc.) would be useful there. However, regular management should be applied too. This could be financed from funds devoted to technical reclamation. Recently, a complex study of plants and several arthropod groups has shown that the spontaneously developed sites host various endangered species. On the contrary, no endangered plants and arthropods occur in the technical reclaimed parts of the heaps since they are colonised by common generalists (Tropek et al. 2012). Technical reclamation was necessary only on sites where there was a danger of autoignition, but it is recently averted. In conclusion, no other technical reclamation is needed nor desirable.

/ Ostrava region /

Most of the heaps in the Ostrava region were lowered, translocated or are under the process of being so. This is probably being done in the good believe that it helps to include them into the landscape. However, we believe that some of them should be maintained even in the landscape. If the heaps are not present in large quantities, then they increase landscape diversity and, in the case of the Ostrava region (with a long history of mining), they can be considered as a part of the landscape. Interesting wetland habitats are formed in the undermined sites.

Initial stages of succession are typified by *Epilobium dodonaei* (Koutecká and Koutecký 2006), originally a species of fluvial gravel deposits. Other species include *Chenopodium botrys*, *Oenothera* sp. div., *Erigeron annuus* and *Conyza canadensis*. *Calamagrostis epigejos* expands and can arrest succession also here. Woody species establish relatively well, mainly *Betula pendula*, poplar hybrids (hybrids of *Populus nigra* and *P. canadensis*) and willows (*Salix caprea, S. purpurea, S. alba, S. fragilis*).

Early stages of succession host large populations of rare insect species. Important are mainly the non-forest communities. 17 Red List species of plants and 14 species of animals were found on spoil heaps of the Ostrava region. Most of them occur on spontaneously re-vegetated sites and only a few were on sites reclaimed by forest reclamation.

All of the spoil heaps of the Ostrava region have the potential to develop well by spontaneous succession. If they are scheduled to be a natural area (e.g., forest, green belt areas), priority should be given to spontaneous succession (especially in the case of smaller heaps). We suggest a diversity of reclamation approaches (forest reclamation with or without addition of topsoil) for the extensive heaps. Part of the heap should be scheduled for spontaneous succession. Spontaneous succession is also here more suitable for biodiversity than forest reclamation. Formation of a forest by spontantaneous succession is slower than by forest reclamation, but a continuous forest is not always the target. Succession can be directed here depending on the target, for example, by selective cutting or planting of desirable trees. When the succession is blocked by some expansive or invasive species, like *Calamagrostis epigejos*, *Reynoutria* sp. div., *Solidago canadensis* and *S. gigantea*, forest planting can be appreciated (in the case of tall species like *Reynoutria*, the planted saplings should be at least 2 m high prior to planting to give them chance to survive the strong competition). The invasive and common *Robinia pseudacacia* should be suppressed where it is possible. Invasive species are more common in the Ostrava region than in the other districts, but their role is minor and they are not a large-scale problem.

/ Other spoil heaps /

Spoil heaps in other coal mining districts were less studied. This is because they are not so extensive. There are spoil heaps near Plzeň (Pilsen) in the western part of the country and in the Žacléř-Svatoňovice district in the north. These spoil heaps are usually rather old; mining was terminated there at least 20 years ago. Most of them were translocated or lowered, while some were technicaly reclaimed. Spontaneous succession leads there to a woodland of *Betula pendula* with low cover of the understory (Pyšek and Stočes 1983). The heaps have a conical topography with an unstable and stony substrate, which is not favorable for the formation of continuous vegetation cover.

A similar situation is on spoil heaps after uranium mining in the Příbram region. Continuous vegetation cover is formed mainly on flat sites or on north facing gentle slopes. There are some important annual plant species in the initial stages (common is *Microrrhinum minus*), while mainly *Tussilago farfara*, *Hieracium pilosella* agg., *Fragaria vesca*, *Poa compressa* and *P. pratensis* s.l. and also *Calamagrostis epigejos* are common later (Dudíková 2007). Even after 20 years, woody species are established only sparsely. These are mainly represented by *Betula pendula* and *Rosa* sp. div. Sites without vegetation are common. However, even these spoil heaps are biologically valuable,

/ Orchids (*Cephalanthera alba* in this case) occasionally occur in spontaneously re-vegetated spoil heaps. Photo: Jiří Řehounek

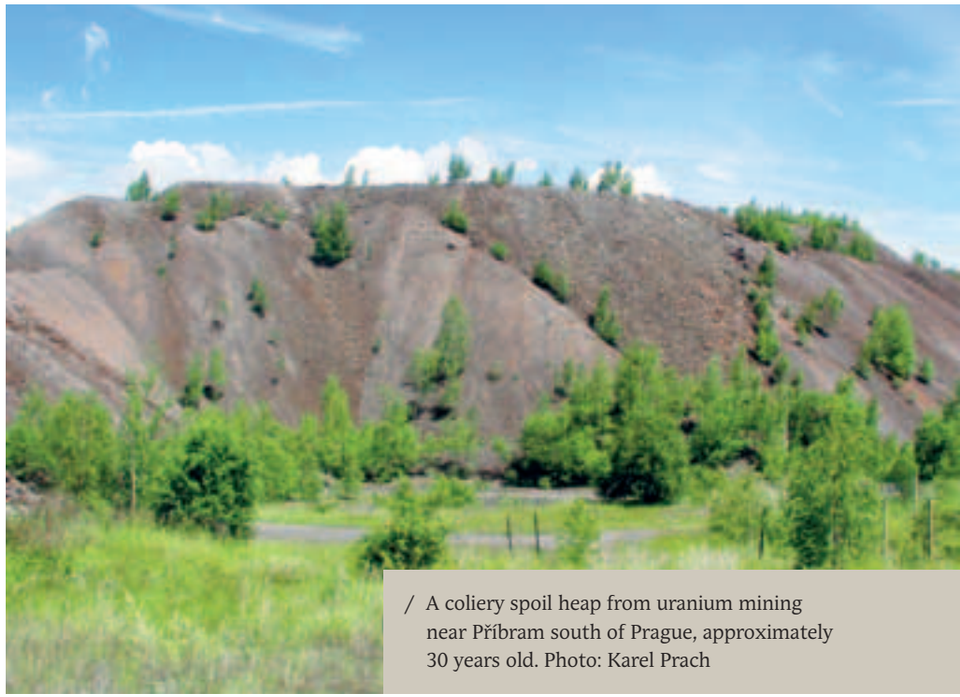
for example for the large number of lichens (not analyzed yet in detail) which occur there. Heaps after uranium mining in the Jáchymov region have a higher vegetation cover (around 40 %). In addition to *Betula pendula*, *Picea abies* was abundant in this colder and wetter region (Dostálek and Čechák 1998).

There are abundant grasses (*Agrostis capillaris* and *Avenella flexuosa*) on ore heaps in the Stříbro region and in the Krušné hory Mts. Later, mosses and lichens are common under the closed canopy of trees (mainly *Betula pendula*, *Populus tremula*, *Salix caprea*, *Acer pseudoplatanus* and *Picea abies*). *Picea abies* is more abundant on colder and wetter sites, mainly in higher altitudes.

Spontaneous succession can be used in all of these cases. Technical measures can be considered on sites which are endangered by erosion or where there is danger of contamination of the surroundings (mainly in the case of ore heaps). Unfortunately most of the conical heaps are lowered or dislocated, and then technically reclaimed. We consider such heaps as the heritage of the industrial era and thus it is valuable to maintain at least a few of them. That is planned in the Příbram region (which we appreciate), but all of them were abolished in other districts where conical heaps were typical.

/ Specific principles of spoil heaps restoration /

1. Reduce the extent of technical reclamation and include spontaneous (or directed) succession into the restoration schemes. Almost the whole area of heaps has the potential to be restored spontaneously. Considering other interests, it would be valuable to leave 60 % of the heap area to spontaneous succession, but in reality we would appreciate at least 20 %.
2. It is important to form a heterogenous surface during the heaping process. Deep depressions especially enable the formation of wetlands (including aquatic habitats) both in the centre of the heap and on its edge (this is valid for the extensive heaps after brown coal mining). Wetlands are the most valuable habitat on the heaps.



/ A coliery spoil heap from uranium mining near Příbram south of Prague, approximately 30 years old. Photo: Karel Prach

3. In the case of technical reclamations (afforestation), it is important to maintain a heterogenous surface. It is essential not to drain the wetlands if it is not important for operational and safety reasons.
4. Dedicate some spontaneously overgrown heaps to surface disturbing human activities, such as motocross, paint-ball etc. The disturbed surface usually supports biodiversity. Moreover, on heaps, such activities do not interrupt other people.

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Stone quarries

/ Spotted Fritillary (*Melitaea didyma*). Photo: Martin Hrouzek

/ Stone quarries

Editors: Robert Tropek, Lubomír Tichý,
Karel Prach & Jiří Řehounek

Coauthors: Petr Bogusch, Petr Heneberg,
Tomáš Chuman, Martin Konvička, Anna Lepšová,
Jan Novák, Luboš Stárka & Vít Zavadil

/ Introduction /

Stone mining has affected the Central European landscape since ancient times, but until the medieval times its effect was negligible. Most of the consumption consisted of the collection of stones from crop fields. Occasional mining was concentrated to the easy accessible sites. That is why the remainders of old stone mining are usually on bare rocks, where the stone is weathered and is easier to mine. With increasing consumption of stone, the easy available resources were exploited. The increase of demand for stone led to the development of more efficient mining technologies which increased the impact on the mining sites.

Old stone quarries established since the medieval times until the industrial revolution in the 19th century were smaller and with more diverse topography than quarries established later. There, the stone was mined mainly by hand or with the use of a small amount of explosives. The stone for mining was carefully chosen. The difference from recent mines is obvious. The walls were smooth, because the mining was carried out according to layers. After several decades, these mines began looking like a natural part of the surroundings. They looked like natural rocks or small depressions and their human made origin is hardly distinguishable. Since the second half of the 19th century, mining for stone has been in large quantities using industrial technologies. This led to the establishment of recent extensive quarries, which are often divided into several floors. Spoil is dumped into the surroundings, which often look unnatural in the landscape. Hence, the restoration of natural and esthetic values of quarries has become an interest of the society.

Stone mining is an important part of the mining industry in the Czech Republic. In 2007, a total of 44 millions tons of decorative stones and building stones were mined from 239 quarries, covering an area of 16.3 km^3. Another 12 millions tons of limestone (including dolomite) were mined from 22 quarries. There are 1 362 ha under reclamation. By 2007, 4 083 ha had been reclaimed (Starý et al. 2008).

/ The Na Chlumu limestone quarry in the Bohemian Karst near Prague. Photo: Karel Prach

Stone quarries are more or less equally spread around the Czech Republic, but limestone quarries are naturally concentrated in the several limestone rich districts, mainly the Bohemian Karst near Prague and the Moravian Karst in the eastern part of the country. Both are important botanical and zoological areas. Moreover, these areas are also important for studying the geological history and paleontology. Although the limestone quarries are more extensive than building stone quarries, they have a larger potential for spontaneous recovery of natural values. This is mainly because of the substrate, but also because of their landscape position in areas with rich flora and fauna.

/ Geology and Geomorphology /

Stone quarries are important localities for the geological sciences. Profiles reflecting the geological history are exposed especially in the deeper quarries. Unique profiles of ancient seashores were revealed by mining. Remnants of volcanic activity are also well documented in several localities.

Granite and eruptive rocks (basalt, trachyte, phonolite) are most often mined. In addition, granulite, other metamorphic rocks, e. g. slate, and sandstone and marlite are also mined.

/ A limestone quarry in the Pacova hora nature reserve near Tábor in the southern part of the country. Photo: Jiří Řehounek

/ Technical reclamation /

In technical reclamation, the surface of the quarry is leveled first, which is often done by deposition of various waste material. Abandoned quarries often serve as rubbish tips. Then the surface is covered by topsoil and trees are usually planted. This approach suppresses habitat diversity and the natural value of the locality. Technical reclamations significantly reduce the potential of the quarries to be refugia for many organisms. It was documented in one extensive study (Tropek et al. 2010) considering 10 groups of invertebrates and vascular plants in the Bohemian Karst that more than 10 % of the species forming the communities of unreclaimed quarries are rare or endangered species. On the other hand, most common species in the reclaimed quarries were typical for crop fields, forest plantations and intensively managed meadows.

Unreclaimed quarries may increase the heterogeneity of the landscape. They contain rather untypical shapes like bare rocks, deep ravines, and a mosaic of grasslands and shrubs, while the extensive tree monocultures in reclaimed quarries are common also in the surrounding landscape.

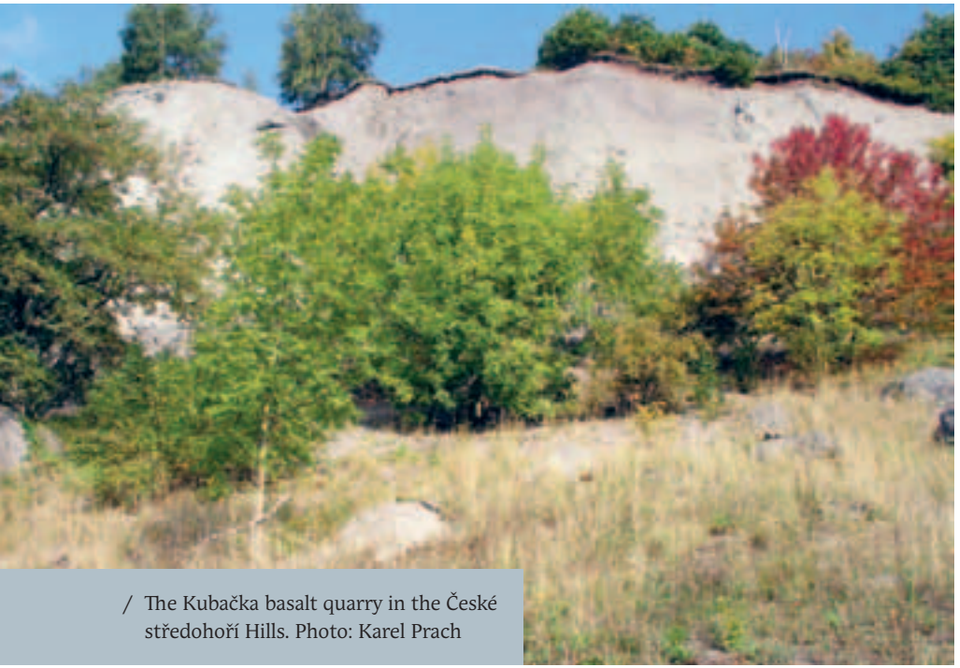
Of course there are situations in which technical reclamations are necessary, for example in the case of possible leaks of toxic compounds, extensive

erosion, or in the close vicinity of human settlements. However, such situations are rather rare and in most cases natural processes are more effective both economically and ecologically.

