EXPERIMENT IN BIODIVERSITY MANAGEMENT OF QUARRY MOKRÁ: Innovative approaches in ecological restoration

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1. Contestant profile

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2. Project overview

Title:	EXPERIMENT IN BIODIVERSITY MANAGEMENT OF QUARRY MOKRÁ: Innovative approaches in ecological restoration
Contest:	Czech republic
Quarry name:	Mokrá quarry
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ABSTRACT

Our project was focused on innovative forms of ecological restoration. The aim was to explore the unconventional methods of both strengthening and practical management of biodiversity in quarries. The Mokrá quarry became the place of our research. We chose invasive and expansive plant species that could pose a problem for the ecological restoration in the quarry as one of the main phenomena of our research. In order to best capture all the phases of vegetation development, we turned our attention to the very beginning of mining and not to the state at the end of it, as is the usual practice. We focused on the surfaces where the mining is yet to take place and where and where the excavated soil is stored. To verify the possibilities of an effective fight and prevention against these species, we designed and tested a few experimental interventions. The goal of the experiment was to establish a method that would be realistically feasible, relatively cheap and most importantly, effective.

The experiments were preceded by an exploration of vegetation and a mapping of plant invasions. Based on the collected data it appears it is not invasive neophytes that are problematic, but rather certain invasive archaeophytes and autochthonous expansive plants.

The expansive *Calamagrostis epigejos* proved to be the most dangerous, followed by *Cirsium arvense*, an invasive archaeophyte, and among neophytes it was primarily *Lupinus polyphyllus*. The next step was to evaluate the efficiency of experiments. Based on the results and our own simple observation, we inferred that biological stabilization of the affected areas should occur as soon as possible in pre-mining areas that have already been disrupted in some way and in subsequent overburden dumps. We found out that the best remediation intervention might be to mow and dig out the biomass. The overburden in the place of mining should occur once the surface has a stable cover of grass and herbal vegetation that does not include any problematic species. A mixture of thin-leaved with an admixture of *Anthyllis vulneraria*. Further work can only be carried out once the area has been stabilised. The main goal is to prevent the diaspora of undesirable species across the quarry and its surroundings. A possible tool of stabilization is mulching of seeds from areas where valuable species are found. In case the area is heavily “infected” with undesirable species, dot spraying can be used. As a part of the stabilization of overburden dumps, soil turf disruption or overlay with gravel in the thicker layer can be used in the accessible parts. As part of the project, experimental areas for planting yellow rattle (*Rhinanthus alectorolophus*) were prepared, as the plant suppresses grass growth and we can therefore apply it to covers of *Calamagrostis epigejos*.

The result of this project is a case study which is an overview of the obtained results, own observation and experience. We described the “process” starting with mining preparation and its course up to the subsequent loading of the excavated area. We suggested measures that would help create a space made up of a varied mosaic of communities. The top part will have forest cover that will serve as an ecoduct. The slopes will then be intended as steppe and forest-steppe formations.

What makes our project unique is that it offers findings on how important working with vegetation succession is not only at the end of mining, but already in the very beginning of the process and keeping track of and paying attention to what used to grow and live on the given areas. When aiming the vegetation development, we consider the uncontrolled spreading of “undesirable” – invasive and expansive – plant species to be a problem. It is necessary to find out which species those are and what we can expect from them in the preparation stages of the mining already. The fact that we deal with soil dumps as a fully-fledged part of the restoration process, is also another innovative approach. The common mining practice does not pay attention to temporary overburden dumps for years. We, however, believe that it is also important to work with these formations and that it is necessary to reclamation them, albeit for a short time. This could prevent many problems in the future and will save a considerable amount of money. In the project, we managed to create a basic overview of findings that could be important for the future of restoration practice. As we mentioned earlier, we would like to optimize the vegetation succession and enable biodiversity development in a landscape of valuable species during the course of mining.

INTRODUCTION AND GOALS

We situated our project in the Mokrá quarry. This quarry offers great opportunities for the research of the unique natural conditions within the Czech Republic. We focused on two parts of the quarry in particular. The first one is formed by the "divide" between the west and the centre of the quarry. This area is made up of part forest cover and part deforested area, which is already pre-prepared for mining. The areas are notable especially because of the transformations and the development before and after the mining. After a thorough excavation, a restoration of the excavated area and its immediate surroundings will follow. A look at the entire mining process is crucial to us. This is why we posed the basic questions right at the beginning, what should be done before the mining takes place at all. They were: **"Should mining be preceded by biological preparation? If so, then what kind? What do we want to protect, support and what can be prevented through a set of suitable measures?"** We were interested in the natural and technical processes in the entire course of mining. At the same time, we paid attention to overburden and to how transported soil is handled. It was the fate of excavated soil that was a mystery to us that we set out to investigate. The first thing we encountered, which was also a decisive impulse for us, were invasive and expansive plant species. Unfortunately, they grow plentifully right in the areas designated for mining. Another important place that has undesirable species are temporary soil dumps. They are often left for a long time with no activity and these species begin to dominate them after some time. Not only can they influence the natural development of communities, but it is also very likely that they will pose as a problem during reclamation and create focal points that will allow further spreading into the immediate surroundings. Besides, by moving the overburden to the soil dumps, invasive species are further supported in their spreading. This is why we aimed our research at the stabilization (remediation) of soil dumps and pre-mining areas against the undesirable plant species.

We divided the project into four parts:
1. Monitoring the areas of interest
2. Plant invasions in the western quarry
3. Experimental interventions
4. Suggestions for measures to strengthen biodiversity

In the first part, we focused on two areas of interest – **area A**, which is designated for mining and **area B**, which is temporary overburden dump. Area A was originally a forest lot. As the limestone mining was underway between the years 2003 – 2006, the forest was cut down. A forest cover has been preserved to this day southward under area A. The area was left untouched until 2015 and it was left to develop spontaneously. Succession species that mostly have expansive characteristics and are invasive were manifested heavily here. The same problem occurs in temporary soil dumps. We examined both areas (A, B) carefully. Within the western part of the quarry, we focused on the mapping of invasive and expansive plant species. Apart from monitoring, we also proposed a series of experiments on area remediation. We verified various measures on these experiments, for example mowing, spraying, controlled burn, etc. In the final part, the obtained data was used for a case study. We worked out specific proposals of measures on how to strengthen and stabilize biodiversity right from the beginning of the mining up to the care of valuable biotopes. In our measures proposal, we also considered the forest cover in the southern part of area A. At the very end of our project, we held an expert seminar. The participants were presented with information on the individual parts of the project and with our conclusions. An excursion to the quarry was a part of the seminar as well, the participants visited our research sites.

Basic information

Mokrá quarry is located approximately 15 km east of Brno. Limestone and limestone slate are mined here for the production of cement and lime. We dealt with our project in the western part of the mining allotment. Here we delineated two areas of interest. It was the area between the west and central quarry and soil dumps in the northwestern part of the quarry. At the end of the 1950s, the area of the present-day quarry was still a forest. It was a combination of oak-hornbeam woods, oak groves and thermophytic dogwood groves. To this day, only a strip between the centre and the west has been preserved. Up until recently, this strip was made up of forest cover. With the plans for mining, it was decided that the western and eastern quarry be joined at the northern third of the divide. Available aerial photos show that in 2003, there was still forest. Then it was cut down in 2004–2006. In 2015, naturally seeded trees were felled in several parts. In the same year, overburden works were initiated.

The lower 2/3 of the divide is preserved as a forest biocentre. The cover is made up of part larch-spruce-pine culture and part sessile oak, common hornbeam, maple, wild service tree and other woody plants.

The second area of interest is located in the northwest of the mining allotment on the temporary soil dumps. Soils from overburdening are stored here in landfills that are several meters long. Temporary soil dumps are not permanent, as they will be disrupted in future and the material will be used for spreading over hollows or the creation of earthwork, which will then later be restored. The age of the soil dump is approximately five years. Over the time, the spreading was carried out in a few stages. Based on the aerial photos, it is visible that the largest loading was carried out in 2011–2012. Since 2014, the overburden dump has gradually become overgrown, from a sporadic vegetation of the primary stages of succession all the way to natural seeded hornbeams and other woody plants. The invasive and expansive species are manifested here as well. We set up experimental areas in the eastern part of the earthwork and conducted experiments with different types of interventions. There is another partially mined area approximately 50 m south of the temporary soil dump where deforestation and overburden took place. We used this area for our experiments with sowing.

METHODOLOGY

1. Monitoring of the area before mining and

We conducted the monitoring in the form of a phytosociological relevé and inventorying. The photography took place in the areas of interest A and B. We conducted inventorying in the forest cover and a glade within area A. The monitoring took place from May until September. We delineated permanent research areas (PRA) of 4 × 4 m for the phytosociological relevés. The areas were pointed with a tapeline and stabilized with wooden pegs. We delineated four PRAs in area A, which were located 1 m from one another. In area B, we chose fourteen PRAs. At the overburden dump, we chose a place with seven PRAs that are located 1 m from one another. Three areas are more distant. Another four PRAs are located close to the overburden dump in an area that has a similar substrate to the overburden dump. Records from the relevés were written down into a field notebook. The records were then transcribed into a table editor. The result evaluation was done using the programs Turboveg, Juice and Canoco.