/ Near-natural restoration /

Spontaneous succession was studied in limestone quarries in the Bohemian Karst (Tropek et al. 2010), the Moravian Karst (Beneš et al. 2003, Tichý 2006), basalt and phonolite quarries in the České středohoří Hills (Novák and Prach 2003, Novák and Konvička 2006) and less frequently in other localities (Haraštová 1996, Tropek and Konvička 2008, Trnková et al. 2010).

In the Bohemian Karst, the quarries are re-vegetated following several successional pathways depending on the habitats. Flat bottoms and floors of the quarries are colonized by plant species such as *Microrrhinum minus*, *Arenaria serpyllifolia*, *Sedum album*, and rarely also by *Epilobium dodonei* and *Crepis foetida* subsp. *rhoeadifolia*. Sparse growths of the grass *Festuca rupicola* established later. Sites with a deeper soil profile are colonized faster. There, ruderal grasslands dominated by *Arrhenatherum elatius* are gradually formed, which are then colonized by woody species, mainly *Rosa* spec. div., *Crataegus* spec. div. and *Acer campestre*. Drier sites are dominated by grasses such as *Brachypodium pinnatum* or *Bromus erectus*. Mesic



/ The Kubačka basalt quarry in the České středohoří Hills. Photo: Karel Prach

sites are quickly overgrown by trees such as *Betula pendula*, *Fraxinus excelsior* and *Populus tremula*. On the other hand, the rock walls are colonized very slowly without any dominant.

Quarries in the České středohoří Hills differ mainly in the speed of succession, which is again highest on deeper soil profiles and lowest on the steep rocks. Annual species such as *Arenaria serpyllifolia*, *Tripleurospermum inodorum* and typical of the region *Senecio vernalis,* prevail in the initial stages of succession. Sites with rocky and shallow soil profiles are then colonized by *Sedum album*, *Erysimum crepidifolium*, *Poa compressa* and *Sanguisorba minor*. On sites with deeper soil profiles, *Tussilago farfara*, *Tanacetum vulgare* and *Artemisia vulgaris* are common. *Arrhenatherum elatius* is the most common dominant of middle successional stages. Later, the quarries are colonized by woody species, mainly *Sambucus nigra*, *Rosa* sp. div., *Cornus sanguinea*, *Crataegus* spec. div., *Betula pendula*, *Fraxinus excelsior*, *Populus tremula*, and sometimes also *Acer campestre* and hybrids of poplars (*Populus* × *canadensis*), occur mainly on sites with deeper soil profiles and wet screes at the bases of rock faces. Grasslands are formed on rocky and dry substrates; these are very similar to natural steppe grasslands in the area (alliance *Festucion valesiacae*). The following species are common in these communities: *Festuca rupicola*, *F. valesiaca*, *Thymus pannonicus*, *Poa angustifolia*, *Fragaria viridis*, *Artemisia campestris*, *Potentilla arenaria*, *Koeleria macrantha* and *Melica transsilvanica*. Successively older stages have the character of a shrubby steppe. When natural or semi-natural preserved steppe communities are present in the close surroundings, the quarries are then easily colonized by the respective species, many of which are rare or endangered.

/ Swordleaf Inula (*Inula ensifolia*). Photo: Lubomír Tichý

In the limestone quarries in the southern part of the Moravian Karst and in adjacent areas, the presence of steppe plant species in the surroundings has a high impact on succession. The spread of succulent or other drought resistant species e. g. *Sedum album*, *Inula ensifolia*, *Sanguisorba minor*, *Aster amellus* and *Genista tinctoria*, is typical in the early stages of succession.

Quarries situated at higher altitudes (i. e. in a more humid and colder climate) are colonized at first by common ruderal species such as *Poa compressa*, *Tripleurospermum inodorum*, *Echium vulgare*, *Rumex acetosella* and *Tussilago farfara*. Grasses, especially *Agrostis capillaris* and *Poa nemoralis*, dominate in later stages,

/ Red-winged Grasshopper (*Oedipoda germanica*). Photo: Pavel Marhoul

but *Calamagrostis epigejos* can also be abundant. Later, fast growing woody species become important (as in most of the quarries). These species include *Salix caprea*, *Betula pendula*, *Populus × canadensis*, *P. tremula* and *Pinus sylvestris*. *Picea abies* can also be important in the higher altitudes on wet sites if its stands are in close vicinity (see also Trnková et al. 2010).

Vegetation in all quarries at lower altitudes is endangered by the invasion of alien species, especially *Robinia pseudacacia*. In the Bohemian Karst, *Pinus nigra* is invasive, while in South Moravia, i.e. in the southeastern part of the country, *Laburnum anagyroides*, *Amorpha fruticosa* and *Colutea arborescens* may invade. The alien *Solidago canadensis* can be abundant on deeper soil. *Erigeron canadensis* can be a common species on flat sites with shallow soil profile. As in other types of mining sites, expansion of the competitively strong *Calamagrostis epigejos* can be problematic.

Species rich communities can establish spontaneously in most of the quarries. Succession can also be directed by such measures like cutting too dense woody species or eradication of invasive species. The saved funds for reclamation can then be used for preservation of the diverse mosaic of habitats in the quarry or restoration of the surrounding landscape, which is often influenced by mining. A useful investment could be to support the cultural and educational value of the quarry. Building of nature trails and view points on a properly restored quarry with atractive endangered species can also be a good advertisement for the mining or reclamation companies.

Succession of valuable communities can be supported by some extensive measures of restoration ecology, such as sowing of desirable species or the spreading of hay from nearby preserved localities.

/ Specific principles of stone quarry restoration /

/ During the mining process /

- Do not mine in the whole quarry at the same time, but continue gradually across the area designated for mining („quarry walking through the landscape“, Konvička et al. 2005). Abandoned parts of the quarry should remain without intervention. Valuable communities also establish on sites prepared for mining, i.e. sites with stripped topsoil. This increases the colonization rate of valuable species from the surrounding landscape, because they colonize the quarry foreland first and then they can spread into the excavated sites where the mining activities are finished.
- It is valuable to mine locally below the level of the ground water and form small and shallow pools.
- Minimize spoil deposition and try to keep such deposition without ruderal species. At the end of the mining, the spoil should be covered by broken stone.

/ Apollo (*Parnassius apollo*). Photo: Martin Hrouzek

- Preserve as much as possible natural and semi-natural habitats in the close surroundings of a quarry.
- Do not mine the dominant relief types in the landscape, but rather mine into the deep.

/ After the mining process /

- Maintain young successional sites. Initial successional sites are usually crucial for nature conservation. Therefore, it is desirable to block locally the succession towards a closed woodland through active disturbance management. This is especially essential for invertebrates, which need large populations for survival. From this standpoint, large quarries are paradoxically better for nature conservation than smaller ones.
- Do not completely clean the quarry of rocks and rubble, as they can provide suitable microhabitats for various organisms.
- It is important to suppress invasive species in both the surroundings and inside of a quarry (it is better to start during the mining process or even before).
- Control invasive tree species and temporarily cut also other trees to maintain non-forest habitats over a sufficiently large area.
- Take care of periodic lakes at the bottom of the quarry, and prevent their being overgrown by application of regular disturbances.

/ The Růženin lom limestone quarry near Brno. Photo: Lubomír Tichý

/ Examples of good practices /

/ Růženin lom quarry /

Location: NW outskirts of Brno, south facing slope of Hády hill, abandoned limestone quarry of about 6 ha (49°13'10"N, 16°40'17"E).

History: Mining was terminated at the beginning of the 1960s; later the place served as a disposal site for debris. The site was restored after 1998.

Geology: Limestone of Paleozoic origin prevails; in the eastern face is sporadically revealed granodiorite and Mesozoic limestone.

Botany: Currently, the species diversity of vascular plants is two times higher than before reclamation, reaching up to 80 plant species per m^2! Among the remarkable species are: *Cornus mas, Aster amellus, A. linosyris, Pulsatilla grandis, Epipactis palustris, Veronica spicata, Onobrychis arenaria, Inula ensifolia, I. hirta* and *Thesium dollineri*.

Zoology: Small pools in the quarry host several species of frogs (*Bufo bufo, Pseudepidalea viridis, Rana dalmatina* and *R. temporaria*), and sporadically *Bombina bombina* and *Hyla arborea*. Tailed amphibians include *Lissotriton vulgaris*. Reptiles are represented by *Natrix natrix*. Among the permanently nesting birds are *Falco tinnunculus* and *Phoenicurus ochruros*, while the owl *Bubo bubo* was recorded as nesting.

Management: The Růženin lom quarry was reclaimed by methods of directed succession from 1998 to 2002 (Tichý 2005). Invasive tree species were removed and the surface of the quarry was modified. More than 60 termophilous plants species were sown into the limestone debris mixed with a low amount of soil. These, together with species of seed bank origin, formed a diverse mosaic of open xeric grasslands.

/ Jezírko quarry /

Location: South of Dobříš, southwest of Prague, (49°46'14"N, 14°9'52"E).

History: The history of mining is rather old. An extensive quarry is seen even on the military maps from the 19th century. Mining was terminated at the beginning of the 1990s in order to protect a valuable geological profile in the quarry face. Due to the mining activities, a diverse mosaic of early successional stages was formed, which hosts a variety of rare and endangered species.

Geology: Building stone (shales, siltstones, wackes and conglomerates) was mined in the quarry.

/ The Jezírko quarry southwest of Prague. Photo: Robert Tropek

Botany: A diverse mosaic has developed consisting of early successional stages including bare ground, sparse xerophilic grasslands, ruderal habitats, closed mesic grasslands, woodland and early successional wetland communities in depressions. Many species occur which are retreating from the surrounding landscape, such as *Thymus pulegioides*, *Dianthus carthusianorum*, *Anthylis vulneraria* and *Filago arvensis*.

Zoology: The diverse mosaic of habitats enabled colonization by a variety of rare thermophilic and wetland species, including the birds *Charadrius dubius* and *Lanius collurio*, insects *Zorochros meridionalis*, *Scolitantides orion*, *Spialia sertorius*, *Myrmeleotettix maculatus, Oedipoda coerulescens, Nysius helveticus, Coptocephala rubicunda*, spiders *Titanoeca quadriguttata, Xysticus ninnii, Zelotes puritanus, Zodarion rubidium,* and others.

Management: After termination of mining at the beginning of the 1990s, the quarry was left to spontaneous succession, which resulted in the establishment of a diverse mosaic of habitats. Recently, expansive shrubs were removed. Grasslands are mown and harrowed to maintain habitat diversity. This management will probably maintain the importance of the quarry for rare species. A lake in the middle of the quarry was not colonized by rare species until now. Data were taken mainly from Tropek et al. (2007).

/ Kladrubská hora quarry /

Location: South Bohemia, Tábor district, 0.5 km south from Dolní Hořice, (49°25'50"N, 14°50'57"E).

History: The mine has been documented since the 18th century. Mining continued until the 1960s, when it was stopped due to technical reasons.

Geology: There are several abandoned limestone quarries, one large quarry with three floors and several small peasant quarries in its surrounding. It is a mineralogically important locality.

Botany: Communities on rocks and debris, xerophilic grassland and secondary woodland in various successional stages are developed. In one smaller mine, there

/ A limestone quarry in the Kladrubská hora nature reserve in the southern part of the country. Photo: Jiří Řehounek

are the last individuals in the country of the very rare fern *Ceterach officinarum*. There are also four species of orchids: *Epipactis atrorubens, Cypripedium calceolus, Epipactis helleborine* and *Cephalantera damassonium*. Other interesting and rare species include *Botrychium lunaria, Orobanche elatior, Orthilia secunda, Helianthemum grandiflorum* subsp. *obscurum* and *Rubus saxatilis.*

Mycology: Kladrubská hora is also an important mycological locality. Together 250 species of fungi were recorded in the mined sites and their surroundings. The following species occur directly in the quarries: *Entoloma incanum, Helvella solitaria, Helvella macropus* and *Tricholoma cingulatum*.

Zoology: The vertebrates recorded in the site include the owl *Bubo bubo*, lizards *Lacerta agilis* and *Anguis fragilis*, and snakes *Natrix natrix* and *Vipera berus*. Also present are the overwintering bats *Plecotus auritus* and *Myotis myotis*. Insect species include, for example, *Coptocephala rubicunda, Pyrrhalta viburni* and the highly endangered *Crepidodera lamina*.

Management: Expansive shrubs and trees are cut regularly. A part of the data was taken from Abazid et al. (2009).

/ Examples of bad practices /

/ Lom Ve skále – Cikánka II quarry /

Location: Near the villages Zadní Kopanina and Lochkov nearby Prague, (50º0'12"N, 14º19'42"E).

History: The site is located in a densely inhabited area, where human presence is documented since the Neolithic age. Limestone mining has been documented since the 13th century, in the 17th – 18th centuries and the second half of the 20th century. The close surroundings of the quarry is a rocky area covered mainly by xerophilic grasslands and bushes. Mining in the 20th century was rather extensive and terminated approximately 30 years ago.

Geology: This limestone area is an important site for paleontology. We can find here fossils of the trilobites *Platyscutellum formosum slivenecense, Crotalocephalus albertii, Pragoproetus pragensis* and brachiopod *Dalejodiscus subcomitans*.

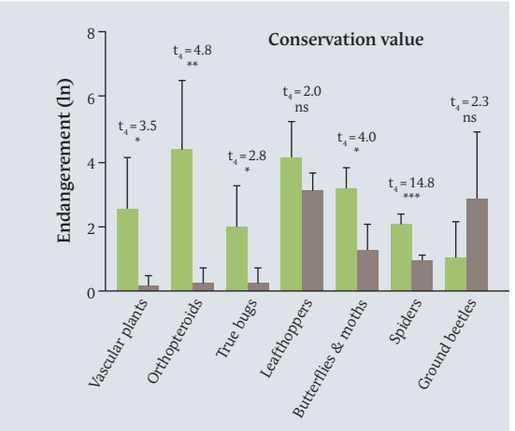
Botany: Most of the remaining spontaneously re-vegetated area is formed by a mosaic of xeric grassland, young woodland and bare rocks on quarry faces. Several rare species were found on the unreclaimed site, such as *Stipa pennata, S. pulcherrima, Teucrium botrys, Sedum acre, Anthericum liliago, Helianthemum canum, Lactuca perennis, Gentianopsis ciliata, Anthericum ramosum, Cornus mas* and

/ A technically reclaimed part of the Ve skále quarry with dominance of Bush Grass (*Calamagrostis epigejos*). Photo: Marián Trník

Botriochloa ischaemum. The reclaimed site (see above) is overgrown mainly by a species poor grassland with high dominance of *Calamagrostis epigejos*.

Zoology: The following rare species of arthropods were found in the unreclaimed sites: *Eresus kollari, Sitticus penicillatus, Zodarion italicum, Oedipoda germanica, Calliptamus italicus, Himacerus major, Nabis ericetorum, Doratura exilis, Allygidius atomarius, Euscelis distinguendus, Mendrausus pauxillus, Hamearis lucina, Iphiclides podalirius, Pyrgus carthami, Hesperia comma, Thymelicus acteon, Hipparchia semele* and *Hemaris tityus*. These species do not colonize the reclaimed sites.

Management: Until the 1990s, the quarry was left to spontaneous succession, which led to the spread of species from surrounding valuable habitats and to the development of valuable sparse grasslands and woodland. However, during the 1990s, debris from demolished buildings and other spoil was deposited into the quarry, being presented as part of a "reclamation" which completely destroyed the present communities. "Reclamation" damaged most of the area. Spontaneously re-vegetated areas now cover less than 0.2 ha. Covering the site by topsoil completed the destruction of natural values and led to the development of species poor ruderal communities without any value for nature conservation. The invasive



/ A comparison of the importance of unreclaimed (green) and technically reclaimed (grey) limestone quarries in the Bohemian Karst near Prague (Tropek et al. 2010).

Robinia pseudacacia has recently been spreading into this "reclaimed" site. In the near future, no management measures are planned nor are measures for supporting rare species or communities, or for conserving important geological profiles.

Data were taken mainly from Vítková (2009) and Tropek et al. (2010).

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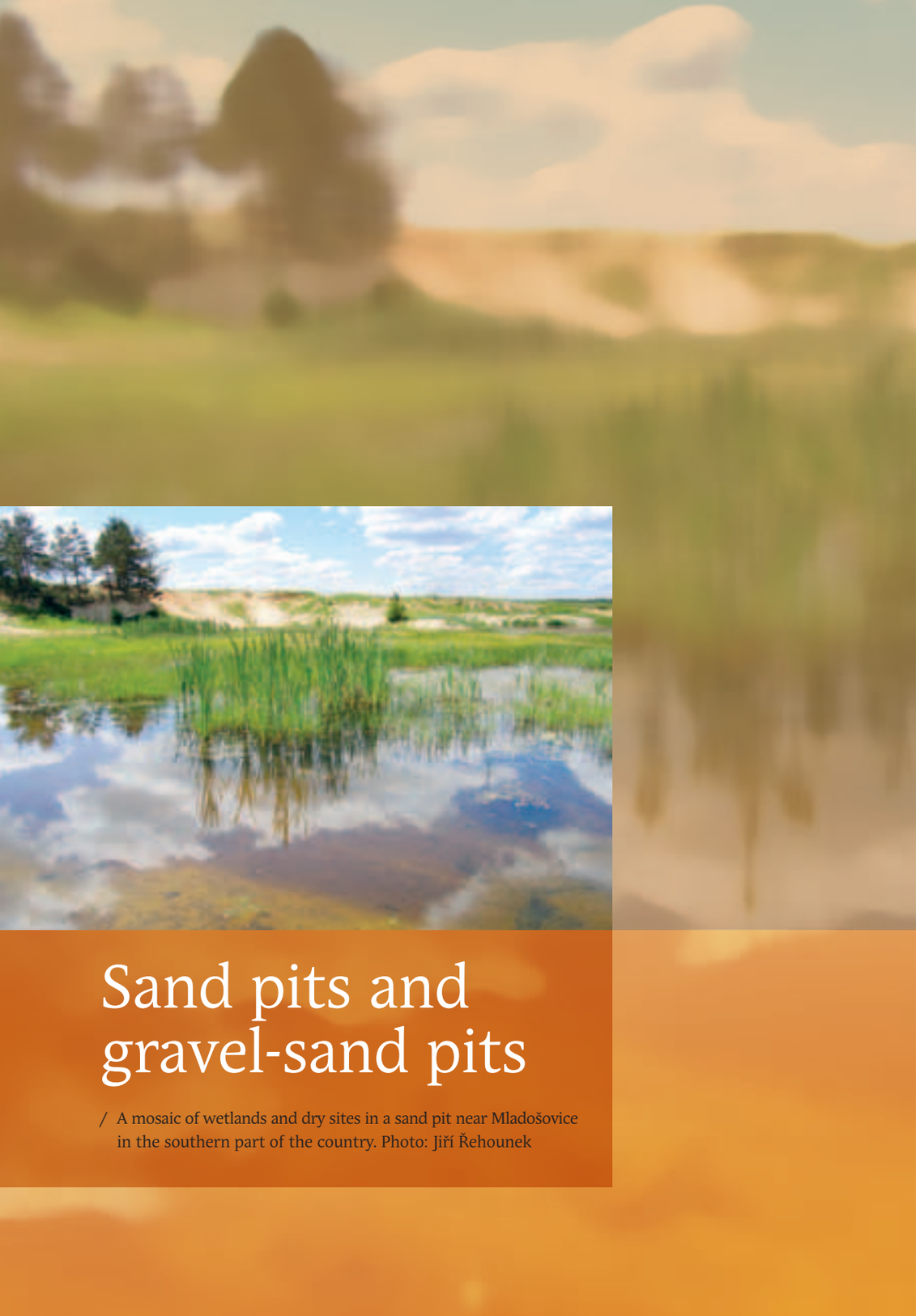

Sand pits and gravel-sand pits

/ A mosaic of wetlands and dry sites in a sand pit near Mladošovice in the southern part of the country. Photo: Jiří Řehounek

/ Sand pits and gravel-sand pits

Editors: Klára Řehounková & Jiří Řehounek

Coauthors: Luboš Beran, Petr Bogusch, Jaroslav Blízek, Milan Boukal, František Grycz, Miroslav Hátle, Josef Hlásek, Petr Heneberg, Petr Hesoun, Martin Konvička, Anna Lepšová, Tomáš Matějček, Ladislav Rektoris, Luboš Stárka & Vít Zavadil

/ Introduction /

Mining of gravel and sand is important phenomenon highly affecting the landscape in some parts of the Czech Republic.

In 2007, 231 sites of exploitable sand and gravel deposits were officially registered out of which 88 were mined. Historically, the total number of large mined sand and gravel-sand pits is 169 and they cover an area of 114 km^2 (Starý et al. 2008). Even from these basic data, it is obvious that restoration after mining of these resources is highly important in several districts of the Czech Republic (e.g. Hátle 2008).

/ Geology and geomorphology /

Sand and gravel originated mainly from river, lake and sea sedimentation and aeolian processes (blown sand). Most of the deposits have a quaternary origin, but a few originate also from other periods (Tertiary and Secondary).

Sand mining forms the surface mostly into concave anthropogenic shapes. Convex shapes are predominantly formed by heaps of stripped topsoil both inside and outside of the sand pits. Mining in sand pits increases the rate of some geomorphologic processes, such as wind and water erosion or landslides. Mining also reveals important geologic and geomorphologic phenomena which deserve protection and are scientifically interesting, including stratigraphic profiles and paleontological or mineralogical findings.

/ Technical reclamation /

Reclamation usually results in arable land, forest plantation or artificial lakes. The productivity of arable land is usually low in comparison with that in the

/ Contrast between a pine plantation and a near-natural restoration site in a sand pit in the Třeboňsko Protected Landscape Area and Biosphere Reserve in the southern part of the country. Photo: Jiří Řehounek

surroundings. Forest plantations consist mostly of Scots pine (*Pinus sylvestris*) monocultures. Their quality is low for both silviculture and nature conservation. In some sand pits, exotic species are even planted, such as *Picea pungens* and *Quercus rubra*; the latter becomes invasive in some areas. Unfortunately, prior to afforestration, the surface of the sand pit is covered by topsoil with a humus content. This approach is highly destructive for rare species with low competitive ability and communities.

Irrespective of the method of technical reclamation, i.e. conversion to arable land or other agricultural use and afforestation, in most cases, the result is a sand pit with low geodiversity and biodiversity. Thus, technical reclamations lead to the destruction of valuable habitats and the extinction of rare and endangered species or prevent their establishment.

/ Near-natural restoration /

Practically all mining sites for sand and gravel-sand have a large potential to be restored by spontaneous succession or other near-natural approaches. Including the approaches into restoration projects should be based on a detailed survey of the locality and also reflect the spontaneous establishment of organisms during the mining process. It is desirable to maintain or increase landscape heterogeneity during the mining process to establish a large variety of habitats for later restoration.

The easiest and cheapest method of restoration is spontaneous succession. Today, we have available a rather complex knowledge of successional pathways (Řehounková and Prach 2006, 2008, Prach et al. 2008). Annual plants prevail at the beginning of succession, but the exact species composition depends on the habitat type. On dry sites, species like *Trifolium arvense*, *Conyza canadensis* and *Filago minima* dominate, while *Alopecurus aequalis* and *Juncus bulbosus* often occur on wet sites and in the littoral zone. Annual vegetation is followed in all types of habitats by perennial species. Common species on dry sites include *Poa palustris* subsp. *xerotica* or *Agrostis capillaris*, while *Juncus effusus*, *Phalaris arundinacea* and *Glyceria fluitans* are the most frequent on wet sites and in the littoral zone. *Tussilago farfara* and *Elytrigia repens* dominate mainly on steep and instable slopes. Vegetation of open grasslands with *Corynephorus canescens*, a typical species of sandy habitats, can be found on dry sites. After approximately ten years, perennial herbs and graminoids prevail such as *Achillea millefolium*, *Festuca ovina*, *Avenella flexuosa* and *Calamagrostis epigejos* on dry sites, and *Carex brizoides* and *Deschampsia cespitosa* on wet sites. *Carex vesicaria* often dominates in the littoral zone.

Except for sand pits in warm and dry areas of south Moravia and around the Elbe River, the succession results in terrestrial woodland habitats. The species composition of the forest depends on the level of the ground water and the surrounding vegetation. On dry sites in regions with a more cold and humid climate, a closed woodland is formed over a few years. Such woodland is usually dominated by *Betula pendula*, *Pinus sylvestris*, *Quercus robur* and *Sorbus aucuparia*. In the understory, typical woodland species such as *Vaccinium myrtillus* and *V. vitis idaea* later appear. Succession on wet sites usually leads towards stands dominated by willows (*Salix* spp.) or *Alnus glutinosa*. Aspen (*Populus tremula*) can occur locally.

In warm and dry regions, a successional stage similar to a steppe woodland develops and can persist for decades.

Littoral vegetation is similar throughout the Czech Republic and in its later succesional stages includes growths of *Phragmites australis*, *Typha* spp. and tall sedges

/ Shrubby grasslands can persist in sand and gravel-sand pits in relatively dry and warm lowlands for a long time. Photo: Jiří Řehounek

(*Carex gracilis*, *c. vesicaria* or *c. rostrata*). The target vegetation can be restored relatively quickly (within 25 years) by spontaneous succession, especially when the respective vegetation is present in the close surroundings.

Undesirable ruderal and invasive species are usually present only in the younger successional stages and later (approximately after 10 years) disappear (Kočár 1997, Řehounková and Prach 2008). The only exception is *Robinia pseudacacia*, but only in dry and warm regions. *R. pseudacacia* can completely change the direction of succession and form monodominant stands with a few nitrophilous species in the understory (Řehounková and Prach 2008). Suppression or eradication of *R. pseudacacia* is highly desirable.

There are some possibilities to direct succession. Besides the already mentioned suppression of invasive species, we can, for example, plant indigenous woody species suitable for the habitats. However, this should not be monocultures of seedlings planted in rows as is the common practice in technical reclamation. Such species then can further spread and colonize the sand pit. The planting or sowing of pioneer woody species (willows, aspen and poplar) is most likely needless. Their introduction may be needed only in isolated sand pits, e.g. within extensive arable fields, where there is a lack of diaspores, but even there pioneer woody species often colonize the sand pit. Nevertheless, all planting and sowing of woody species should be carefully considered, because their rapid establishment can suppress rare species and communities.

Management measures targeted to some selected important species represent a third way of near-natural restoration. They are usually more expensive, but would be practiced only in small parts of the restored area. Plants which are dependent on such targeted management include *Lycopodiella inundata*, which needs regular mechanical disturbances of wet sand.

There is a relatively long tradition of management measures targeted to vertebrates. For example restoration of small water bodies is important for breeding of the toad *Epidalea calamita* and other amphibians, or the restoration of vertical walls for nesting sand martins (*Riparia riparia*). In 2009, 57 % of sand martins in South Bohemia nested in the sand pits adjusted for their nesting (Heneberg 2009).

Experience with management of sand pits directed to invertebrates is rather low, although there is a large number of endangered species, especially among the insects which depend on this type of habitat. Generally for invertebrates, it is important to maintain a heterogenous mosaic of habitats where patches of bare sand, vertical sandy faces and early successional stages are present.

/ Specific principles of sand and gravel-sand pits restoration /

- Among the invasive species, it is important to consider mainly *Robinia pseudacacia*, especially in the warm and dry regions. *R. pseudacacia* colonizes the sand pit with high probability when it grows in the close surroundings. Succession then does not continue towards the desirable direction. Hence, the spread of *R. pseudacacia* into the sand pit should be prevented.
- If it is possible, no large water body should be formed during sand or gravel-sand extraction, but rather a system of connected smaller lakes of various depths with a shallow littoral zone and a large number of "peninsulas". Some lakes should remain unconnected with the system. An acceptable alternative is one large water body but with gentle slopes forming a broad and shallow litoral zone.
- Sand pits are an important secondary habitat for many birds nesting in burrows. Hence, it is desirable to plan the mining in a way which forms suitable conditions for their nesting, i.e. creating vertical sandy faces and their regular renewal beyond the breeding periods. Management must be provided even after the finishing of the mining.
- It is important to provide appropriate management for early successional stages (open sands, dry grasslands, oligotrophic wetlands) even after the end of mining. Measures for maintaining them should arrest succession or push the succession back by removing trees, providing severe disturbances of the soil surface,

/ Marsh Clubmoss (*Lycopodiella inundata*) occurs on wet sandy sites. Photo: Jiří Řehounek

/ A generalized scheme of the course of spontaneous succession in sand and gravel-sand pits in the Czech Republic (adapted from Řehounková and Prach 2006, 2008). Three main successional seres were distinguished: dry, wet and semi-aquatic. The dry sere was further distinguished based on geographic regions, i.e., relatively dry and warm lowlands, and wetter and colder highlands. Each successional stage is characterized by dominant species of vascular plants. In bold are those which start to dominate in the respective successional stage. Desirable target and undesirable (mostly composed of alien species) late successional stages (>41 years) are indicated.

Undesirable stage	*Robinia pseudacacia* groves	None	None	None
Target old stage	Shrubby grassland	**Deciduous woodland**	***Alnus* and *Salix* carrs**	**Tall sedge, Reed and *Typha* beds**
Old stage (>41 yrs)	**Perennial grasses & shrubs**	**Trees**	**Trees & shrubs**	**Perennial graminoids**
Late stage (26–40 yrs)	Perennial grasses **& shrubs**	**Trees, perennial grasses & herbs**	**Shrubs & Trees**	**Perennial graminoids**
Middle stage (11–25 yrs)	Perennial grasses & herbs	Perennial grasses & herbs **+ shrubs & trees**	Perennial graminoids & herbs, shrubs **+ trees**	Perennial graminoids
Young stage (4–10 yrs)	**Perennial herbs** & grasses		**Perennial graminoids & herbs + shrubs**	**Perennial graminoids**
Inicial stage (1–3 yrs)	**Annual herbs, grasses**		**Annual graminoids**	
Landuse	Agrarian (arable land) & Urban	Woodland & Agrarian (grassland)	Any	
Altitude	Lowlands	Uplands	Any	
Climatic region	Warm & Dry	Cold & Wet	Any	
Sere	Dry	Wet	Shallow water	

Increasing site moisture

maintaining the bare sand, and maintaining and disturbing shallow lakes without reed (*Phragmites australis*).