2. Plant invasions in the western quarry

As a follow-up to inventorying, a data collection was carried out on the presence of invasive and expansive plants. The monitoring was conducted in the western quarry. We conducted mapping in different places of the quarry in the form of an inventory and an easy scale of occurrence. The records were written down in a table. Apart from the quantity evaluation, we sorted the species into introduced invasive species (archaeophytes and neophytes; naturalised and invasive species) and autochtothonous expansive species. We included species which are currently considered to be expansive on the Czech territory in our list of expansive plants and also some species which act like expansive species in the quarry itself, therefore they can locally be considered as such. Based on the overview of plant invasions and expansions we could determine which species are the most problematic and where they are most commonly found.

We noted 10 archaeophytes (introduced “old residents” that made their way to the Czech territory before 1492), the most problematic of which are the creeping thistle and dwarf elder, and tall oat-grass potentially in the future. There were 11 neophytes (newer introduced species that made their way after 1490) in the mapped area. They were often found only sporadically, where attention needs to be paid especially to large-leaved lupine and common broom. 13 species can be found in the category of native expansive species. The most dominant among those is wood-small reed and then for example rubus.

3. Experimental interventions

As part of PRAs, we conducted experimental interventions. To goal was to determine which option is efficient and the least time-consuming. Based on the experience of individual team members we proposed several interventions that were realistically feasible. We situated the main part of the experiments in area B and the following three experiments in area A.

We conducted the following experiments in area B: covering with stones, digging with a spade, covering with two types of foil, mulching, mowing the area twice, herbicide spraying and controlled burn. One area was not intervened in and one area is prepared for the sowing of *Rhinanthus alectorolophus*. At the beginning of May, that is before the experiments were initiated, we mowed the areas with a brush cutter and we raked and cleared the mowed biomass (the control area remained unmowed). In the course of May we covered the area with stone which was done manually using a wheelbarrow. We used gravel fraction up to 50 mm in a 20 cm layer. We carried out the disruption by manually digging through the area into the depth of 30 cm. In July, we installed two types of non-woven fabrics. The first was a black geotextile which is semipermeable and can absorb precipitations. The second was felt, which was covered with a plastic film on one side (this fabric is commonly used in room painting). We fastened the fabric with stones. In July, we conducted mulching with hay. The source of hay was a steppe area located approximately 1 km away. In July, one of the PRAs was mowed, then Roundup Klasik herbicide spray was applied (1 : 40) and controlled burn was carried out using a hand flamethrower. The last area on site is prepared for the sowing of *Rhinanthus alectorolophus*. Unfortunately we did not make the sowing as that can only be carried out towards the end of October.

In a different part within area B we carried out experimental sowings. We carried out sowing in the established PRAs on three surfaces and then we delineated a fourth PRA as to serve the means of controlling. We chose our species through an “open competition”. Each member of the team suggested five species they liked and that they had had experience with. After that we made a list of competition species which we took a vote on. Each species got a point and species that received the most points were included in the list. Based on this competition, we chose the following mixtures (working title „cocktails“):

Mixture I: *Festuca rupicola* 48 %, *Lolium multiflorum* 25 %, *Anthyllis vulneraria* 27 %;
Mixture II: *Festuca rubra* 60 %, *Plantago media* 5 %, *Trifolium incarnatum* 35 %;
Mixture III: *Anthyllis vulneraria* 43 %, *Plantago media* 5 %, *Festuca rupicola* 52 %.

Before sowing, they were disrupted with a hoe and rearranged with a rake. The rate of sowing was 200 g / area (12.5 g / m^2). Further interventions (weeding, irrigation or mowing) were not carried out.

There were three experiments in area A – mowing, controlled burn and herbicide application. Mowing ended up being applied once only. The procedure of individual experiments was the same as with area B. The goal was to verify interventions in the place where preparation works for mining will be carried out in the near future.

The analysis of the results was carried out based on the phytosociological relevés, a description in the form of a SWOT analysis and the declaration on how time and money consuming each intervention was.

4. Suggestions for measures to strengthen biodiversity

We described the process of mining preparation, mining itself and ecological restoration of areas A and B. We paid special regard to forest cover in a part of the area A, which will be heavily influenced by mining and thus it needs to be stabilized as well. Apart from the outcomes of monitoring and experiments we worked with information available on the region. Consultations with our supervisor and the quarry leader were an important source of information.

RESULTS

1. Monitoring areas of interest

A. Overburden dumps

This overburden dump is already 5 years old. To store soil, its top parts are still used while the circumference and terraces have remained untouched and without any intervention for a long time. Its bases, the oldest and the most developed parts as far as succession goes are most heavily grown over with vegetation, where *Sambucus ebulus* dominates. It belongs into the *Sambucetum ebuli* association and to the *Arction lappae* alliance which unites various types of nitrophilic ruderal vegetation of biennial and perennial species on anthropogenic substrates. This association is not rich in species and therefore, apart from elder, we can find *Calamagrostis epigejos*, mugwort (*Artemisia vulgaris*), common nettle (*Urtica dioica*) or *Gallium aparine*. *Rubus* sp. is another dominant in this group (*Rubus fruicosus* agg.). These places seem to be, perhaps because of their location on the foot, the most fertile. The slopes and top parts, which are still irregularly disrupted and filled with excavated material seem to be the exact opposite. The community on the erosion edges can be characterised as

Poo compressae-Tussilaginetum farfarae – a ruderal vegetation of bare areas with coltsfoot. This is complemented by for instance the creeping thistle (*Cirsium arvense*), wild carrot (*Daucus carota*), curly dock (*Rumex crispus*) or mugwort. On the top surface, the *Melilotetum albo-officinalis* has developed – a ruderal vegetation with honey clover and yellow sweet clover. Both of these associations fall under the *Dauco carotae-Melilotion* alliance which unites ruderal vegetation of biennial and perennial species on shallow rocky substrated. The soil conditions do not exactly match (it is soft, not that rocky), however species typical for these communities can be found on the temporary soil dumps here. Moreover, the *Poo compressae-Tussilaginetum farfarae* can be considered to be in the earliest succession stage and at the same time a sort of a vanguard of vegetation with the *Melilotetum albo-officinalis* dominative clovers. Clovers (especially honey clover – *Melilotus albus*) can be commonly found together with blueweed (*Echium vulgare*), and mugwort (*Artemisia vulgaris*) or tansy (*Tanacetum vulgare)*. The terrace, which winds along the eastern part of the temporary soil dump, was however key to our research. This is where *Calamagrostis epigejos* dominated and where we founded a total of 10 experimental areas, where it achieved an average cover percentage of 70 %. This type of community is usually not classified in any way, this is why it does not belong into any association, but in a broader sense it belongs to the *Artemisietea vulgaris* class – xerophilous ruderal vegetation with biennial and perennial species. It was found on the areas along with some of the aforementioned ruderal species and introduced species, most importantly the annual fleabane (*Erigeron annuus)* and the large-leaved lupine (*Lupinus polyphyllus*). Forest species like wood spurge (*Euphorbia amygdaloides*), wood forget-me-not (*Myosotis sylvatica*) or windflower (*Anemone nemorosa*) were found to have survived sporadically and in open stations that were exposed to the sun, more valuable species of were found too, such as the cushion spurge (*Euphorbia epithymoides*), the hairy violet (*Viola hirta*) and *Carex caryophyllea*. Woody plants (most notably hornbeam – *Carpinus betulus*) grew scattered across the areas and could only be found in the juvenile stage.

B. A fresh landfill of overburden

The overburden was probably brought here three years ago. In the meantime, a community that is identical with the frequently disrupted parts of temporary soil dumps – *Poo compressae-Tussilaginetum farfarae* has arisen. When creating the first phytosociological relevés (before digging with a spade and sowing, 4 PRAs), coltsfoot was accompanied by species such as *Bromus japonicus*, the introduced scentless mayweed (*Tripleurospermum inodorum*) and in times of reclamation the generally problematic, juvenile Canadian poplar (*Populus ×canadensis*), wild carrot and lucerne (*Medicago sativa*).

C. Clearing

In this part of the quarry, the forest had already been chopped down 10 years ago and in the meantime, it was grown over by almost exclusively competitively strong, expansive and invasive plant species. Vegetation is heavily dominated by *Calamagrostis epigejos*, much like at the temporary soil dump terrace with the difference that the creeping thistle is represented here heavily as well. There are still many forest species which survived here, it is *Carex montana, Carex pilosa,* sweetscented bedstraw (*Gallium odoratum)*, addersmeat (*Stellaria holostea*), early dog-violet (*Viola reichenbachiana*) or spring vetchling (*Lathyrus vernus*). The area is yet to be overburdened and apart from the aforementioned dominating plants, among other future complications could be Canadian goldenrod (*Solidago canadensis*). You can find the ordination plot of the DCA analysis **in Appendix A.**

D. Mosses

In the phytosociological relevés of the PRAs we also recorded the coverage of bryophytes which were then collected for further determination. Only mosses and no liverphytes were found. The moss layer was only developed in areas on the overburden dump (area B) and on the clearing in the places designated for mining (area A). They were by far not present in all the images, they could be found in 19 PRAs out of 25 altogether, and that's counting in repetitions. In the rather juvenile areas of overburden dumps with sowing experiments (sub-area B), none grew on the first or second imaging. Certain species still need revision and this is why they are not included in the table of phytosociological relevés, they were not parts of analyses and we only offer a brief overview of them in the Appendixes (Appendix A). In the irrigated covers of *Calamagrostis epigejos* where humidity was held fairly well and the area was quite covered in shadows, species such as *Amblystegium serpes*, *Brachythecium rutabulum, Oxyrrhynchium hians* or *Homalothecium sericeum* could be found. In the more open areas, more ruderal mosses of disturbed stations grew directly on bare soil – *Bryum* *rubens*, *Bryum klinggraeffii, Ceratodon purpureus* and *Barbula unguiculata* and *Funaria hygrometrica* were very abundant. The coverage ability of mosses on the images was rather low, at best up to 10%, but more commonly around 2%. After the interventions of digging with a spade, geotextiles (possibly due to overheating and drying) and stone covering (could not be verified precisely), they were not noted again. A more general trend in the withdrawal or replacement of species will probably be demonstrated after a long time only.