/ Examples of good practices /

/ Pískovna u Dračice sand pit /

Location: Near Rapšach, left bank of the Dračice River, Třeboň district; area 7.5 ha (48°53‘35“N, 14°56‘2“E).

History: Sand was mined in the locality from the 1980s to the beginnig of the 1990s. At first, there was no clear scheme. Mining destroyed the original habitats (forest plantation, meadow, pasture and arable field). At the same time, interesting geologic and geomorphologic phenomena were revealed, and unique habitats and successional sites were created. Because of the intervention of the nature conservation authority (Třeboňsko Protected Landscape Area) the planned deposition of building wastes and forest reclamation were not realized. Instead, three small water bodies were created to increase habitat heterogenity.

Geology: Mining of Quaternary fluvial gravel-sand on an alluvial terrace of the Dračice River exposed the original bottom of the basin, which is formed by gneiss. Processes of sedimentation are now clearly visible.

/ Most localities of Natterjack Toad (*Epidalea calamita*) occur in abandoned sand pits. Photo: Jiří Řehounek

/ A mosaic of dry and wet sites in the Pískovna u Dračice nature reserve in the Třeboňsko Protected Landscape Area and Biosphere Reserve in the southern part of the country. Photo: Jiří Řehounek

Botany: There are typical xeric habitats on exposed rocks and sands, including open sand grasslands with *Corynephorus canescens*. Other typical species include *Teesdalia nudicaulis*, *Carex ericetorum*, *Jasione montana* and *Chamaecytisus ratisbonesis*. *Gnaphalium uliginosum*, *Gypsophila muralis* and *Hypericum humifusum* occur on the sand pit bottom.

Mycology: This sand site became a well known mycological locality. After several rainy autumn days, it is possible to find tens of rare species of fungi. *Psilocybe montana* commonly grows in extensive sites overgrown by moss *Polytrichum piliferum*. *Hypholoma subericaeum* grows in the litter of the *Typha* spp. on the bank of the lake. The locality is the only site in the South Bohemia, where occurs another red list species *Mycenastrum corium*.

Zoology: A relatively large number of invertebrate species (mainly hymenoptera and orthoptera) was recorded especially in dry and warm sandy habitats of the locality, e. g. *Oedipoda coerulescens* and *Sphingonotus coerulans*. The spider *Arctosa perita* lives in unconsolidated sand under the faces of the sand pit. Many species are confined to the small lakes, being mainly the amphibians *Epidalea calamita* (with one of the largest population in the region), *Pelobates fuscus*, *Rana dalmatina*, *Hyla arborea*, *Triturus cristatus* and *Lissotriton vulgaris*. The locality is a nesting site for sand martins (*Riparia riparia*) and nesting by the rainbow bird (*Merops apiaster*) was recorded in 2002. In 2008 there was repeatedly recorded hoopoe (*Upupa epops*) in its nesting time.

Management: Re-creation of sites with bare sand, by cutting expansive trees and shrubs. Small scale extraction of the sand is allowed (re-creation of sand pit faces with documentation of sedimentation and for nesting sand martins). In addition, there is periodical re-creation of small lakes.

/ Successional site in the Cep I sand pit /

Location: Near Cep, Třeboň district, NW edge of the mining area Cep I, area approximately 6 ha (around 500 × 120 m), 48°55‘4“N, 14°52‘60“E.

History: A mining area of gravel-sands was established in 1981 south of an older mining area. In the middle of the 1990s the restoration scheme was rearranged on the request of the Administration of the Třeboňsko Protected Landscape Area and the site was left to spontaneous development. In 2002 – 2006, the surface was modulated and shallow lakes were created. Communities of bare sand and oligotrophic wetlands gradually established in the site. Slopes at the edge of the site are afforested by *Pinus sylvestris* and *Quercus robur* as a compromise between near-natural and traditional forest reclamation.

/ A biocentre in the sand pit Cep I in the Třeboňsko Protected Landscape Area and Biosphere Reserve in the southern part of the country. Photo: Jiří Řehounek

Geology: The site is formed by Quarternary fluvial gravel-sand of an alluvial terrace of the Lužnice River. Underbed is formed mainly by clays of Cretaceous origin, which is sporadically exposed by the mining. Clay further increases the site heterogeneity. Part of the site is covered by deposition of unused mined material.

Botany: Recently, spontaneous succession of wetland communities includes species such as *Typha latifolia*, *Juncus effusus*, *Juncus articulatus*, *Peplis portula*, *Eleocharis acicularis*, *Eleocharis palustris*, *Alisma plantago-aquatica*, *Utricularia australis*, *Ranunculus flammula*, *Juncus bulbosus*, *Elatine hydropiper* and *Scutellaria galericulata* in a diverse mosaic with sandy communities with *Vulpia myuros*, *Avenella flexuosa* and *Agrostis capillaris*. Willows are growing in the center of the locality and at the margins aspens, birches and pines also occur. Expansion of the competitive species *Calamagrostis epigejos*, *Phalaris arundinacea*, *Bidens frondosa* and *Tussilago farfara* is in progress.

/ A small sand pit surrounded by pine forests in the Třeboňsko Protected Landscape Area and Biosphere Reserve in the southern part of the country. Photo: Jiří Řehounek

Zoology: The critically endangered *Epidalea calamita* lives in the locality. Other amphibians present are *Pelobates fuscus*, *Rana dalmatina*, *Hyla arborea* and *Lissotriton vulgaris*. Sandy banks are used by nesting *Charadrius dubius*.

Management: The site is relatively young and part of its surface is still modulated. Nature conservation management has not been carried out there yet. Cutting of trees and shrubs, and re-creation of lakes and bare sand are planned in the future.

/ Forestry sand pit – Cep /

Location: The sand pit is located in a forest near Cep (Třeboň district), area: 2.25 ha (48°55‘24“N, 14°50‘20“E).

History: Mining started in 1987. At present, sand is mined only occasionally for the purposes of the Forests of the Czech Republic, a large state company, which manages most of the forests in the Czech Republic. Sand was used mainly for the building of forest roads. The mining was done in cooperation with the authority of the Třeboňsko Protected Landscape Area and succession has proceeded towards valuable wetland communities. Technical reclamation has not been carried out. The sand pit is now overgrown by woody species and the oldest lakes are changing into peatlands.

/ Sand Martin (*Riparia riparia*). Photo: Jan Ševčík

Geology: The locality is formed by a several metre thick layer of Tertiary sands, which covers Upper Cretaceous Senonian sandstones. Yellow sand prevails which contains larger particles of ferruginous conglomerates. Silicified wood (probably of Senonian origin) can be found here.

Botany: Vegetation of various successional stages is present on the locality. Different communities occur on bare sand, clay, shallow lakes and peatland. The area contains several endangered species, such as *Drosera rotundifolia*, *Lycopodiella inundata* and *Hypericum humifusum*.

Zoology: The site is part of a Natura 2000 locality, which was established for the protection of the newt *Triturus cristatus*. Other amphibians include *Lissotriton*

/ Sand Martins (*Riparia riparia*) nesting in the front of a sand pit near the town of Borovany in the southern part of the country. Photo: Jiří Řehounek

vulgaris, *Mesotriton alpestris*, *Bufo bufo*, *Pelobates fuscus*, *Rana dalmatina*, *Pelophylax esculentus* and *Pelophylax lessonae*. Abundant population of the lizard *Lacerta agilis* is also present. The locality is important also for the dragonflies *Aeschna grandis*, *Anax imperator* and *A. parthenope*. However, the most important is the presence of *Leucorrhinia dubia* and mainly *L. albifrons*, which occurs only in several localities in the Czech Republic. Leaves of willows, birches and aspens provide food for many butterfly caterpillars.

Management: Occasional mining is conducted under the supervision of the nature conservation authorities. Management is done in the way which diversifies ecological conditions, which supports rare and endangered species. An originally planned forest reclamation, consisting of covering the site with topsoil and afforestration by pine, will not be realized. In the case that the owner will lose interest for mining in the locality, it would be necessary to block or reverse succession by cutting trees and shrubs, as re-creation of bare sand and re-creation of small water bodies.

/ Pískovna Třebeč sand pit /

Location: 250 m east from Třebeč (South Bohemia); area 0.75 ha (48°52‘21.289“N, 14°41‘10.399“E).

History: Sand has been occasionally mined in the locality since the middle 1990s. Intensive mining was prevented because of the high natural value of the locality. The site is managed by the local Calla NGO, which mainly renews the sand pit face for sand martins.

Botany: Most of the locality is covered by the woody species *Alnus glutinosa*, *Betula pendula*, *Salix caprea*, *Salix cinerea* and *Populus tremula*. Remnants of a meadow community are found along the upper edge of the sand pit. Early successional communities are currently establishing on bare sand. Wet sites are dominated mainly by *Alopecurus aequalis*, *Juncus bufonius* and *Gnaphalium uliginosum* and on drier sites by *Poa annua*, *Gypsophila muralis* and others. The spoil heaps in the southern part of the sand pit are covered by ruderal vegetation. *Typha latifolia* and *Phragmites australis* dominate in small lakes. The rest of the sand pit bottom is dominated by *Epilobium hirsutum*, *Lythrum salicaria*, *Agrostis capillaris* and *Calamagrostis epigejos*.

Zoology: The locality is an important nesting site for sand martins (*Riparia riparia*). Tens to several hundreds of pairs of sand martins nest each year. Present are also the amphibians *Bombina bombina*, *Hyla arborea*, *Pelophylax esculentus* syncl., *Pseudepidalea viridis* and *Bufo bufo*. Endangered species are represented by the lizard *Lacerta agilis* and the beetle *Cicindela campestris*.

Management: The number of nesting pairs decreased after termination of the mining. Hence, active management was started in 2002. The face of the sand pit is renewed annually by partial excavation. Small pools for amphibians were renewed in 2009.

/ Klara’s island in the CEP II sand pit /

Location: Cep (near Suchdol nad Lužnicí); a lake was created by mining, Klara’s island is in southeastern part of the sand pit. The island has an area of approximately 0.3 ha (70 × 40 m). The total mining area of the sand pit is about 101 ha (1 500 × 500 m); 48°54’59”N, 14°52’40”E.

History of the area: Mining of the Cep II sand pit started in 1979. A majority of the area is formed by a large lake formed by extraction of gravel-sand below the water level. A part of the extracted material, having a prevalence of clay particles, predominantly situated in the peripheral parts of the pit, was deposited in the southern part of the lake to create the island in 2005 (December).

Geology: see CEP I (p. 60)

Botany: similar to CEP I (see p. 60). The gentle slopes are colonized by *Agrostis scabra* in the northern part of the sand pit. On wetter sites grow e. g. *Juncus tenuis*,

/ Permanent experimental plots on Klara's island. Photo: Klára Řehounková

Juncus articulatus, *Juncus bulbosus*, *Filago minima* and rarely also *Hypericum humifusum* and *Vulpia myuros.*

Zoology: similar to CEP I (see p. 60). Moreover, the following rare species live in the pit: amphibians (*Triturus alpestris*, *T. vulgaris Rana lessonae)* and reptiles *(Lacerta agilis*, *L. vivipara*, *Vivipara betus*, *Natrix natrix*). A large colony of *Charadrius dubius* nests in sandy faces in the southern part of the pit. Another two birds are food bounded to the sand pit: the birds of prey *Falco subbuteo* and *Sterna hirundo*.

Restoration: Application of near-natural restoration methods (i. e. spontaneous and directed succession, and treatment to support rare or endangered species) by the Administration of the Třeboňsko Protected Landscape Area led to the decrease of technical reclamation (i. e. afforestation with *Pinus sylvestris* following spreading of an organic layer) in extracted areas since the end of the 1990s. The recent restoration scheme assumes a further increase in the proportion of near-natural restoration in all recently mined areas; mostly the creation of a gentle lake coastline (including Klara's island) with favourable conditions for shallow water vegetation. Technically afforested banks are additionally planted with *Quercus robur* and *Alnus glutinosa*, the latter on wetter sites.

In 2009, Klara's island was used in an experimental trial to restore psammophytic grasslands in the sand pit. Since this vegetation type has become very rare and fragmented in the whole region, there is a chance to support the establishment of this vegetation type on suitable new sites such as abandoned sand pits. Raking was used as a method to harvest seeds and cryptogam material. Although some target species may locally establish spontaneously (Řehounková & Prach 2008), raking probably speeds up the process substantially and includes more species.

In September 2009, almost 1000 litres of raking material was gathered in two types of habitats in the Třeboň Basin where rare and retreating psammophytic communities still occur. Phytosociological relevés were made on the donor sites including inventory of mosses and lichens. Three variants (control, two different types of donor sites) were realized in a complete block design with five replicates. A ratio of 1:1 for donor and receptor sites was used. All permanent experimental plots were analyzed by phytosociological relevés prior to and a year after the experiment started and soil samples were collected.

The first very promising preliminary results indicate that 80 % of higher plants typical of psammophytic grasslands (20 of 25 species) successfully established (see below). There is still a chance for the other species to establish in the next few years from seeds. It seems that also mosses and lichens established successfully, especially all dominant species. We are aware that the observation time of the experiment was short (only 2 years) to analyze success of the transition. However, it appears that this method of restoration of rare and endangered plant communities seems to be very promising.

/ List of higher plant species which occurred in psammophytic grasslands within the donor sites. Shown are the species successfully established and still not established on the island after only two-year experiment.

	Yes (20 species)	**Not yet** (5 species)
Species establishment on the island	*Agrostis capillaris*, *Calluna vulgaris*, *Corynephorus canescens*, *Dianthus deltoides*, *Euphrasia striga*, *Festuca brevipila*, *Festuca ovina*, *Filago arvensis*, *Hieracium pilosella*, *Hypochaeris radicata*, *Jasione montana*, *Leontodon autumnalis*, *Leontodon hispidus*, *Luzula campestris*, *Pimpinella saxifraga*, *Teesdalia nudicaulis*, *Thymus pulegioides*, *Trifolium arvense*, *Veronica officinalis*, *Viola canina*	*Carex pilulifera*, *Danthonia decumbens*, *Chondrilla juncea*, *Nardus stricta*, *Potentilla argentea*

/ Examples of bad practices /

/ A pine plantation in a sand pit in close vicinity to the Váté písky Nature Reserve, where psammophytic vegetation is protected and which can be a source of diaspores if the sand pit is not reclaimed. Photo: Jiří Řehounek

/ A restored colony of Sand Martins (*Riparia riparia*) in a sand pit located in the southeastern part of the country. Photo: Petr Heneberg

/ A plantation of alien Colorado Spruce (*Picea pungens*) in a sand pit in the southeastern part of the country. Photo: Jiří Řehounek

/ Destruction of a sand pit in the Elbe River lowland in which occurs the critically endangered Ramshorn Snail (*Anisus vorticulus*). Photo: Luboš Beran

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Mined peatlands

/ Tussocks of cottongrass (*Eriophorum vaginatum*) spontaneously established in the restored Soumarský most peatland in the Šumava Mts. Photo: Petra Konvalinková

/ Mined peatlands

Editor: Petra Konvalinková

Coauthors: Petr Bogusch, Petr Hesoun, Petr Horn, Martin Konvička, Anna Lepšová, Vladimír Melichar, Ladislav Rektoris, Jan Šťastný & Vít Zavadil

Peatlands are relatively rare habitat in the Czech Republic. It is estimated that preserved peatlands cover 0.3 % of the area of the country. Most of the peatlands are situated in the mountains around the borders. Particular peat bogs are rather isolated having an "island" character with specific flora and fauna. Typically, there is a relatively large number of glacial relicts (Spitzer et al. 1999).

The peat is currently mined in several localities, but no new peatland is expected to be mined. The size of particular mining areas ranges from 100 to 200 ha. Peat mining is done according to the special law (n. 61/1956 Sb.).

The type of peat extraction is crucial for how the mined peatlands are restored. Three types of peat mining has been conducted in the Czech Republic:

1. Mining by hand (block-cut mining) – used until the 1950s.
2. Industrial harvesting (milling method) – used from the 1950s until recently; it requires deep drainage of the whole area.

/ Wet extraction by dredger. Photo: Petra Konvalinková

/ Large-scale industrial peat harvesting. Photo: Petra Konvalinková

/ List of recently mined peatlands in the Czech Republic.

Locality	Region	Altitude (m a. s. l.)	Mining in process	Restoration
Borkovice	Veselí nad Lužnicí / Soběslav	420	–	spontaneous succession, forest and agricultural reclamation, ecological restoration in part
Branná	Třeboň	440	+	forest reclamation, spontaneous succession
Hrdlořezy	Třeboň	460	+	forest reclamation, spontaneous succession, ecological restoration in part
Příbraz	Třeboň	470	+	mining will be finished soon; spontaneous succession, forest reclamation, inundation is planned
Člunek	Jindřichův Hradec	540	+	spontaneous succession
Světlík	Šumava foreland	740	+	spontaneous succession, agricultural reclamation
Horní Borková	Šumava Mts.	740	–	spontaneous succession
Soumarský Most	Šumava Mts.	750	–	spontaneous succession, forest reclamation, ecological restoration
Vlčí Jámy	Šumava Mts.	780	+	spontaneous succession
Krásno	Slavkovský les Mts.	780	–	spontaneous succession
Hora sv. Šebestiána	Krušné hory Mts.	850	+	spontaneous succession, forest reclamation
Abertamy	Krušné hory Mts.	870	–	forest reclamation in part
Františkovy Lázně	Cheb	432	–	mining for medical purposes

3. Wet extraction – extraction is done by an excavator without drainage; it is usually conducted in a limited area with the peat used for balnaeological purposes.

In the following text we will focus mainly on industrial harvesting as the most important type of peat extraction.

/ Geology and geomorphology /

Peatlands emerged at or after the end of the last glacial period 10 000 – 15 000 years ago mostly on impermeable substrates, e. g. clay. In simplified classification, three types of peatland can be distinguished depending on the source of water:

1. Minerotrophic peatland (fens) – supplied by mineral groundwater, mainly in lowlands;
2. Ombrotrophic peatland (bogs) – supplied by precipitation water, mainly in mountains;
3. Mixed mire – supplied by both mineral groundwater and precipitation, usually occurs in intermediate altitudes.

Milliny and block-cutting of peat occur mainly in ombrotrophic peatlands and mixed mires. The peat is formed mainly by peat moss (*Sphagnum* spp.), cotton grasses (*Eriophorum* spp.) and wood.

/ Near-natural restoration with artificially created pools and planting of bog pine (*Pinus rotundata*) supervised by the Administration of the Třeboňsko Protected Landscape Area. Photo: Petra Konvalinková

The topography of the mined area is determined mainly by the type of extraction. In block-cut peatlands, elevated strips and depressions occur more or less regularly. Wet extraction leads to water pools with steep banks. Industrial harvesting produces a dry, extensive flat area with a regular grid of drainage ditches. Areas between the ditches have a convex shape which makes their drainage easier. The remaining thickness of the peat at the end of extraction differs. Some localities were mined down to the mineral substrate, while in other localities extraction was stopped at various depths. The usual thickness of the remaining peat is 0.5 – 1 m. A thickness of 0.5 m is the minimum required now by law. Chemical properties of the remaining peat correlate with its depth. pH, degree of peat decomposition and amount of nutrients were found to be important factors affecting vegetation succession (Lanta et al. 2004, Bastl et al. 2009, Konvalinková and Prach 2010).

Bare peat is a relatively hostile substrate. It has no plant diaspores, exhibits low nutrient availability, and the dark surface is strongly overheated. There is also strong wind and water erosion, and the surface is disturbed by frost. Moreover, desiccated peat has a low ability to accept water (hydrophobic character).

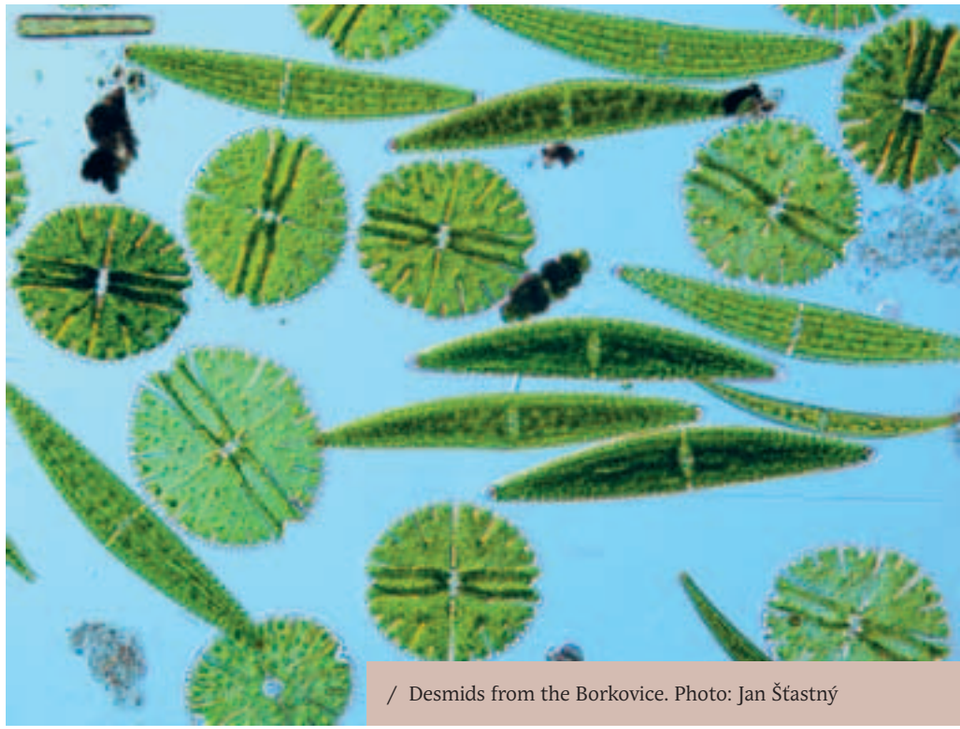
/ A dam across a drainage ditch increasing the water table as part of a restoration scheme in the Vraky peatland in the northwestern part of the country near the border with Germany. Photo: Jana Jiskrová

/ Technical reclamation /

In the last decades, the most common way of reclamation was afforestration. The convex topography of the mined area is leveled and tree seedlings are planted, preferably Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*). The drainage system is kept functional. Another method of reclamation is conversion into arable land. This approach was common mainly in the past in lowland fen localities. Mined peatland could also be flooded when the topography of the area was suitable and there was a source of water nearby.

The reclamation method is usually chosen according to the wish of an owner. Peatlands not owned but hired by the mining company are usually afforested and further used by the owner.

Afforestration or conversion into arable land results in low biodiversity. Afforestration leads to dense stands of *P. sylvestris*, where the understory is almost absent or dominated by common species of herbs and shrubs. The peat is further desiccated and mineralized, because of evapotranspiration by trees. Flooding could be a better option, but only when the pool is not deep and without fish. In such a case, we can expect development of wetland vegetation at least along the pond shore and restoration of peat formation over the long-term.



/ Desmids from the Borkovice. Photo: Jan Šťastný

/ Near-natural restoration /

Apart from inundation, the easiest and cheapest method of peatland restoration is spontaneous succession. Good examples include block-cut areas which were left unreclaimed after peat extraction. Today, some of them are important localities protected as nature reserves. Where the hydrological regime was favourable, the peatland vegetation re-established. Mining resulted inrejuvenation as these sites were pushed back towards early successional stages. Such sites are important refugia for species of open and wet habitats.

Some parts of industrially mined peatlands were also left unreclaimed. There, succession is affected mainly by the following factors:

/ Golden-ringed Dragonfly (*Cordulegaster boltonii*). Foto: Petr Jiskra

1. Level of water table, its fluctuations during the year, water pH and conductivity
2. Quality of the substrate – degree of mineralization, pH, portion of organic carbon, etc.
3. Source of diaspores, mainly the presence of peatland vegetation in the surroundings
4. Microclimatic conditions

Deep drainage of industrially mined peatlands (1m or more, often down to the mineral bed) leads to a decrease in the ground water. The peat is quickly decomposed and mineralized, which increases nutrient availability. Such conditions favor competitively strong species instead of peatland species, which colonize such a site slowly or not at all. Large-scale industrial mining also increases the chance of establishment of anemochorous ruderal and expansive plant species.

Sites with low ground water table are often colonized by *Calamagrostis epigejos* which can block succession for years. Other common grass species include *Avenella flexuosa*, *Deschampsia cespitosa*, *Calamagrostis villosa*, *Molinia caerulea*, and *Phalaris arundinacea*. The birches *Betula pendula* and *B. pubescens*, Scots pine *Pinus sylvestris* and Norway spruce *Picea abies* are the most frequent woody species. If succession is not blocked, a woodland establishes within 20 years.

Wetland and peatland vegetation (including *Sphagnum* mosses) establishes when the ground water table is around 0.3 m below the surface. On sites with low remaining peat or springs of mineral rich water, species of springs, wet meadows and mixed mires prevail, especially *Juncus effusus*, *J. filiformis*, *Peucedanum palustre*, *Agrostis canina*, *Viola palustris*, *Cirsium palustre*, *Lysimachia vulgaris*, *Galium palustre*, *Lycopus europaeus*, *Carex nigra*, *C. panicea*, *C. rostrata*, *C. canescens*, *Potentilla erecta*, *Molinia caerulea* and *Eriophorum angustifolium*. Willow (*Salix cinerea*) and birches (*Betula* spp.) prevail among woody species. Heathland and acidophilous short-grass meadows, such as *Nardus stricta* grasslands, contain *Lycopodium clavatum*, *Nardus stricta* and *Juncus squarrosus*. Species typical of a peatland appear when the depth of the remaining peat is at least 0.4 m. These include mainly *Eriophorum vaginatum, E. angustifolium*, *Vaccinium uliginosum*, *V. vitis-idaea*, *Oxycoccus palustris*, *Calluna vulgaris*, *Melampyrum pratense*, *Ledum palustre*, *Drosera rotundifolia*, *Empetrum nigrum*, *Andromeda polifolia* and *Carex pauciflora*.

A functioning drainage system permanently prevents (even on sites left to spontaneous succession) an increase of the ground water table to the original level, which is usually 0 – 0.2 m below the surface. It is important to restore the water regime to support the establishment of wetland and peatland vegetation. This should be the first step in the ecological restoration of peatlands. In the

/ Cotton grass (*Eriophorum vaginatum* and *E. angustifolium*) and sedge (*Carex rostrata*) 7 years after restoration started in the Soumarský most peatland in the Šumava Mts. Photo: Petra Konvalinková

Czech Republic, first attempts at ecological restoration of peatlands started in the last decade. Until now, measures leading to ecological restoration were carried out only on one locality.

/ Restoration measures /

a) Improving the water regime

The drainage system should be dammed or filled. This will increase the ground water level and decrease runoff from the locality. It also decreases ground water table fluctuations. The drainage system could be filled by undecomposed peat. Another possibility is to build system of dams with overflow. Local material is used such as wood (*Pinus sylvestris* and *Picea abies*) or compressed peat. In some projects, more durable wood (*Robinia pseudacacia* or *Quercus* spp.) is used. Dams are sometimes fixed by geotextile. The ground water table should increase up to the peat surface, which is essential for restoration of peat forming processes and non-forest peatland habitats. On mined localities with some remnants of valuable forest communities (*Pinus rotundata* bog forest etc.), it is possible to increase the ground water just to the level which is not harmful for tree root systems.

It is valuable to dig small and shallow water bodies. They can help speed up peat formation. Small depressions help to catch rain water and water from melting snow, and generally increase the diversity of a locality. They can be suitable habitats for some species of plants and animals (water *Heteroptera*, dragon flies and other insects, rotifers, amphibians, birds, etc.).

b) Introduction of species and use of hay

It is better to directly plant and sow desirable peatland species only in localities with limited sources of diaspores and an appropriate water regime.

Both generative and vegetative parts of plants and mosses can be used. Vegetative fragments of *Sphagnum* mosses are successfully used.

A commonly used and relatively cheap method of species introduction is the spreading of hay from a preserved habitat over the locality. This can serve not only as a source of diaspores, but it can also improve microclimatic conditions on the peat surface (shading, reduction of evaporation, etc.). Only the use of local hay and local sources of diaspores from preserved neighboring localities are acceptable.

Large scale tree planting is acceptable only in localities originally overgrown by trees. Planting of trees is undesirable in originally treeless localities. On the contrary, it is sometimes desirable to remove (often repeatedly) established trees to restore the original treeless character of a locality.

c) Modification of the surface

In some cases it is good to prevent surface runoff of water and erosion of the peat by the building of dams (see p. 72). It is possible to spread a thin layer of peat in cases when the peat was mined down to the mineral layers.

d) Other measures

The restoration of many peatlands is limited by disrupted contacts with the surrounding landscape. Their isolation is often accomplished by compact forest plantations. For example, juvenile stages of many butterflies (*Colias palaeno*, *Boloria aquilonaris*, *Vacciniina optilete*) live on peatlands, but adults obtain nectar from surrounding meadows. Connection with the surrounding landscape should be part of the restoration.