E. Forest

Between the central and western quarry, you can find the foot of the former hill and there is a fragment of a forest that further splits into two stripes along the east-west direction. The upper eastern slope part is grown over with karstic oak-hornbeam grove that is rich in species and includes for instance dogwood. Among the most important finds are the red Helleborine (*Cephalanthera rubra*), the white Helleborine (*Cephalanthera damasonium*) and Helleborines (*Epipactis* spp.) and among other noted finds on the location are the lady orchid (*Orchis purpurea*) which we have not verified though. From a phytogeographical point of view, the find of *Gallium schultesii* is remarkable. In the lower western flat area the original forest was replaced in the 1950s with coniferous plants (the development of the area can be found in Appendix A). In this modified area conifers do not regrow, however many species of the original deciduous undergrowth have remained and the regrowth of deciduous bushes and trees in the shrub layer present in the preserved part on the slope is already growing out. The most interesting discovery is probably the fact that the preserved area has no record of undesirable species spreading, even though it is a small fragment of the forest that is surrounded by disrupted and contaminated areas from all sides. This implies the main suggestion for the preparation of mining: in case the quarry area should extend towards the forest, it is desirable to leave the felling to the time just before the mining and not a few years in advance, because in such case this area would become a space for invasive and expansive plant species to spread.

2. Plant invasions in the western quarry

Overview of invasive and expansive species growing in western Mokrá quarry

The mapped area is distinguished by a considerable heterogeneity of stations, as piles of overburden of various age, artificial forest culture, rather well-preserved oak-hornbeam woods and dogwood grove, forest clearing, freshly excavated areas, landfills of stones and gravel, and newly emerging and abandoned paths can be found there. The supply of diasporas is rather good – it is a large open space with frequent movement of various transport and mining means which allow the plants to spread easily too. A quarry is a potential "hotspot" for the spreading of species further into its surroundings.

Among **introduced plants** in the examined areas, species that are archaeophytes were the ones that spread the most. In the Czech Republic they most commonly penetrate the vegetation of semi-natural dry lawns and meadows and they are among the abundant field weeds. Natural conditions in deserted areas of the quarry highly contribute to such spreading. Neophytes and introduced species on the other hand had a minority presence, as they are more commonly found in more humid biotopes with productive soils such as mesophilic and floodplain forests, pastures and areas surrounding watercourses.

Among **archaeophytes** (6 species), the creeping thistle (*Cirsium arvense*) seems to be the most problematic, followed by the dwarf elder (*Sambucus ebulus*) and to some extent even the tall oat-grass (*Arrhenatherum elatius*). The creeping thistle grows in certain areas as a sort of a vanguard to *calamagrostis epigejos* (for example in clearing waiting for the excavation of overburden) and together they are almost equally dominant. It always appears in the early stages of succession and in damaged soils. It commonly grows as a weed among grains and root crops and it is also common in ruderal stations, landfills, along roads, on abandoned fields and humid meadows. It needs to be eliminated before its bloom and mowing seems to be the most efficient method here. In our experiments, it was the most tolerant to the application of herbicides.

We noted a total of 11 **neophytes** out of which the biggest possible complications in the future (even during reclamation) could be caused by two legume species – the large-leaved lupine (*Lupinus polyphyllus*) and the common broom (*Cytisus scoparius*). Other species were rather sporadic or they appeared in larger amounts only temporarily in freshly bare areas. Those were for example the Canadian horseweed (*Conyza canadensis*). Large-leaved lupine used to be planted to enrich the soil with nitrogen, as grazing for wild animals and it is still grown as a decorative perennial. There is quite a lot of it in all parts of the quarry already and one must count with it when considering eliminations.

Mowing seems to suffice and the worst method with this plant was covering with stones, which it could grow through fairly easily and fast.

With **autochthonous expansive** plants we first needed to define what should even be considered as such. We decided to include species that are in various publications considered to be expansive on the Czech territory and also species that currently spread extremely fast throughout the quarry in various phases of vegetation succession. To distinguish those which could be a problem for the quarry, there is an estimation scale of species abundance see chart in Appendix B). Overall, we distinguished 13 expansive plants, among which the most problematic one is *Calamagrostis epigejos* and rubus (*Rubus fruticosus* agg.). *Calamagrostis epigejos* is a species with a very broad ecological valence, it's perennial, it spreads vegetative and in large amounts even generatively, it has a massive root system and creates a compact vegetation with a large amount of older grass. It expands in large amounts to different types of disrupted stations. Its elimination is best cared for through mowing, while controlled burn might have actually even reinforced it. You can find a list of all invasive/expansive species **in Appendix B**.

3. Experimental interventions

Experiments on the overburden dumps

To find out the efficiency of individual interventions, we conducted a simple analysis. Based on it we decided that a fairly simple and available intervention that promises good results is mowing with a subsequent digging out of the older plants. Another rather feasible intervention is the disruption of the turf. We did this manually with a spade (which required 48 minutes/16 m^2). We also carried out stone covering manually. This was rather demanding as the whole area had to be spread over with soil with a wheelbarrow. Bringing the stones and spreading them also proved to be time-consuming and physically challenging. Spraying is an effective and fast method with immediate results, but this depends on the previous mowing. Two experiments entailed covering the entire area with fabrics. At first sight, undesirable species were not entirely killed under the canvases, but their vitality and cover ability lowered. *Calamagrostis epigejos* survived under the fabrics. One canvas was thinner, the second one thicker and covered with foil on one side. There was low humidity under this common black geotextile and the species were burnt. Humidity was better preserved under textiles with foil and more species could survive this way. Controlled burn proved to be relatively complicated. This type of disruption was carried out under control using a hand flamethrower and a shovel. In one case, the area burned very slowly, whereas the second one progressed faster. The spread of fire proved to be quite dangerous. This is why this intervention requires at least two people among which one controls the fire. When counting the costs, the final cost was counted as the rate per m^2. This is the absolute price. In case of a bigger intervention on 1, the cost would have to be recalculated to be relative, where individual items are split among a larger amount of work. The cheapest intervention is the manual disruption of turf. An area of 1 m^2 can be disrupted for 17.2 CZK (0.6 €). It is necessary to point out that with this type of intervention, there were no material costs unlike with the others. The second cheapest method was the double mowing at 19.3 CZK (0.7 €). However if we only did the mowing once as was the case with area A, the price is 10.7 CZK (0.4 €) for 1 m^2. The third cheapest option was herbicide spraying – 20.1 CZK (0.7 €). The installation of foil-felt textile proved to be the least effective. The costs were 47.1 CZK (1.7 €). Stone covering seems to be equally inefficient (46.4 CZK / 1.7 €). The third least efficient intervention was covering with a common geotextile, where the cost was 36.1 CZK (1.3 €). The average intervention price in this case was 30 CZK (1.1 €).

Sowing experiments

Individual sowings can be characterized in the following way. In mixture I, *Anthyllis vulneraria* was quite vital and covered the area rather well in certain areas. With *Lolium multiflorum*, the sowing was not efficient, based on a volume of 27 % in the mixture. *Festuca rupicola* was average when compared with 48 % in the mixture. *Trifolium incarnatum* grew very well and managed to cover the area in a few area at the same time. However later it suffered from drying and began losing its vitality. *Plantago media* produced a few specimen, but it did not have any distinct effect. In the case of mixture III, *Festuca rupicola* was the successful one and considering its volume in the mixture, it can be considered a rather vital species. *Anthyllis vulneraria* was another vital species. *Plantago media* produced a few specimen. When recalculating (CZK, without VAT) individual mixtures we found out that mixture III is rather expensive at 21.6 CZK / m^2 (0.8 € / m^2) including manual sowing. That's 56 % of a higher cost than with the cheapest mixture, mixture II 13.8 CZK / m^2 (0.5 € / m^2).

Mixture I cost 16.6 CZK / m^2 (0.6 €). Prices of the seeds themselves ranged approximately at CZK / m^2 - mixture A 7.3 (0.3 €); B: 4,8 (0.2 €); C: 11,8 (0.4 €). The different seed prices can be explained by the financial demands of individual components. For example with *Plantago media* the price is 5 850 CZK / kg. In comparison, the second herbal species *Anthyllis vulneraria* costs 280 CZK/Kg. Similarly to grasses, where *Festuca rupicola* costs 1 027 CZK / m^2 in sharp distinction to *Festuca rubra* 92 CZK/kg.