/ Specific principles of peatland restoration /

1. The methods of restoration depend on the desired target:
- restoration of the original peatland habitat, including peat formation;
- establishment of an alternative wetland or other habitat;
- maintaining populations of some species;
- restoration of some ecosystem services; in the case of peatlands, it is important to consider their other functions in the landscape such as water regime, effect on microclimate, carbon cycling, etc.

2. Although most peatland species are dependent on wet or aquatic water habitats, some of them use drier and open habitats, e.g. heathland, or use the mosaic of all. If it is possible, a diverse mosaic of habitats should be maintained or restored.
3. After restoration of abiotic conditions, i.e. mainly re-wetting, the following measures can be carried out to direct succession:
- removing trees and shrubs if succession proceeded further than wished;
- small scale disturbances which improve conditions for particular species;
- maintenance and renewal of dams in the drainage system (usually after 5 – 10 years);
- management of habitats of rare animals (e.g. pools for newts)
- direct visitors to the locality onto stable routes; the routes should lead through important parts of the locality to satisfy the visitors, but a large part of it should remain undisturbed (peatlands are often a breeding area for rare birds which are sensitive to disturbance).

/ Examples of good practices /

/ Soumarský most peatland /

Location: Šumava Mts. National Park, the left bank of the Vltava river, area 56 ha (48°54‘25“N, 13°49‘42“E).

History: Peat extraction began in the 19th century. Small scale hand mining continued until 1945. Industrial extraction started on 53 ha in the 1960s, but was stopped in a part of this area in the 1980s. Mining was gradually terminated at a remaining peat depth of about 0.5 m. This area was afforested mainly by *Pinus*

sylvestris and to a lesser extent by *Picea abies*. Mining was terminated in the rest of the locality in 2000 due to the intervention from the Šumava National Park authorities. In this area, the remaining thickness of peat was more than 1 m. We deal here with this part.

Geology: Mining was done on an ombrothophic peatland. The remainining peat was composed of *Eriophorum* spp. and *Sphagnum* mosses with a large portion of wood.

Botany: In 2007, approximately 50 % of the locality was covered by spontaneous vegetation, around 40 % was bare peat and the rest was water bodies. Due to the increase of the water table, there was a massive spread of *Eriophorum vaginatum*. *Eriophorum angustifolium* is abundant along the ditches, while *Carex rostrata* locally occurs on wetter sites. Bare peat is now slowly being colonized by *Calluna vulgaris*, *Vaccinium uliginosum* and *V. myrtillus*. *Juncus effusus*, *Carex canescens* and *Molinia caerulea* are present among other wetland species. *Sphagnum* mosses are growing on approximately 8 % of the area due to their reintroduction and spontaneous colonization. Most common are *Sphagnum fallax*, which occurs on bare peat, and *S. cuspidatum* in water. Other species rarely there occur: *S. rubellum*, *S. magellanicum* and *S. girgensohnii*. There are often stands of *Betula pubescens* and *Pinus sylvestris* along the drainage ditches with *Picea abies* in the understory. The occurrence of some ruderal species, such as *Calamagrostis epigejos* and *Lupinus polyphyllus*, is restricted to small parts of the locality; they do not seem to be spreading.

Zoology: Several wetlands birds occur on the water bodies.

Management: The first part of the restoration was blockage of the drainage system, at first the lateral, later the main drainage ditches. Another measure of restoration of the water regime was creation of shallow depressions on the peatland surface. In total, 14 shallow depressions were formed with a size of approximately 10 × 10 m. Erosion of the surface was locally prevented by trunks placed on the peat and fixed by sticks. This was done mainly to sites where water flows during precipitation extremes. After these technical measures, wetland plants were reintroduced, at first higher plants, but later mainly sphagnum mosses. Mulch from surrounding peaty meadows was spread over the peatland to facilitate species introduction and for improving the microclimate. Some trees and shrubs were cut in order to reduce evapotranspiration.

/ Borkovice /

Location: near Veselí nad Lužnicí (South Bohemia), area: around 170 ha (49°13‘56“N, 14°37‘49“E).

/ Restoration in the Borkovice peatland in the Třeboň Biosphere Reserve. Photo: Jiří Řehounek

History: Mining by hand started approximately in the middle of the 19th century and lasted approximately 100 years. In 1949, there a nature reserve was established on an area of 31 ha. In 1953, the peat started to be extracted industrially nearby and for this reason the nature reserve was canceled in 1957. Fortunately, the peat extraction did not reach the area of the former nature reserve. The excavation was terminated in 1987. In 1980, the nature reserve was re-established on an area of 55 ha. The mining was stopped at the edge of a stand of *Pinus rotundata*, but the drainage ditches affected the stand. In 2000, the reserve was enlarged by another 35 ha, which included also the industrially mined part. Totally, about 400 ha of the peatland were excavated. The industrially mined area was mainly agriculturally reclaimed or afforested. Birch and pine forest developed over most of the area left to spontaneous succession.

Geology: The locality is part of the Třeboň Basin. Ombrothrophic and mixed mire peats of various depths are present over most of the area.

Botany: Mesothrophic wetlands with *Carex rostrata* and *Juncus effusus* have developed in overflow sites. *Phragmites australis* and *Eriophorum angustifolium*

sporadically dominate. *Juncus bulbosus* and *J. articulatus* grow in the wet peat. Thousands of individuals of the carnivorous plant *Drosera rotundifolia* grow on bare and wet peat. The fern *Dryopteris cristata* rarely occurs. Close to the original *Pinus rotundata* forest, hybrids of *Pinus rotundata* and *P. syvestris* (*Pinus × digenea*) occur and also some indigenous peatland species such as *Ledum palustre* and *Vaccinium uliginosum*. *Potentilla palustris* and *Lysimachia thyrsiflora* grow at the edges of water bodies, *Utricularia australis* occurs in the water bodies. *Betula pendula* and *Pinus sylvestris* grow on dry sites. Dry peat is invaded by the invasive moss *Campylopus introflexus* originating from the Southern hemisphere. It was recorded for the first time in the Czech Republic in this locality (in 1988).

Algology: In total, 110 species of Desmids (Desmidiales) were recorded in the water bodies. For some of them, this site is the only known locality in the Czech Republic.

Zoology: The water bodies host a large number of amphibians: *Lissotriton vulgaris*, *Triturus cristatus*, *Pelophylax lessonae*, *P. esculentus*, *Rana temporaria* and *R. arvalis*. Larger water bodies are important for dragonflies, including several rare species. The site is a Natura 2000 locality for the dragonfly *Leucorrhinia pectoralis*. Water bodies are also nesting sites for several birds (*Gallinula chloropus*, *Fulica atra*, *Anas crecca*, *A. platyrhynchos* and *Circus aeruginosus*). Nests of *Gallinago gallinago* and *Carduelis flammea* were recorded in the litoral vegetation. Rarely, *Grus grus* was observed. The dry sites are occupied by the reptiles *Lacerta agilis*, *Zootoca vivipara*, *Anguis fragilis*, *Vipera berus* and *Natrix natrix.* Elk (*Alces alces*) was also recorded there.

Management: Drainage ditches were dammed on several sites in 2000. This led to increased water levels and the forming of several pools. Moreover, several pools were created by heavy machinery. Trees and shrubs were cut in the sites with hybridised *Pinus rotundata* (AOPK ČR 2004).

/ Krásenské bog – rašeliniště V borkách /

Location: Western Bohemia, 825 m a. s. l.; area: 72 ha (50°6‘35“N, 12°45‘41“E).

History: The peat was mined by hand from the middle of the 19th century to approximately 1945. Industrial mining started in 1980. The south part of the peatland was extracted to the mineral layer; in the central part 2 – 3 m of peat remained and the vegetation cover was only removed in the northern part. The mining was stopped around 2000. Restoration measures started in 2008 after the agreement of the owner (the town of Loket). In 2009, the municipality started low scale peat extraction for medical purposes.

/ Heath (*Calluna vulgaris*) in the Krásenské rašeliniště peatland in the western part of the country. Photo: Petra Konvalinková

Geology: The locality is a typical ombrotrophic peatland.

Botany: The original vegetation was preserved only in a small area of the peatland. It is formed by a diverse mosaic of communities, which reflects the undulating topography. In small water bodies *Carex rostrata*, *Drosera rotundifolia* and *Eriophorum angustifolium* occur, with mosses being represented by *Sphagnum majus*, *S. molluscum*, *S. balticum* and *Warnstorfia fluitans*. In drier sites, *Andromeda polifolia*, *Calluna vulgaris*, *Empetrum nigrum*, *Eriophorum vaginatum*, *Oxycoccus palustris*, *Vaccinium spp.*, and mosses *Polytrichum commune*, *P. strictum*, *Sphagnum fuscum*, *S. magellanicum*, *S. papillosum* and *S. rubellum* prevail. *Pinus rotundata* occurs sporadically, which are now slowly spreading. Bog spruce forests (*Sphagno-Picetum*) grow around the peatland. Peat on the mined sites is overgrown by peatland species such as *Eriophorum vaginatum*, *E. angustifolium*, *Calluna vulgaris*, *Betula* spp., *Pinus rotundata* and *Picea abies*. The carnivorous species *Drosera rotundifolia* is present in large populations. *Sphagnum fallax* and *S. majus*, the latter mainly in the water bodies, occur. Non peatland species are present only around the former roads.

Zoology: The reptiles *Zootoca vivipara* and *Vipera berus*, and the frog *Rana temporaria* were recorded.

Management: Restoration measures were carried out in 2008 and 2009 and included mainly removal of the rail road, partial filling of the main drainage ditches in the centre of the locality by available material, damming of the drainage system and building of six small water bodies.

/ Examples of bad practices /

/ Pine (*Pinus sylvestris*) plantations in the Hrdlořezy peatland in the Třeboň Biosphere Reserve. Photo: Petra Konvalinková

/ Pine (*Pinus sylvestris*) plantations in the Branná peatland in the Třeboň Biosphere Reserve. Photo: Petra Konvalinková

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Overall comparison

/ A formerly extracted peatland, now the Přebuzské vřesoviště heathland nature reserve in the Krušné hory Mts. in the western part of the country. Photo: Petr Krása

/ Restoration of post-mining sites – overall comparison

Karel Prach, Klára Řehounková & Jiří Řehounek

Basic information allowing a mutual comparison of the considered habitats is summarized in Table 1. The possibility for post-mining sites to be restored by spontaneous succession is clearly evident from the previous chapters. At least 95 % up to 100 % of the sites have the ability to recover spontaneously. How much we can use this potential still remains a question. From Table 1 it is obvious that its current use is low and technical reclamation largerly prevails. Participants of the workshop held in České Budějovice (from which this booklet originated) agreed that it would be feasible under present conditions for at least 20 % of the area to be left to spontaneous succession or restore it to a near-natural stage. The important goal is to make spontaneous succession equal to technical reclamation in the respective legislation. Protection of biodiversity should be more emphasized. To leave smaller mining site unreclaimed should be allowed by legislation. In the longer term, it would be feasible to leave about 60 % of the surface of post-mining sites to spontaneous or directed succession. We, of course, respect that technical reclamation is necessary or at least not harmful on sites endangered by erosion, in the close vicinity of human settlements, roads, etc., in the case of toxic substrates where there is a danger of contamination of the surroundings and on sites designed for sport and recreation. However, we stress that technical reclamation of the post-mining landscape should create habitats for rare and endangered species or at least it should not be detrimental to them (as it often is).

From the detailed scientific studies and field observations of many scientists, it is obvious that spontaneous succession leads (excluding exceptions) to the development of continuous vegetation cover within 10 – 20 years. The formation of a continuous vegetation cover is usually the main task of reclamation. Even in the case of technical reclamation, vegetation cover is not established immediately and requires some time. Revegetation by spontaneous succession is therefore as comparably fast as technical reclamation. Stabilized late successional stages are reached relatively fast, in many cases within 20 years. This does not mean that the

/ Table 1. Overview of sites disturbed by mining in the past 50 years in the Czech Republic, central Europe, in regards to their ability to natural regeneration. Italics indicate approximate estimates. / * Each site is usually composed of differently aged parts. ** Number of crosses indicates importance evaluated as a relative degree. According to Prach et al. (2011).

Type of mining site	Area influenced [km²] and number of sites in the country *	Number of sites investigated in detail *	Time to continuous cover of vegetation is usually formed [yrs]	Time to more or less stabilized late vegetation is usually formed [yrs]	Presence of protected and endangered species **	Invasive organisms	Estimated potential for spontaneous succession [% of total area influenced]	Prescribed use of spontaneous succession in restoration projects [% of total area influenced]	Recommended technical measures
Spoil heaps from coal mining	270 *70*	35	15	20	++ Higher plants, stoneworts, birds, amphibians, insect	Unimportant	95	0.01	Leveling of surface, sowing or planting – locally on eroded and toxic sites, or close to settlements
Sand and gravel-sand pits	45 *220*	36	10	20	+++ As above	Locally black locust	100	<5	Eradication of black locust
Mined peatlands	10 15	15	10	25 (dry sites) 60 (wet sites)	+ Higher plants	Unimportant	100	11	Increase of water table
Stone quarries	62 300	120	20 (except steep slopes)	30	+++ Higher plants, insects	Locally black locust	100	<5	Eradication of black locust

vegetation does not change, but that the change is later not so fast and obvious. In the relatively humid climate of Central Europe, spontaneous succession usually leads to formation of a woodland. It is not necessarily the desirable state, as mentioned in previous chapters. Successional woodland stands usually host less species of various groups of organisms than mosaics of forest and non-forested habitats and young and old successional stages. Hence, we consider as locally useful the pushing back of succession towards young stages by cutting trees and shrubs, by mechanical disturbance of the soil surface, etc. These activities should be included into the restoration schemes rather than expensive technical measures.

People are sometimes afraid that unreclaimed post-mining sites are sources of weedy and invasive species. We are not aware of any such cases. If invasive species occur on the post-mining site, they are colonizers from the close surroundings. On the contrary, the importance of post-mining sites for rare and endangered species is obvious as described in more detail in the previous chapters.

For post-mining sites, it is highly important to have distinct and heterogenous topography of the surface. High geodiversity is an important prerequisite for high

/ A pool originated by peat extraction in the Borkovice peatland in the Třeboňsko Biosphere Reserve. Photo: Jiří Řehounek

/ An initial successional stage in a sand pit. Photo: Jiří Řehounek

biodiversity. Hence, we consider as unnecessary the expensive leveling of the surface, which is a usual part of technical reclamation. A heterogenous topography can be formed during the mining process. The workshop from which this booklet emerged clearly showed that mining sites can contribute to the quality of nature if they are properly designed and then left to spontaneous succession. However, mining should not destroy more valuable sites than it can create.

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Main principles

/ A nest of the Little Ringed Plover (*Charadrius dubius*). Photo: Jan Ševčík

/ Main principles of near-natural restoration of mining sites

Although mining has a large impact on the landscape, in many cases abandoned mines can be beneficial for the surrounding landscape and can be a refugium for many plants, animals and fungi. Many endangered species, some of them common in the past but now vanishing, often survive in active or abandoned but unreclaimed mines, and on spoil heaps originating from the mining activities.

The high natural value of the mining sites is conditioned by the occurrence of nutrient poor habitats in terms of nitrogen and phosphorus, which is often in contrast with the surrounding eutrophicated landscapes. Hence, mining sites are refuges especially for competitively poor species. Therefore, mining sites are important for the protection of biodiversity. A properly designed reclamation can support biodiversity, but many reclamation measures are detrimental for it. We have to remember that the Czech Republic is obligated to protect biodiversity according to several international conventions, mainly the Convention on Biological Diversity.

After mining or spoil deposition ends, we consider that, in most cases, near-natural restoration is the most suitable means of restoration. By near-natural restoration, we mean spontaneous succession either unassisted or assisted. We suggest using management measures which support endangered communities or species during mining and especially in the post-mining stage. For successful implementation of near-natural restoration, we suggest to respect the following principles:

1. Prior to mining it is important to conduct a biological inventory of the locality, both in the mining area and its surroundings. It is desirable to direct mining in a way that maintains as much of any semi-natural habitats as is possible in the close surroundings. Most species colonize post-mining sites from a distance not longer than approximately 100 m.

2. Restoration schemes and an environmental impact assessment (EIA) should be prepared by specialists who are aware of the recent findings in the field of restoration ecology, and with the possibilities and limitations of mining technologies.

It should be obligatory for specialists to be regularly introduced to the recent findings of restoration ecology in specialized courses. This should be implemented into the legislation of the Czech Republic.

3. A general restoration scheme is known before mining starts and it should respect potential possibilities of the locality. However, the possibility of a later change should be maintained both during and afters mining.

4. The mine should be monitored even during the mining process, which can reveal the presence of endangered species and communities as well as the presence of geological and geomorphological phenomena. Justified changes to a restoration project should be suggested and included into the restoration schemes.

5. Invasive species should be monitored before, during and after the mining process. If they are a threat for successful restoration, they should be eradicated.

6. A majority of the post-mining sites have the ability to recover spontaneously – i. e., can be restored by spontaneous succession, which can be, in some cases, directed, arrested or pushed back. In larger mines, at least 20 % of their area should be left to spontaneous succession. Sites with the highest natural value should be preferably chosen. Smaller mines are usually quickly overgrown spontaneously. Hence, their whole area could be left to spontaneous succession.

7. If endangered species and communities occur on the mining site, proper management should be applied to maintain them. The management can be paid from the funds of mining companies dedicated to reclamation or public funds dedicated to nature conservation.

8. The most valuable mines should be declared as nature reserves and proper management should be preferably applied there.

9. The mining site should increase the diversity of the landscape. At the end (but better during the mining process), there should be reinforced or created irregularities on flat surfaces. Creating or maintaining a shallow lakeside is important in flooded mines.

10. At the end of the mining process, technical equipments and waste should be removed from the mining site.

11. Nutrient rich topsoil should be removed from the mining site scheduled for near-natural restoration and not returned to it. This should be considered in the preparation of the restoration schemes. When nutrient rich topsoil is returned back to the mining site, only a few competitively strong (often invasive) species are supported and biodiversity decreases.

12. In the case of larger mining sites, gradual mining and subsequent restoration are most appropriate for nature conservation. If mining is extended over a longer period, the abandoned parts of the mine should gradually be left to spontaneous succession. This may result in more valuable communities which are diverse in both age and space.

13. It is valuable to conduct scientific research in all types of mining sites. It is also desirable to establish permanent plots for regular monitoring. Plots should be respected by the mining companies.

Near-natural restoration is not the only way of restoration. However, it should be included into legislation of the Czech Republic as to be equal to agricultural and forest reclamation.

These principles were formulated at a scientific workshop, which was held on 27th January 2010 in České Budějovice.

German experiences

/ Mined site Roßbach situated in the centre part of Saxony – Anhalt (Germany). Photo: Anita Kirmer

/ A reflection of ecological restoration of surface-mined land based on German experiences

Anita Kirmer, Annett Baasch, Sabine Tischew

/ Introduction /

During the last few decades, the post-mining landscapes in eastern Germany have been subjected to intensive scientific research and successful application of new methods in ecological restoration (e.g. Herbst and Mahn 1998, LENAB 1998, FBM 1999, FLB 2003, Felinks et al. 2004, FWB 2004, Tischew 2004). These studies documented a high variety of successional stages in the mined sites that could contribute to the development and maintenance of biological diversity in post-industrial areas (Schulz and Wiegleb 2000, Felinks 2004, Tischew and Lorenz 2005) and offer numerous possibilities for restoration and nature protection (Kirmer and Mahn 2001, Tischew 2004, Tischew and Kirmer 2007). In mined sites where successional processes have been undisturbed for decades, various grassland types, heaths, reed and fens, as well as various woodlands, have developed (see the next page). The stages of development, species composition and stand structure of these biotopes are very different. In such areas, rare plant species (e.g. *Orchidaceae, Ophioglossaceae*) can frequently be found. 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 potentials of the mining areas must be protected and included in future reclamation schemes. Mined sites that are integrated into their natural environment and landscape will have positive effects on the quality of life in the region.

But spontaneous succession needs time (e.g. Baasch et al. 2010). A combination of extreme site conditions and increasing distance to appropriate seed sources in the surrounding area delays colonization (e.g. Řehounková and Prach 2006).

/ Examples of spontaneous vegetation development in the Geiseltal lignite mining district; left: the Roßbach mined site (June 2008); right: the Mücheln mined site (July 2002). Photos: Anita Kirmer

Ecological restoration methods, such as application of diaspore-rich green hay and sowing of site-specific species of regional origin, are very successful in accelerating near-natural vegetation development (Pywell et al. 1995, Kirmer and Mahn 2001, Kiehl et al. 2006, Kirmer and Tischew 2006, Baasch et al. 2012, Kirmer et al. 2012). These methods are meant to replace traditional reclamation methods and reduce expensive aftercare. They should promote sustainable development of species-rich plant communities that are optimally adapted to the given site conditions. Some authors (e.g. Keller and Kollmann 2000, McKay et al. 2005) 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.

This chapter summarizes results of several studies on spontaneous and assisted site recovery in former lignite mining areas of eastern Germany (e.g. Tischew and Kirmer 2003, Tischew 2004, Kirmer et al. 2008, Baasch et al. 2012, Kirmer et al. 2012). The aim is to determine opportunities for the integration of spontaneous and assisted site recovery into restoration schemes in mined sites.

/ Case study: Spontaneous succession /

Special aspects of colonization processes were analyzed in ten mined sites in Saxony-Anhalt. Before the political change in eastern Germany, lignite mining areas were forbidden zones with limited access because of their high economic importance. Therefore, in most states of the former German Democratic Republic, mining areas were excluded from floristic mappings. Starting in 1949, floristic mappings provided an inventory of all higher plant species based on grid cells with a 5.5 km mesh size. Between 1994 and 2002, we sampled floristic data in the formerly restricted mined sites and compared them with the incomplete floristic data bases of the states Saxony-Anhalt and Saxony. The analysis of both data sets helped to determine the distances species had been able to bridge. The selected sites are developing via spontaneous succession and consist of different successional stages, such as pioneer vegetation, psammophytic or calcareous grasslands, and pioneer forests, which are dependent on age and substrates and reed or initial fen vegetation, which are related to water availability. The stages range in area from 1 to 2.6 km² and in age between 14 and 55 years (for details see Kirmer et al. 2008). In the floristic mapping of the state Saxony-Anhalt, an average of 453 species was recorded in the surrounding area (30 km²) of the mined sites, 357 having the ability to grow under mining site conditions (see below). A comparison of species numbers between mined sites and surrounding grid cells showed that more than 55 % of the species from the regional species pool had already immigrated into the mined sites. An analysis of all recorded species in the mined sites showed that the nearest occurrence of 23 % of the species was more than 3 km distant to the mined sites, and that the nearest occurrence for 3.8 % of the species was more than 10 km away.

/ Potential seed sources in the surroundings of the mined sites in comparison to species already present (n = 10).

Average number of all recorded species within 0 – 3 km of the mined sites (= grid cell from floristic mapping)	453 *(SD ±)*
Average number of species that are potentially able to grow under mining site conditions in 0 – 3 km surroundings of the mined sites	357 *(SD ± 111)*
Average number of species able to grow under mining site conditions in the 0 – 3 km surroundings which are already present in the mined sites	201 *(SD ± 60)*
Occurrences of species already present in the mined sites in the grid cells of the floristic mappings (%)	
< 3 km	76.8 *(SD ± 12.8)*
3 – 10 km	19.3 *(SD ± 10.9)*
10 – 17 km	2.4 *(SD ± 2.1)*
> 17 km	1.4 *(SD ± 0.7)*

In total, 74 rare and endangered species were present in the 10 study sites (for examples see the next page). Occurrences more than 17 km away from the mined sites were recorded for: *Dactylorhiza fuchsii, Hieracium zizianum, Platanthera chlorantha,* and *Utricularia vulgaris*.

Immigration from very long distances can be explained by extraordinary events, such as gales, thermally induced turbulence, and chance dispersal by animals (e.g.

/ Common Centaury (*Centaurium erythrea*), mined site Kayna-Süd, distance of the nearest occurrence in the surroundings is 3–10 km. Photo: Anita Kirmer

/ Bee Orchid (*Ophrys apifera*), mined site Kayna-Süd, distance of the nearest occurrence in the surroundings is 10–17 km. Photo: Anita Kirmer

/ Common Moonwort (*Botrychium lunaria*), mined site Roßbach, distance of the nearest occurrence in the surroundings is 10–17 km distance. Photo: Andreas Lebender

/ Red list species in mined sites in Germany and their distance to the nearest occurrences in the surrounding area based on data of floristic mappings in Saxony-Anhalt.

Tackenberg et al. 2003, Nathan et al. 2005). In our study, dispersal by wind and birds proved to be of significant importance (Kirmer et al. 2008). The availability of large-scale competition-poor space in the mined sites enhances the establishment probability of these species. The post-mining pits and tips seem to act as large seed traps in the landscape and tend to accumulate species over time.

Unlike several studies which report unsatisfactory colonization of small-scale restoration sites (e.g. Bakker et al. 1996, Coulson et al. 2001), immigration of plant species into large-scale mined sites is more successful. The specific characteristics of these areas, such as nutrient-deficiency, high heterogeneity in terms of substrate, hydrology and geomorphology, created many niches for establishment (Tischew and Kirmer 2007) and species tend to accumulate with ongoing time.

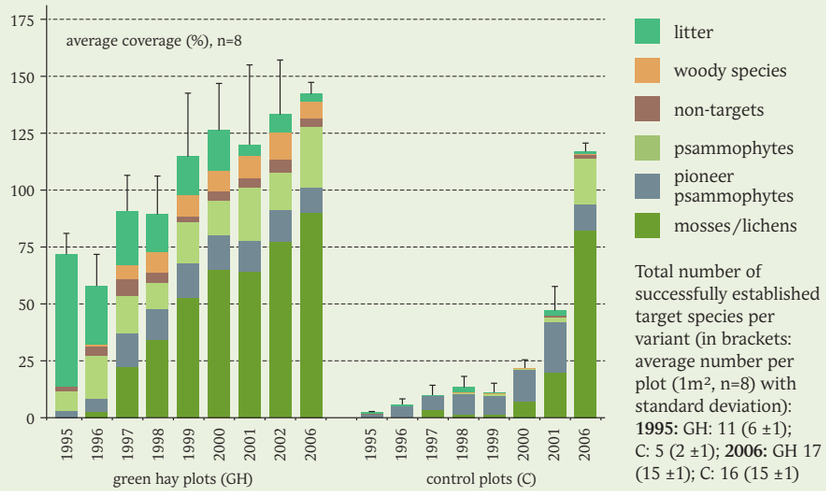
/ Case studies: Establishment of different grassland types on raw soils /

/ Target vegetation: psammophytic grassland /

The Goitzsche mined area is part of the Bitterfeld-Delitzscher mining district in the northern part of Saxony-Anhalt. Our study site is situated in the final mine pit

/ Trial in the Goitzsche mined area; left: slope before restoration (April 1994); right: green hay plot after 8 years (August 2002). Photos: Anita Kirmer

Holzweißig-West (51°26' N, 12°20' E), on an unvegetated slope with a northern aspect, inclination of ca. 15° and altitude of 78 m above sea level. The slope was remodelled in spring 1994 (see above) and the substrate consists of quaternary sand with an average pH value (KCl) of 4.4, a phosphorus content of 0.2 mg·100 g soil^{-1} (Olson method), and a total nitrogen content of 0.05 %. A trial was established on



/ The Goitzsche mined area case study: development of the average coverage of species groups on green hay and control plots between 1995 and 2006 with standard deviation for total ground cover. Total and average number of successfully established target species is given for 1995 and 2006.

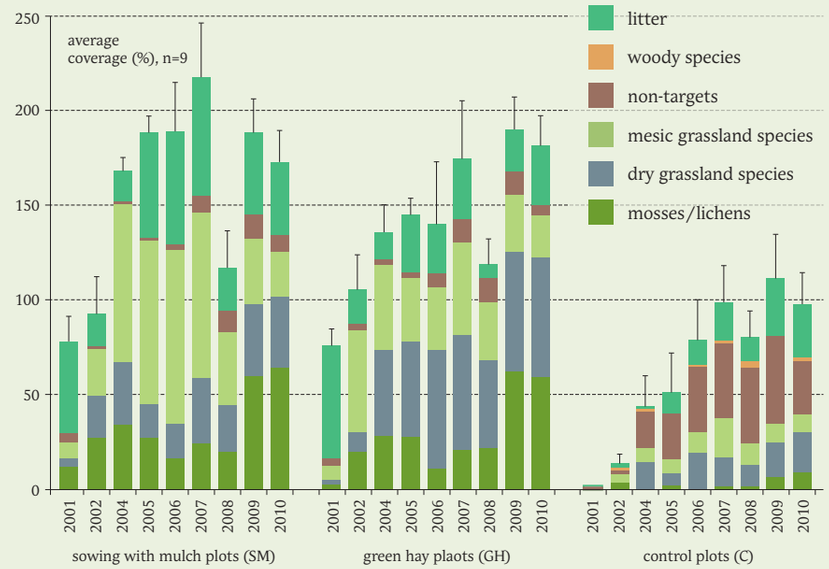
0.01 ha in August 1994, using green hay from an adjacent psammophytic grassland. The green hay was spread with a thickness of approximately 1 kg·m^{-1} by hand. A total number of 65 species were potentially transferable by green hay, including 19 target species. The untreated control plots are situated ca. 120 m west of the hay transfer area on the same slope. Monitoring of vegetation development was done on eight 1 m² plots per variant between 1995 to 2006 (except 2002 – 2005, for more information see Kirmer 2004).

On the slope, no erosion occurred on treated as well as untreated sites. Untreated control plots showed a delayed vegetation development compared to plots with application of green hay. After 11 years, both variants became very similar in the coverage and number of target species (see the previous page). The developing mosses and lichens are typical species of psammophytic grasslands. The final transfer rate of target species from green hay amounted to 84 % in 2006.