4. Suggestions for measures to strengthen biodiversity

The outcome of the previous parts is a practical collection of measures that we summarized in the case study (**Appendix D**). The study is focused on an area, where mining and the preparation thereof is soon to take place – **area of interest A**. We extended the restoration process to other phases beyond restoration itself: pre-mining preparation and mining itself. Additional stages are the proposal of biomonitoring, dealing with the issue of temporary soil dumps, control and elimination of undesirable plants, stabilization of forest cover and a long-term care for biotopes. In the following part, we will briefly describe the individual processes (a more detailed description can be found in **Appendix D**)

Mining preparation. Mining is preceded by the felling of any potential woody plants and overburdening. Everything needs to be timed just right to prevent the possibility of invasive/expansive undesirable species spreading any further. A preventive measure is to stabilize by temporarily grassing over with a mixture we designed ourselves: "Starting cocktail" (*Festuca rubra*, *Lolium multiflorum*, *Festuca rupicola*, *Anthyllis vulneraria* a *Plantago media*). Mulching with hay from locations with valuable species is an alternative as well. In case undesirable species have expanded in the area, the overburden cover needs to be cut down and the raked biomass taken away. After some consideration, herbicide spraying can be used with certain species. Only then can the area be sowed with a mixture of grasses.

Stabilization and remediation of temporary soil dumps. Temporary soil dumps are particularly susceptible to plant invasion, especially if they have been left without any interventions for a long time. We suggest that these overburden dumps be remediated and stabilized. This is called the "temporary reclamation". Stabilizations mean that the area is grassed over with the "Starting cocktail" mixture. In newly loaded temporary soil dumps, stabilization must begin right away. In older overburden dumps that have already been overgrown, remediation must be done first – mowing and digging out the biomass, or possibly treating the problematic species with herbicides. As part of remediation, the semiparasitic *Rhinanthus alectorolophus* can be sown among *Calamagrostis epigejos*.

The mining process. The mining should proceed in one direction, from the west to the central quarry. The mining should be followed by the spreading of soil. Two conditions have to be fulfilled – the soil must be deposited when already stabilised and the restoration process must begin as soon as possible.

Terrain modelling. In our case, the phase of spreading and modelling the restored process is decisive. We propose creating slopes from the west and the east. The top of the overburden dump will be made up of a wavy surface. The slopes will not be monolithic. It will be a complex of slopes with different slants, lengths and orientations. They will be reinforced by micro-terraces, benches and artificial erosion rills.

Biological measures. Our goal was to create a varied mosaic of biotopes in a forest-forest-steppe-steppe combination. The closer the biotopes are to the centre of soil dumps, the closer it will be to an open country. The edges of the slopes will have more forest cover. This measure should apply to only 20% of the entire area. We suggest the planting of woody plants, mulching and controlled sowing. The rest of the area will be left to spontaneous succession. We count on the fact that the areas will already contain reserves of grasses thanks to the previous stabilization of temporary soil dumps. Besides, we count on the original biotopes being close and therefore, the seeds can be carried by the wind. An important element is the connection of forest covers on the top of the overburden dumps, which will create a bio-corridor. We suggest changing the problematic coniferous part of the forest to a deciduous one with species that will would better withstand dryness. We suggest a gradual elimination of conifers in favour of oaks, lindens, hornbeams, checker tree etc.

Follow-up care. All biotopes need to be continuously cared for. Environmentalist management seems to be a suitable type of care. Target vegetation should be preserved by blocking the succession, for example, it is necessary to maintain bare areas or bushes. Control and elimination of invasive/expansive plants is also a part of the care.

DISCUSSION

We summarized our discussion contributions into a few points which interconnect the Results chapter and individual appendixes:

- We consider invasive/expansive plant species to be the main problem in the deserted areas of the quarry. The most dangerous species are autochthonous expansive and introduced invasive neophytes, where the *Calamagrostis epigejos* is the most problematic of all. It is essential to fight the undesirable species **actively** or **passively.**
- Many experiments have shown that undesirable species can be reduced or eliminated actively. Mowing seems to be the most suitable method. In one area (A) we only applied mowing once and twice in area B. Both interventions proved to be effective. Nevertheless it is not possible to find out which mowing was more effective. Generally speaking, mowing for a second time is a safe bet. The right timing is also a very important factor. In general, it is necessary to cut down certain species before their bloom/ripeness. In case the plant is capable of blooming for a second time, second mowing is necessary.
- As a result, further interventions were effective after they had been carried out, but they varied in terms of being money and time consuming. With gravel, we would choose a thicker layer next time, at least 40–50 cm. Controlled burn is a traditional method that is among the cheaper interventions. Unfortunately this cannot be an area-wide intervention for safety reasons. Moreover, controlled burn can only be carried out in the winter and not in the summer, which would pose an actual risk of many species being killed. As a suitable method, turf disruption can be applied. Manual disruption is only suitable for small areas or areas that are not accessible for mechanization. For disruption in larger areas (above 50 m^2), classical ploughing or disruption by “finish disc harrow” could be more efficient. Covering with textile is not efficient due to its price and the stability of the canvases is an issue as well. Herbicide spraying is a fast and efficient method. It is however not suitable for applying on larger areas. It is necessary to point out that in a way it is poison and a health-damaging, foreign substance. This is why this method needs to be thought out, the spraying needs to be done by a trained person and the mixture of the substance must have a low concentration.
- In some remediation cases, it is suitable to combine the interventions – for instance mowing completed with spraying of problematic species, followed by the removal of biomass and a subsequent grassing over the area. One intervention that we have considered was a clearing, however we did not manage to do so for time reasons. It could be another possible experiment in the future.
- We consider sowing to be an experiment as well. Many species that have reacted fairly well were used, even though the sowing was carried out in May and there was no irrigation done after the sowing. From this perspective, it seems that autumn would be a better time – the seeds get moisture from the autumn and winter rainfall and they do not have to face extreme weather in the quarry too much. The question is the composition of individual sowing mixtures. We created a simple mixture virtually “for the start” (we named it “Starting cocktail”). We would like to try out other types in the future and thus create another reclamation mixture. Types that we have considered are: *Koeleria macrantha*, *Agrostis stolonifera*, *Trifolium rubens* or *Medicago minima* (these types were also a part of the original suggestions for the mixture).
- Apart from three sowing mixtures, we have PRAs prepared for the sowing of *Rhinanthus alectorolophus*. Unfortunately, its sowing date is only October. Nevertheless, we will sow on the prepared areas and we will observe the efficiency thereof. We believe that *Rhinanthus alectorolophus* can be an option for remediating areas in quarries.
- An important discussion contribution is the issue of stabilization and remediation. Do we carry them out or not? We understand stabilization as a preventive tool for directing and improving a place. We consider remediation to be an active tool that is interventions that lead to the suppression of the presence of undesirable species. If stabilization/remediation will be carried out in the way that we understand it, large costs can be cut in the fight against undesirable species.
- We also proposed stabilization for the examined forest cover, which is rather valuable, for example because of the presence of *Cephalanthera rubra*, and this alone is a reason why it is necessary to preserve it in a self-sustainable condition. The measures we propose are not too complicated as our approach entails classical cultivation of the forest.

CONCLUSION

Ecological restoration was key for us in this entire project. We are aware that the functional natural restoration leads to a wider biodiversity in quarries. In the Mokrá quarry, we contributed towards the understanding thereof by a series of partial mapping of various taxon, especially vascular plants. When researching biodiversity, it is good to get to know and understand partial succession processes and define what target state we would like to achieve and what could block or hinder it. As far as negative development of vegetation in quarries goes, we consider it to be one that leads to the domination of a few species (or even one species only) from the very beginning, exactly the way that some of the species we studied can do it. Therefore our main goal was to “safeguard” the quarry from undesirable expansions and invasions of certain species.

We came up with a series of more or less innovative methods and approaches towards ecological restoration in our project. The fight against undesirable species can be done through prevention and/or active intervention. We suggest that the biological interventions be carried out not only at the end of the mining, but already before it and also during its course.

The used tools should be various types of remediation and stabilization. Temporary soil dumps that are used for restoration are in many cases made up of soil that shows a large amount of diaspora of undesirable species. This is why we want to safeguard the soil right at the very beginning. This way, we can turn the succession in the right direction and as a bonus, the large amounts of money spent on the elimination of these species in the quarry and its surroundings (in this case the landscape park Moravian Karst) will not have to be spent anymore.

We tested a series of traditional (e.g. mowing) and non-traditional (e.g. covering the vegetation with geotextile) methods as a means of remediation and stabilization. We designed a unique grass-herb mixture “*Starting cocktail*”. As part of the project we prepared areas where we will sow *Rhinanthus alectrolophus*.