/ Target vegetation: dry grassland /

The Roßbach mined site is situated in the Geiseltal mining district in the centre of Saxony-Anhalt (Germany). The trial was located on an artificial unvegetated slope with an inclination of ca. 8°, an eastern aspect, and an altitude of ca. 123 m above sea level (11°54'5.46"E, 51°14'27.98"N). In August 2000, the slope was shaped within the scope of remediation measures. The substrate consists of dumped loess with a pH value ($CaCl_2$) of 7.5. The material came from deeper soil layers, thus representing features of primary succession (no soil development, no soil seed bank).

Beginning in September 2000, the trial was established as a complete block design with three blocks and three variants: (1) Variant S – Sowing: 15 herbs and 6 grasses were sown with a density 2 g·m^{-1} or 860 seeds·m^{-1} (site-specific seed mixture of autochthonous species). After sowing, a mulch layer with seed-poor green hay was applied by hand with a thickness of approximately 5 cm. The selection of the sown species was based on their ability to grow on dry, sunny sites (dry and mesic grassland species), satisfy aesthetic demands, ensure a fast vegetation development and prevent erosion in the first few years; (2) Variant H – Diaspore-rich green hay: The donor site for green hay was a Natura 2000 site approximately 20 km distant to the mined area. The vegetation consists of a mosaic of semi-natural dry and mesic grassland with a total number of 97 higher plant species. There are 62 target species (*Festuco-Brometea* and *Arrhenatheretea* species). On 6 September 2000, diaspore-rich green hay was mown with cutter bar mowers, immediately transported to the Roßbach mined site, and evenly distributed by hand with a density of approximately 1 kg·m^{-1} (5 cm thickness); (3) Variant C – Untreated control with spontaneous succession. Each variant was conducted on a total area of 0.38 ha. Mowing was done in 2002 and 2007, while manual removal of woody plants occurred in 2005. Monitoring was performed on three 25 m² plots per variant and block between 2001 and 2010 (except in 2003; for more information see Baasch et al. 2012).



Total number of successfully established target species per variant (in brackets: average number per plot (25m², n=9) with standard deviation): **2001:** GH: 41 (25 ±3); SM: 43 (25 ±2); C: 20 (8 ±3); **2010:** GH 49 (33 ±4); SM: 46 (25 ±5); C: 39 (25 ±3)

/ Trial in the Roßbach mined site: development of the average coverage of species groups on green hay, sowing and control plots between 2001 and 2010 with standard deviation for total ground cover. Total and average numbers of successfully established target species is given for 2001 and 2010.

The input of appropriate seeds via green hay and sowing clearly accelerated vegetation development compared to the untreated control (see above). Channel erosion took place exclusively on untreated control plots during the first 2–3 years (see the next page), while on the green hay and sowing variants, the mulch layer protected the surface from the beginning. With ongoing decomposition of the mulch, the developing vegetation overtook this function. Also, on the control plots, the establishing vegetation (ca. 50 % cover in the third year) stabilised the surface. Compared to the treated plots, control plots had a higher share of non-target species on total coverage. Species exchange between variants caused an increasing similarity in vegetation composition over time. Most of the target species on the control variant originated from the green hay and sowing variants. In 2010, the final transfer rate of successfully established species from green hay was 74 % on green hay plots, while the final establishing rate of sown species was 95 % on sown plots (see Baasch et al. 2012).

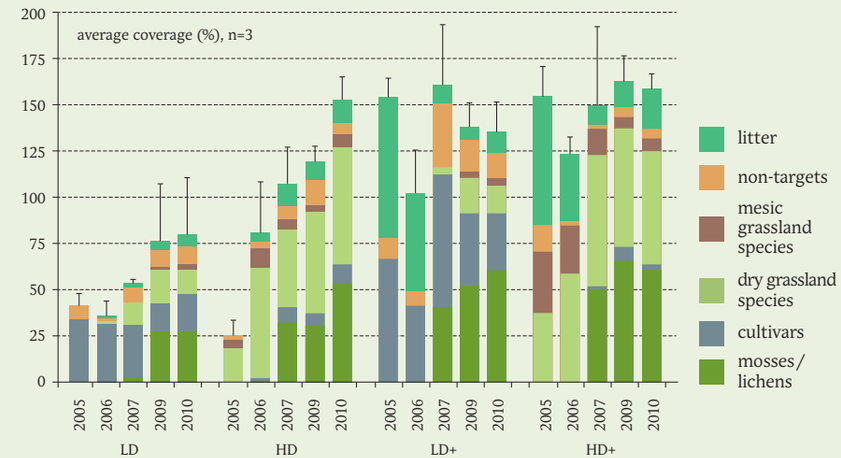
/ Trial in the Roßbach mined site; left: channel erosion on a control variant on the border to a sowing variant after two years (August 2002); right: sowing variant after 10 years (Juni 2010). Photos: Anita Kirmer

/ Target vegetation: mesic grassland /

The active Profen mining site is part of the Zeitz-Weißenfels-Hohenmölsener lignite mining district, which is situated in the south-eastern part of Saxony-Anhalt /Germany. In December 2004, our trial was established on an unvegetated slope (51°8'21" N, 12°9'12" E) consisting of freshly dumped boulder clay mixed with sand with an average pH ($CaCl_2$) of 7.9, a south-western aspect, an inclination of ca. 20°, and an altitude of 170 m above sea level. Phosphorous amounts were up to 0.13 mg·100 g soil^{-1} (Olson method) and total soil nitrogen to 0.03 %. The surface of the slope was profiled with caterpillar-tracked vehicles to create safe sites for germination and establishment.

Four variants were installed using a complete block design with three replicates on a total area of 1.2 ha (240 m × 50 m). A low-diversity (LD) seed mixture with 60 % *Festuca ovina* cultivars, 30 % *Festuca rubra* cultivars, and 10 % *Lolium perenne* cultivars was sown with a density of 100 kg·ha^{-1} (approx. 9 700 seeds·m^{-1}). A high-diversity (HD), site-specific seed mixture containing 11 grasses, 10 legumes and 30 other herbs of regional origin was sown with a density of 36 kg·ha^{-1} (approx. 2450 seeds·m^{-1}). Both sowing variants were established either with or without a seed-poor mulch layer (LD+, HD+) of ca. 3 – 5 cm thickness. Sowing and mulching was done by hand. Permanent plots were monitored between 2005 and 2010 (except 2008) (for more information see Kirmer et al. 2012).

Sowing of a high-diversity seed mixture clearly accelerated the vegetation development (see the next page). An additional mulch layer facilitated the establishment of sown species on LD and HD variants and led to a higher coverage of the herb layer in the first year. After six years, the influence of the mulch layer decreased for the benefit of the seed mixtures (Kirmer et al. 2012). Despite species exchange between sites, sites sown with different seed mixtures were still dominated by different sets of species in the final year of our study (see the next page). Whereas high-diversity mixtures increased the rate of vegetation development in the direction to highly diverse semi-natural grasslands, low-diversity mixtures considerably delayed the successional progress (see Kirmer et al. 2012).



Total number of successfully established target species per variant (in brackets: average number per plot (25m², n=3) with standard deviation): **2005:** LD: 21 (6 ±0.5); HD: 34 (22 ±4), LD+: 18 (7 ±3); HD+: 43 (23 ±3); **2010:** LD: 26 (12 ±0); HD: 46 (28 ±3); LD+ 45 (18±2); HD+: 48 (33±4)

/ Trial in the Profen mining site: development of the average coverage of species groups on low-diversity (LD) and high-diversity (HD) sowing variants with standard deviation for total ground cover. Application of an additional mulch cover is indicated with +. Total and average numbers of successfully established target species are given for 2005 and 2010.

/ Trial variants in the Profen mining site after seven years of development; left: low-diversity mixture of grass cultivars, right: high-diversity mixture of site-specific species of regional origin (August 2011). Photos: Anita Kirmer

/ Opportunities and perspectives for integration of natural potentials in ecological restoration of surface-mined land /

Mined sites are used and developed for different purposes such as agriculture, forestry, tourism and nature conservation. If the specific characteristics of these sites (nutrient-poor substrates, heterogeneous site conditions) are not destroyed, they can provide habitats even for rare and endangered plant and animal species (e.g. Prach and Pyšek 2001, Prach 2003, Tischew and Kirmer 2003, Pełka-Gościniak 2007). In Saxony-Anhalt, a high variety of successional stages was found in surface-mined land that could contribute to the maintenance of biological diversity in the region (e.g. Tischew 2004). This offers considerable potential for recreational activities as well as nature conservation. Until now, almost 2000 ha of Saxony-Anhalt's former mined land are protected by the nature conservation law. In addition, more than 12 500 ha have been bought by Nature Foundations, mostly for conservation as wilderness areas without management as well as for public education and sustainable tourism with low impact on the natural environment (Tischew and Kirmer 2007).

Today, in lignite mining plans of active open-cast mining sites in Germany, approximately 10–15 % of the area is generally designated as priority area for nature and landscape. Restoration planning of these priority areas must include free-of-charge natural forces, such as spontaneous succession, as well as ecological restoration methods. This combination will ensure the development of self-sustaining ecosystems valuable for nature conservation as well as recreational purposes. At least, this may partially counteract the adverse impacts of mining on nature. Important preconditions for successful development are designation of priority areas for natural development at an early planning stage, determination of necessary ecological methods for assisted site recovery, and early public relations to achieve public acceptance.

On sites endangered by erosion or nearby settlements, ecological methods of assisted site recovery should be used more frequently (e.g. Hadačová and Prach 2003, Tischew 2004). The methods are very successful in accelerating vegetation development. The selection of target species or vegetation communities should be based on an analysis of the site conditions and a prognosis of the spontaneous vegetation development of the sites to be restored. Especially on raw soils, the use of a mulch layer facilitates germination and establishment, and prevents erosion. Based on our results, we do not recommend using low-diversity seed mixtures of cultivars in the restoration of surface-mined land. High-diversity mixtures with species of regional origin performed similar or even better with respect to ecosystem services (biomass production, erosion control). In the face of increasing land-use pressures and loss of biodiversity, we should take the opportunity to develop species-rich grasslands in mined sites in a relatively short time.

Despite the success of the methods presented in this chapter, the transfer of knowledge between scientists, practitioners and administrative organizations has proven to be insufficient. Frequently, only ecological basics (e.g. successional mechanisms) have been studied in detail, but the essential next step, the transfer of knowledge into practice, is missing or incomplete. This step can only be taken in cooperation with stakeholders and local authorities (Prach et al. 2001). In this context, successful demonstration projects are most useful.

The evaluation of restoration success is another important issue in mined sites as well as in other restoration areas (e.g. Harris and van Diggelen 2006, Tischew et al. 2009, Conrad and Tischew 2011). Scientifically relevant, practicable and cost-effective monitoring concepts must be developed that include aims and targets of ecological restoration in the region concerned.

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/ Contact to editors and main authors /

Annet Baasch
Anhalt University of Applied Sciences
Department for Nature Conservation
and Landscape Planning
Strenzfelder Allee 28
DE – 06406 Bernburg
Germany
e-mail: a.baasch@loel.hs-anhalt.de

Anita Kirmer
Anhalt University of Applied Sciences
Department for Nature Conservation
and Landscape Planning
Strenzfelder Allee 28
DE – 06406 Bernburg
Germany
e-mail: a.kirmer@loel.hs-anhalt.de

Petra Konvalinková
Českomoravský štěrk, a. s.
Mokrá 359
CZ – 664 04, Mokrá
Czech Republic
e-mail: konvalin@centrum.cz

Karel Prach
Faculty of Science USB
and Institute of Botany CAS
AV ČR Třeboň
Branišovská 31
CZ – 370 05 České Budějovice
Czech Republic
e-mail: prach@prf.jcu.cz

Jiří Řehounek
Calla – Association for Conservation
of the Environment
Fráni Šrámka 35
CZ – 370 04 Česke Budějovice
Czech Republic
e-mail: RehounekJ@seznam.cz

Klára Řehounková
Faculty of Science USB
and Institute of Botany CAS
AV ČR Třeboň
Branišovská 31
CZ – 370 05 České Budějovice
Czech Republic
e-mail: ms_cora@hotmail.com

Lubomír Tichý
Faculty of Science MU Brno
Terezy Novákové 1283/64
CZ – 621 00 Brno
Czech Republic
e-mail: tichy@sci.muni.cz

Sabine Tischew
Anhalt University of Applied Sciences
Department for Nature Conservation
and Landscape Planning
Strenzfelder Allee 28
DE – 06406 Bernburg
Germany
e-mail: s.tischew@loel.hs-anhalt.de

Robert Tropek
Faculty of Science USB
and Institute of Entomology CAS
Branišovská 31
CZ – 370 05 České Budějovice
Czech Republic
e-mail: robert.tropek@gmail.com

/ Working Group for Restoration Ecology /

The group exists as a part of the Department of Botany, Faculty of Science, University of South Bohemia in České Budějovice (Budweis). The informal working group gathers not only botanists bus also specialists from other fields and departments of the faculty, as well as several institutes of the Academy of Sciences of the Czech Republic. The members are interested especially in using ecological succession in restoration of various human-disturbed sites, such as sites disturbed by mining, restoration of grasslands on ex-arable land or various neglected and wrongly managed grasslands, and restoration of natural species composition and functioning of degraded forests, especially plantations. Results are published in top ecological journals as well as popular publications. Spreading the ideas of restoration ecology to the public is emphasized. For details see the website http://botanika.prf.jcu.cz/restoration.

/ Calla – Association for Conservation of the Environment /

The NGO Calla engages mostly in development of renewable energy resources and nature conservation. The association is also a member of the Net Ecological Advisory Centres of The Czech Republic (STEP) and Regional Net of Environmental Centres for South Bohemia (KRASEC). Restoration and conservation of natural valuable sand pits and other mining sites are long-term activities of this NGO. For details see the website www.calla.cz, www.calla.cz/piskovny, www.calla.cz/brehule.

Address: Fráni Šrámka 35,
CZ – 370 04 České Budějovice, Czech Republic
Phone: +420 387 310 166
Fax: +420 384 971 939
E-mail: calla@calla.cz
Bank account: 3202800544/0600 (GE Money Bank)

/ The working group of Prof. Dr. Sabine Tischew /

The working group of Prof. Dr. Sabine Tischew, Anhalt University of Applied Sciences, has widespread and long-term experience within the field of ecological restoration and habitat management. The first project started in 1994, focussing on new approaches in sustainable restoration of surface-mined land, using spontaneous succession and assisted site recovery. Between 1997 and 2011, more than 30 international and national research projects have been realised, dealing with grassland and heathland ecosystems in cultural landscapes and mined sites. Special emphasis is on the exchange of experiences between research and practice.

Near-natural restoration vs. technical reclamation
of mining sites in the Czech Republic

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Cover photo (Jiří Řehounek): Tree frog (*Hyla arborea*)

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