If you are not clear on why use such unconventional approaches towards biodiversity protection by now, we will tell you. *We did not consider the process of restoration after the mining has finished, we did not consider the restoration in one part of the quarry only. We considered the restoration in the mining preparation phase already, we considered temporary soil dumps, we considered invasive and expansive plants as the main issue, we tried innovative methods and we tried traditional methods in the unique environment that is the Mokrá quarry.*

PERSONS INVOLVED

Persons involved in this project were experts from Masaryk University (Pavel Veselý and Veronika Kalníková, Department of Botany and Zoology), Mendel University in Brno (Vilém Jurek, Department of Silviculture). Petr Lupač, Jakub Salaš, Jakub Gašpar and Martin Vyhnal helped us with the technical side of the project. Employees of the HeidelbergCement Czech republic were an integral part of the persons involved. At the end of our project we held a meeting of experts in Mokrá quarry, which was attended by 28 people.

LIST OF APPENDIX

Appendix A – Monitoring interest areas
Appendix B – Plant invasions in western quarry
Appendix C – Experimental interventions
Appendix D – Proposals for improving biodiversity
Appendix E – Seminar experiment in biodiversity management
Appendix F – Not only plants...

To be kept and filled in at the end of your report

Project tags (select all appropriate): This will be use to classify your project in the project archive (that is also available online)	
Project focus: ☒Biodiversity management ☐Cooperation programmes ☐Education and Raising awareness ☐Endangered and protected species ☒Invasive species ☒Landscape management - rehabilitation ☐Rehabilitation ☒Scientific research ☐Soil management ☐Urban ecology ☐Water management Flora: ☒Conifers and cycads ☒Ferns ☒Flowering plants ☒Fungi ☒Mosses and liverworts Fauna: ☐Amphibians ☐Birds ☒Dragonflies & Butterflies ☐Fish ☒Mammals ☐Reptiles ☐Spiders ☐Other insects ☐Other species	Habitat: ☐Cave ☒Cliffs ☐Fields - crops/culture ☒Forest ☒Grassland ☐Human settlement ☒Open areas of rocky grounds ☒Recreational areas ☒Screes ☒Shrubs & groves ☐Soil ☐Wander biotopes ☐Water bodies (flowing, standing) ☐Wetland Stakeholders: ☒Authorities ☐Local community ☐NGOs ☐Schools ☒Universities

APPENDIX A – MONITORING INTEREST AREAS

Localization of research plots in the western quarry

Floristic inventory of species in the western quarry

Forest vegetation:

Acer campestre
Acer platanoides
Acinos arvensis
Aegopodium podagraria
Ajuga genevensis
Ajuga reptans
Alliaria petiolata
Alyssum alyssoides
Anemone nemorosa
Anemone ranunculoides
Arabis hirsuta
Arabis pauciflora
Arenaria serpyllifolia
Arrhenatherum elatius
Artemisia vulgaris
Asarum europaeum
Asplenium trichomanes
Berberis vulgaris
Brachypodium sylvaticum
Bromus benekenii
Bromus tectorum
Buglossoides purpurocaerulea (C4 a)
Bupleurum falcatum
Campamula patula
Campanula persicifolia
Campanula rapunculoides
Campanula trachelium
Cardamine impatiens
Carex digitata
Carex montana
Carex muricata agg.
Carex pilosa
Carpinus betulus
Cephalanthera damasonium (C4 a)
Cephalanthera rubra (C2 b)
Cirsium arvense
Convallaria majalis
Cornus mas (C4 a)
Cornus sanguinea
Corylus avellana
Crataegus laevigata
Crepis foetida subsp. *rhoeadifolia*
Dactylis polygama
Daphne mezereum
Dryopteris filix-mas
Echium vulgare
Epilobium sp.
Epipactis helleborine agg.
Equisetum arvense
Euonymus verrucosa
Eupatorium cannabinum
Euphorbia amygdaloides (C4 a)
Fagus sylvatica
Festuca rupicola
Festuca valesiaca
Fragaria moschata
Fragaria vesca
Fraxinus excelsior
Galeopsis tetrahit
Galium album
Galium aparine
Galium odoratum
Galium schultesii
Galium sylvaticum
Geranium robertianum
Geum urbanum
Glechoma hederacea
Hedera helix
Hepatica nobilis
Heracleum sphondylium
Hieracium lachenalii
Hieracium murorum
Hordelymus europaeus
Hypericum montanum
Chaerophyllum temulum
Chenopodium vulgare
Impatiens parviflora
Inula conyzae
Juglans regia
Knautia drymeia
Lactuca serriola
Lactuca viminea (C3)
Lapsana communis
Larix decidua
Lathyrus niger
Lathyrus vernus
Ligustrum vulgare
Lilium martagon (C4 a)
Lonicera xylosteum
Lotus corniculatus
Lysimachia nummularia
Maianthemum bifolium
Melampyrum sp.
Melica ciliata
Melica nutans
Melica uniflora
Melittis melissophyllum (C4 a)
Mercurialis perennis
Mycelis muralis
Myosotis sylvatica
Neottia nidus-avis (C4 a)
Origanum vulgare
Phyteuma spicatum
Picea abies
Pinus sylvestris
Plantago major
Plantago media
Platanthera bifolia (C3)
Poa angustifolia
Poa nemoralis
Poa trivialis
Polygonatum odoratum
Potentilla recta (C4 a)
Primula veris
Pulmonaria obscura
Quercus petraea
Ranunculus lanuginosus
Ranunculus repens
Rhamnus cathartica
Robinia pseudoacacia
Rosa sp.
Rubus caesius

Sambucus ebulus
Sambucus nigra
Sanguisorba minor
Sanicula europaea
Scrophularia nodosa
Sedum acre
Sedum maximum
Senecio germanicus
Senecio ovatus
Sorbus aucuparia
Sorbus torminalis
Stachys sylvatica
Stellaria holostea
Stellaria media
Symphytum tuberosum
Tanacetum corymbosum
Teucrium chamaedrys (C4 a)
Tragopogon dubius
Trifolium repens
Turritis glabra
Urtica dioica
Verbascum chaixii subsp. *austriacum* (C4 a)
Veronica officinalis
Veronica vindobonensis
Viburnum opulus
Vicia hirsuta
Vicia sepium
Vincetoxicum hirundinaria
Viola mirabilis (C4 a)
Viola reichenbachiana
Viola riviniana

Open vegetation:

Acer campestre
Ajuga reptans
Allium oleraceum
Alyssum alyssoides
Anemone nemorosa
Anemone ranunculoides
Arctium lappa
Arctium tomentosum
Arrhenatherum elatius
Artemisia vulgaris
Astragalus glycyphyllos
Atropa bella-donna
Betula pendula
Brachypodium sylvaticum
Bromus benekenii
Bromus sterilis
Buglossoides purpurocaerulea (C4 a)
Calamagrostis epigejos
Campanula patula
Campanula persicifolia
Capsella bursa-pastoris
Carduus acanthoides
Carex digitata
Carex montana
Carex muricata agg.
Carex pallescens
Carex pilosa
Carex sylvatica
Carpinus betulus
Cerastium holosteoides
Cerinthe minor (C4 a)
Cichorium intybus
Cirsium arvense
Cirsium vulgare
Clinopodium vulgare
Convallaria majalis
Convolvulus arvensis
Conyza canadensis
Corylus avellana
Crataegus sp.
Crepis foetida subsp. *rhoeadifolia*
Cruciata glabra
Cynoglossum officinale
Dactylis glomerata
Daucus carota
Descurainia sophia
Echinochloa crus-galli
Epilobium adenocaulon
Epilobium montanum
Epilobium tetragonum agg.
Epipactis helleborine agg.
Erigeron annuus
Erysimum cheiranthoides
Eupatorium cannabinum
Euphorbia cyparissias
Fallopia convolvulus
Festuca pratensis
Festuca rubra
Fragaria moschata
Fragaria vesca
Galeopsis tetrahit
Galium aparine
Galium mollugo agg.
Galium odoratum
Galium sylvaticum
Genista tinctoria
Geranium columbinum
Geranium robertianum
Geum urbanum
Glechoma hederacea
Hieracium lachenalii
Hieracium murorum
Hypericum montanum
Hypericum perforatum
Chamaecytisus virescens (C3)
Chenopodium album agg.
Impatiens parviflora
Inula conyzae
Knautia drymeia
Lactuca serriola
Lactuca viminea (C3)
Lapsana communis
Lappula squarrosa (C3)
Larix decidua
Lathyrus niger
Lathyrus vernus
Leontodon hispidus
Ligustrum vulgare
Lilium martagon (C4 a)
Linaria vulgaris
Lotus corniculatus
Luzula luzuloides
Medicago lupulina
Melica nutans
Melica transsilvanica (C4 a)
Melica uniflora
Melittis melissophyllum (C4 a)
Microrrhinum minus
Moehringia trinervia
Myosotis sp.
Origanum vulgare
Picris hieracioides
Pinus sylvestris
Plantago lanceolata
Poa nemoralis
Poa pratensis
Poa trivialis
Populus tremula
Pulmonaria obscura
Quercus petraea
Ranunculus lanuginosus
Ranunculus repens
Rosa canina
Rubus caesius
Rubus frutisocus agg.
Rubus idaeus
Rumex crispus
Rumex obtusifolius
Salix caprea
Sambucus ebulus
Sambucus nigra
Scrophularia nodosa
Senecio viscosus
Senecio vulgaris
Solanum nigrum
Solidago canadensis
Solidago virgaurea
Sonchus asper
Sonchus oleraceus
Sorbus torminalis
Stellaria holostea
Symphytum tuberosum
Tanacetum corymbosum
Taraxacum sect. *Ruderalia*
Trifolium alpestre
Trifolium pratense
Trifolium repens
Tripleurospermum inodorum
Turritis glabra
Tussilago farfara
Urtica dioica
Verbascum chaixii ssp. *austriacum* (C4 a)
Verbascum lychnitis
Veronica officinalis
Veronica vindobonensis
Vicia hirsuta
Vicia sepium
Vincetoxicum hirundinaria
Viola reichenbachiana

The nomenclature was unified by: Danihelka J., Chrtek J. Jr. & Kaplan Z. (2012): Checklist of vascular plants of the Czech Republic. – Preslia 84: 647–811.

Phytosociological relevés of the experimental plots

[layer, 6 - herb, 7 –juveniles]

		Terrace on a dump	Sowing	Clearing
		1		
Relevé numbers →		12345678912345690	12341234	12341234
Dominants				
Calamagrostis epigejos	[6]	44455445451114+24	...r....	32342444
Cirsium arvense	[6]	++++++.++.+++++++	.++.....	22422777
Tussilago farfara	[6]	2777111+724++++3+	22222727	....
Forest „survivors“				
Anemone nemorosa	[6]	.......+.........	....	+..+....
Anemone ranunculoides	[6]	....	....	...r....
Brachypodium sylvaticum	[6]	....r........+...	....	....
Carex montana	[6]	....	....	..1+.+++
Carex pilosa	[6]	....r............	....	23++++++
Convallaria majalis var. majalis	[6]	....	....	.++...r.
Euphorbia amygdaloides	[6]	....+..r.....r...	....	....
Galium odoratum	[6]	......+..........	....	+.1+..++
Galium sylvaticum	[6]	....	....	.++r..+r
Hypericum montanum	[6]	....	....	+r.....+
Lathyrus vernus	[6]	....	....	.r......
Melica nutans	[6]	....	....	1+++..+.
Moehringia trinervia	[6]	....	....	r.......
Myosotis sylvatica	[6]	..r.+r...........	....	....
Poa nemoralis	[6]	++++++++++......+	+.......	1111.+++
Pulmonaria obscura	[6]	....	....	..r.....
Ranunculus lanuginosus	[6]	....	....	...r+...
Stellaria holostea	[6]	......r..........	....	+1+++.++
Veronica officinalis	[6]	.............r...	....	+.++..++
Viola reichenbachiana	[6]	....	....	++++..r+
„Good“ steppe species				
Alyssum alyssoides	[6]	.....r...........	....	....
Anthyllis vulneraria	[6]	....	.....8.2	....
Bromus japonicus	[6]	....	+.++++r+	....
Carex caryophyllea	[6]	..r..............	....	....
Carex pallescens	[6]	....	....	+..+...+
Clinopodium vulgare	[6]	..........r......	....	..+.....
Euphorbia cyparissias	[6]	.....r...........	....	....
Euphorbia epithymoides	[6]	....r............	....	....
Festuca rubra	[6]	...+.............	....	+.......
Festuca rupicola	[6]	....	.......+	....
Galium album ssp. *pycnotrichum*	[6]	......rrr........	....	....
Genista tinctoria	[6]	........r........	....	....
Luzula campestris	[6]	....	....	+.......
Poa compressa	[6]	...............r.	.....+..	....
Poa pratensis	[6]	+..++.+..........	....	...+...+
Rosa species	[6]	....	....	.r......
Trifolium aureum	[6]	.............r...	....	....
Verbascum chaixii ssp. *austriacum*	[6]	.....r...........	....	+.......
Veronica arvensis	[6]	+................	....	....
Veronica vindobonensis	[6]	....	....	.+.+....
Viola hirta	[6]	......r..........	....	....
Aliens				
Conyza canadensis	[6]	.........++..+..+	....r...	..+.....
Cytisus scoparius	[6]	.....r...........	....	....
Erigeron annuus agg.	[6]	1+++++r..+++++.r+	....	....
Impatiens parviflora	[6]	....	....	...+....
Lupinus polyphyllus	[6]	...rr.r1+....+.1.	....	....
Melilotus albus	[6]	..........+..+..r	....+8+.	....
Populus x *canadensis*	[7]	....	rr..r+.r	....
Solidago canadensis	[6]	....	....	.+++..+.
Tripleurospermum inodorum	[6]	....++....r..+..+	+.r.rr+r	....r+..
Others				
Achillea millefolium agg.	[6]	++..++....+......	....	....
Agrostis stolonifera	[6]	................+	..+.....	....

Ajuga reptans	[6]	+....++.........r	....	++81+.1+
Arctium lappa	[6]	....	....	......+.
Arctium species	[6]	....	....	...+....
Artemisia vulgaris	[6]	.+.r++r.++1..+.++	....	.r+...++
Astragalus glycyphyllos	[6]	+++1++r+..+r.1..+	....	+r++..r.
Atropa bella-donna	[6]	....	....	.r......
Carduus acanthoides	[6]	...r............r	....	....
Carex muricata agg.	[6]	.....rr....+.....	....	+.......
Carlina vulgaris	[6]	..r..............	....	....
Cerastium holosteoides	[6]	.....r...........	....	....
Cirsium vulgare	[6]	+r++.............	.....rr+	....+...
Convolvulus arvensis	[6]	.+...............	....	r.......
Crepis foetida ssp. *rhoeadifolia*	[6]	.............+...	....++++	....
Dactylis glomerata	[6]	+.+++....+...+..r	....	....
Daucus carota	[6]	+++++++++r+.r.+++	..r++r++	....
Echium vulgare	[6]	....	.+...r..	....
Elymus repens	[6]	...............+.	....	....
Epilobium montanum	[6]	....	....	..r.....
Epilobium species	[6]	r++++....+.r..+..	....	r+++....
Epilobium tetragonum	[6]	.........+r.....+	....	......++
Equisetum arvense	[6]	...+.r....+...+..	....	....
Eupatorium cannabinum	[6]	....	....	+++1.11+
Fallopia convolvulus	[6]	....	....	.......r
Festuca pratensis	[6]	..........r......	.....r..	...+....
Fragaria moschata	[6]	....	....	.+.+.r.+
Fragaria vesca	[6]	.+..+..rr.+..+r+.	....	++++.+++
Galeopsis tetrahit	[6]	....	....	++++..r+
Galium aparine	[6]	.r.++.+..........	....	++++++++
Galium mollugo agg.	[6]	++++++...+.++.++r	....	+......+
Geranium robertianum	[6]	+..+++++rr....r.+	....	.....+..
Geum urbanum	[6]	..r..........r...	....	++.+..r.
Glechoma hederacea	[6]	....	....	..+..++.
Hypericum perforatum	[6]	rr++.+++r++.++.++	....	++.....+
Lactuca serriola	[6]	................r	....	....
Leontodon hispidus	[6]	.r..++r..........	....	....
Linaria vulgaris	[6]	.....+.r.........	....	.+.....+
Lolium multiflorum	[6]	....	......+.	....
Lolium perenne	[6]	....	..r....+	....
Lotus corniculatus	[6]	....	....	r.......
Medicago lupulina	[6]	..........r..r...	r.++r...	....
Medicago sativa	[6]	....	..r.....	....
Myosotis species	[6]	....	....	...r...+
Picris hieracioides	[6]	.............++++	....	....
Plantago lanceolata	[6]	.....r..........r	...r..+.	....
Plantago major	[6]	....	......+.	....
Poa annua	[6]	....r.....r......	....	....
Poa trivialis	[6]	....	....	++++.++.
Ranunculus repens	[6]	.r.+..+....+....r	....	.+11.+++
Rubus fruticosus agg.	[6]	..++.+r+..r++.r.r	....	+.+r..1.
Rubus idaeus	[6]	.r+..++1+....+.+r	....	++++.++1
Rumex crispus	[6]	r.+.+++r...r...rr	....	..r..+..
Rumex obtusifolius	[6]	....	....	..++.+r.
Scrophularia nodosa	[6]	.rrr..r..+rr.r..r	....	++1+.++1
Securigera varia	[6]	..r+.....++......	....	....
Senecio viscosus	[6]	....	....	....r...
Stellaria media	[6]	.........r+.r....	....	....
Symphytum officinale	[6]	......+...1......	....	....
Taraxacum sect. *Taraxacum*	[6]	++++.+..+.rr.....	++.+..r.	....
Torilis japonica	[6]	.............r...	....	....
Trifolium incarnatum	[6]	....	.....+8+	....
Trifolium pratense	[6]	...............r.	....	....
Urtica dioica	[6]	+..r+++1.+.r++..+	....	.++++++.
Verbascum species	[6]	....	....	......r.
Vicia angustifolia	[6]	+r.r++..r........	..r.....	....
Vicia hirsuta	[6]	....	....	++++r+.r
Vicia sepium	[6]	...+..1..........	....	....
Vicia tetrasperma	[6]	.........rr......	....	....

Woody species – juveniles

Acer campestre	[7]	......r..........	....	....
Acer platanoides	[7]	r...r......r.....	....	....
Betula pendula	[7]	....	....	.....+..
Carpinus betulus	[7]	.++..r.....r.r...	....	++.r...+
Cornus sanguinea	[7]	.......r.........	....	....
Corylus avellana	[7]	....	....	..+...+.
Populus alba	[7]	....	.r...+..	....

```
Prunus avium                          [7]   ..r.............|........|........
Quercus petraea                       [7]   ................|........|.+......
Salix alba                            [7]   ..r.............|........|........
Sambucus nigra                        [7]   ................|........|.+......
```

Table headers:

Releve number, Date (year/month/day), Altitude (m), Aspect (degrees), Slope (degrees), Cover total (%), Cover herb layer (%), Cover moss layer (%), Height (high) herb layer (cm), Average height herb layer (cm), Experiment type, Longitude, Latitude, Bias_gps

Periodical soil heap
Mokrá (district. Brno-venkov): the northern part of the western limestone quarry, terrace at the periodical soil heap overburden

1 - 20160510, 432, 0, 0, 90, 90, 10, 140, 80, CONTROL
164502.55, 491408.70, 4

2 - 20160510, 432, 0, 0, 90, 90, 5, 140, 70, Turf disturbance
164502.40, 491408.55, 3

3 - 20160510, 432, 0, 0, 85, 85, 5, 120, 60, Black textile foil
164502.24, 491408.14, 2

4 - 20160510, 432, 0, 0, 93, 93, 3, 140, 80, Felt with foil
164502.30, 491408.11, 3

5 - 20160510, 432, 0, 0, 85, 85, 3, 150, 70, II. mowing
164501.91, 491407.51, 3

6 - 20160510, 432, 0, 0, 80, 80, 2, 140, 60, herbicid
164501.33, 491407.33, 3

7 - 20160510, 432, 225, 2, 95, 95, 2, 150, 70, vypalování
164501.16, 491406.68, 3

8 - 20160510, 430, 360, 4, 100, 100, 0, 140, 100, kokrhel
164502.10, 491409.31, 3

9 - 20160510, 430, 360, 10, 85, 85, 2, 110, 50, kámen
164500.99, 491409.29, 3

Periodic soil heap repetition

1 - 20160901, 432, 0, 0, 100, 100, 7, 140, 80, CONTROL
164502.55, 491408.70, 4

2 - 20160901, 432, 0, 0, 80, 80, 0, 130, 30, Turf disturbance
164502.40, 491408.55, 3

3 - 20160901, 432, 0, 0, 5, 5, 0, 30, 10, Black textile foil
164502.24, 491408.14, 2

4 - 20160901, 432, 0, 0, 3, 3, 1, 20, 10, Felt with foil
164502.30, 491408.11, 3

5 - 20160901, 432, 0, 0, 65, 65, 3, 70, 35, II. mowing
164501.91, 491407.51, 3

6 - 20160901, 432, 0, 0, 5, 5, 1, 25, 15, Herbicide
164501.87,491407.33, 3

9 - 20160901, 430, 360, 10, 80, 80, 0, 100, 35, Stone
164500.99, 491409.29, 3

10 - 20160901, 432, 0, 0, 70, 70, 0, 70, 50, Mulching, without previous phytosociological relevé
164502.14, 491407.84, 3

Sowing
Mokrá (district. Brno-venkov): the northern part of the western limestone quarry, between the overburden periodic soil heap

1 - 20160510, 421, 0, 0, 25, 25, 0, 35, 15, CONTROL
164452.72, 491403.25, 3

2 - 20160510, 421, 0, 0, 25, 25, 0, 40, 15, MIX 3
164452.96, 491403.07, 3

3 - 20160510, 421, 0, 0, 25, 25, 0, 35, 15, MIX 2
164452.46, 491402.88, 3

4 - 20160510, 421, 0, 0, 25, 25, 0, 35, 15, MIX 1
164452.28, 491402.73, 3

Sowing repetition

1 - 20160901, 421, 0, 0, 30, 30, 0, 60, 20, CONTROL
164452.72, 491403.25, 3

2 - 20160901, 421, 0, 0, 40, 40, 0, 150, 35, MIX 3
164452.96, 491403.07, 3

3 - 20160901, 421, 0, 0, 30, 30, 0, 50, 20, MIX 2
164452.46, 491402.88, 3

4 - 20160901, 421, 0, 0, 40, 40, 0, 40, 20, MIX 1
164452.28, 491402.73, 3

Clearing
Mokrá (okr. Brno-venkov): eastern part of the western limestone quarry, the mining area

1 - 20160629, 397, 0, 0, 95, 95, 1, 160, 110, Herbicide
164524.10, 491358.10, 2

2 - 20160629, 397, 0, 0, 95, 95, 1, 170, 80, Burning
164524.40, 491358.00, 2

3 - 20160629, 397, 0, 0, 100, 100, 1, 180, 140, CONTROL
164524.50, 491357.70, 2

4 - 20160629, 397, 0, 0, 95, 95, 0, 160, 110, Mowing
164524.10, 491357.80, 2

Clearing repetition

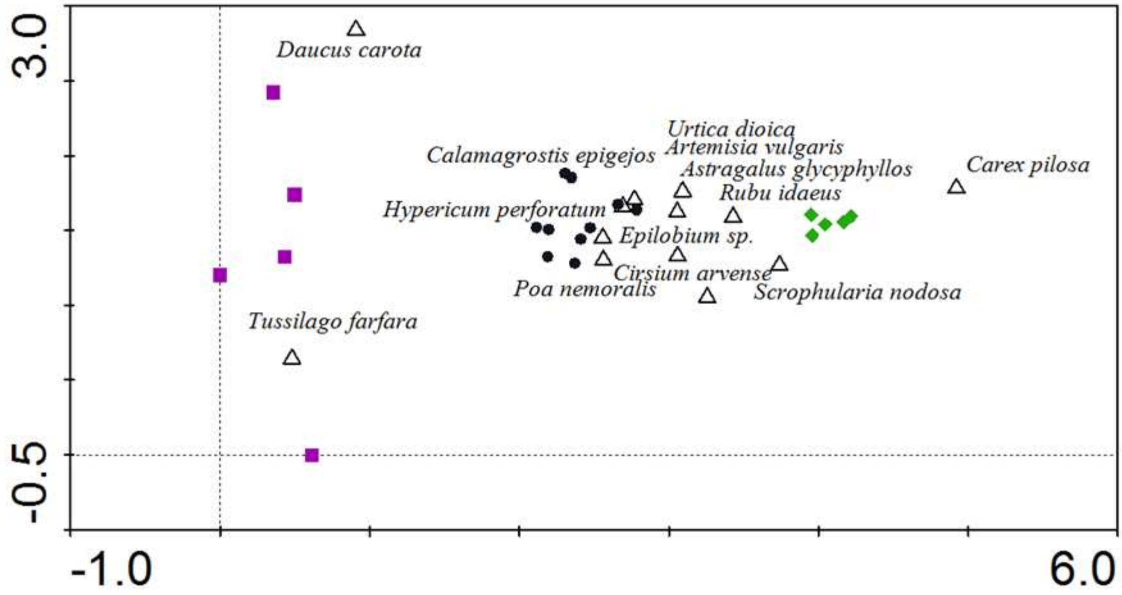
1 - 20160914, 397, 0, 0, 65, 65, 1, 40, 25, Herbicide
164524.10, 491358.10, 2

2 - 20160914, 397, 0, 0, 90, 90, 3, 50, 35, Burning
164524.40, 491358.00, 2

3 - 20160914, 397, 0, 0, 95, 95, 2, 110, 95, CONTROL
164524.50, 491357.70, 2

4 - 20160914, 397, 0, 0, 90, 90, 1, 50, 35, Mowing
164524.10, 491357.80, 2

Detrended correspondence analysis (DCA)



This unconstrained ordination helps to describe differences in vegetation types of “starting points” of the all sampled plots (unchanged control plots from the second sampling are also included). We can see the dissimilarity between the plots – there are plots from the freshly deposited soil (purple colour, plots for sowing, domination of the *Tussilago farfara*), plots from periodical soil heap (black colour, plots for experiments, dominant was *Calamagrostis epigejos*) and plots from glade (green colour, plots for experiments, still lot of the forest species, dominants *C. epigejos* and *Cirsium arvense*). The data were square root transformed, rare species were underweighted and length of the first axis was 4.2. The higher inconsistency was between the species poor relevés of inicial vegetation on the relatively fresh soil deposit and the opposite situation we can see in the relevé groups of the periodical soil heap and glade which were quite compact and similar to each other.

Results of mycological research

1. Hornbeam forest with a dominance of hornbeam and mixture of pine, the upper part of the quarry (49°14'4.785"N, 16°44'49.991"E)

Stereum hirsutum
Russula lepida
Leucopaxillus giganteus
Russula cuprea
Russula olivacea
Russula risigallina
Hapalopilus rutilans
***Russula persicina* (VU)**
Russula chloroides
Phellinus cf. robustus (mladý)
Inocybe bongardii
Amanita rubescens
Marasmius rotula
Clavicorona pyxidata

2. Clearing of vegetation *Cirsium arvense*
(49°13'59.716"N, 16°45'23.845"E)

Bolbitius vitellinus
Infundibulicybe gibba

3. Mixed forest - mainly hornbeam, maple, pine, larch, hazel, oak, spruce
(49°13'55.617"N, 16°45'26.491"E)

Bovista cf. *pusilla*
Xerula radicata
Inocybe godei
Mycena pura
Coprinellus disseminatus
Lepiota castanea
Stereum hirsutum
Xerocomellus chrysenteron

Geastrum fimbriatum
Lepiota boudieri
Cystolepiota seminuda

4. Hornbeam forest
(49°13'55.516"N, 16°45'31.435"E)

Volvariella caesiotincta (VU)
Calocera viscosa
Inocybe rimosa
Coprinellus domesticus


Mushrooms collection from the quarry visit

The nomenclature was unified by: Holec J., Bielich A. & Beran M. (2012): Přehled hub střední Evropy. – Academia, Praha.

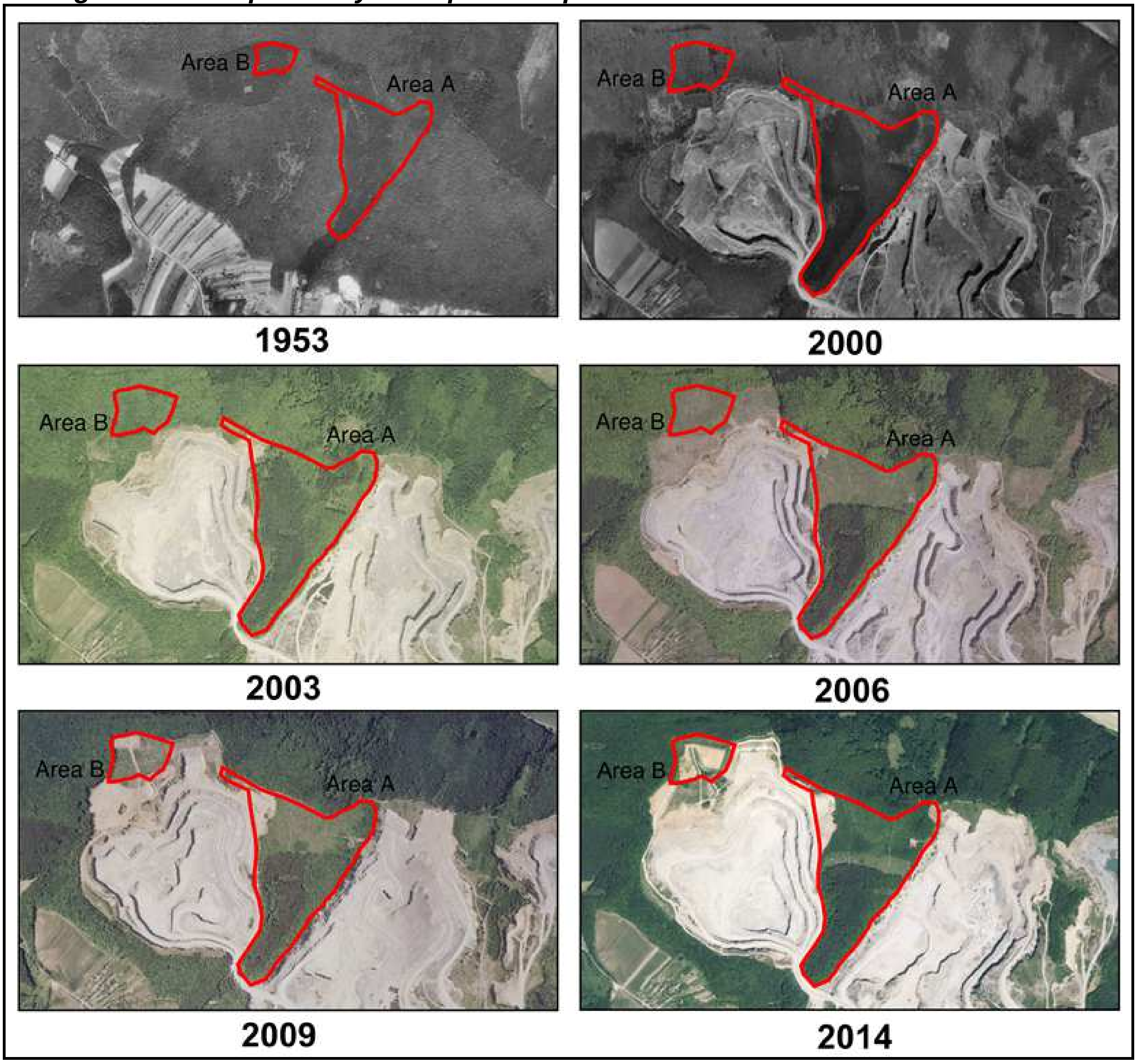
List of bryophytes of phytosociological relevés

Moss layer was recorded only in the experimental plots on the soil periodical heap and glade (but not everywhere), not at all in the youngest plots with fresh soil deposits. The list was made from the collections of 15 relevés. Some bryophyte specimens need revision. Therefore, we did not include them to the table of phytosociological relevés and we did not use them in analysis. So, we present only this short summary. In this list there are no liverworts, because in the relevés we did not find any.

Amblystegium serpens
Amblystegium sp.
Barbula convoluta
Barbula unguiculata
Brachythecium albicans
Brachythecium campestre
Brachythecium laetum
Brachythecium rutabulum
Brachythecium sp.
Bryum argenteum
Bryum caespiticium
Bryum klinggraeffii
Bryum rubens
Bryum sp.
Ceratodon purpureus
Dicranella varia
Didymodon sp.
Funaria hygrometrica
Homalothecium sericeum
Hypnum cupressiforme
Hypnum sp.
Oxyrrhynchium hians
Rhytidiadelphus squarrosus
Tortula subulata
Tortula sp.

The nomenclature was unified by Kučera J., Váňa J., & Hradílek Z. (2012): Bryophyte flora of the Czech Republic: updated checklist and Red List and a brief analysis. Preslia 84(3): 813–850.

Mining area development by orthophotomaps 1953–2014



APPENDIX B – PLANT INVASIONS IN WESTERN QUARRY

List of invasive alien/expansive species in the western part

This list contains non-native invasive species (= invasive archaeophytes and neophytes) and naturalized species (= naturalized archaeophytes or neophytes) and native expansive species that are generally considered as an expansive or that behave expansively in the areas of our interest in quarry. Alien species categories follow the list of non-native plants in the Czech Republic (Pyšek et al. 2012).

Species	Status	Where is home	How much is it in the quarry *
Arrhenatherum elatius	invasive	archaeophytes	2
Artemisia vulgaris	expansive	autochthonous	2
Asclepias syriaca	invasive	neophytes	1
Calamagrostis epigejos	expansive	autochthonous	3
Cirsium arvense	invasive	archaeophytes	3
Conyza canadensis	invasive	neophytes	3
Cytisus scoparius	naturalized	neophytes	2
Daucus carota	expansive	autochthonous	2
Descurainia sophia	naturalized	archaeophytes	1
Echium vulgare	expansive	autochthonous	2
Epilobium adenocaulon	naturalized	neophytes	1
Erigeron annuus	invasive	neophytes	2
Eupatorium cannabinum	expansive	autochthonous	2
Galium aparine	expansive	autochthonous	1
Geranium columbinum	naturalized	archaeophytes	1
Impatiens parviflora	invasive	neophytes	1
Lappula squarrosa	naturalized	archaeophytes	1
Lupinus polyphyllus	invasive	neophytes	2
Matricaria discoidea	naturalized	neophytes	1
Melilotus albus (/officinalis)	naturalized	archaeophytes	2
Microrrhinum minus	naturalized	archaeophytes	1
Populus ×canadensis	invasive	neophytes	2
Robinia pseudoacacia	invasive	neophytes	1
Rubus caesius	expansive	autochthonous	2
Rubus fruticosus agg.	expansive	autochthonous	3
Rumex crispus	expansive	autochthonous	2
Rumex obtusifolius	expansive	autochthonous	1
Sambucus nigra	expansive	autochthonous	1
Sambusus ebulus	naturalized	archaeophytes	3
Solidago canadensis	invasive	neophytes	2
Tanacetum vulgare	naturalized	archaeophytes	2
Tripleurospermum inodorum	naturalized	archaeophytes	3
Tussilago farfara	expansive	autochthonous	3
Urtica dioica	expansive	autochthonous	1

* by Pyšek P., Danihelka J., Sádlo J., Chrtek Jr. J., Chytrý M., Jarošík V., Kaplan Z., Krahulec F., Moravcová L., Pergl J., Štajnerová K. & Tichý L. (2012): Catalogue of alien plants of the Czech Republic: checklist update, taxonomic diversity and invasion patterns. Preslia 84(2): 155–255.

** 1 – sporadic, 2 – locally common, 3 – abundant

Photo documentation

Lupinus polyphyllus (invasive neophytes)

Cytisus scoparius (naturalized neophytes)

Conyza canadensis (invasive neophytes) a *Tripleurospermum inodorum* (naturalized archaeophytes)

Tripleurospermum inodorum (naturalized archaeophytes)

Cirsium arvense (invasive archaeophytes)

Sambucus ebulus (naturalized archaeophytes)

Melilotus albus (naturalized archaeophytes)

Tussilago farfara (in the quarry expansive)

Calamagrostis epigejos (expansive)

Calamagrostis epigejos (expansive) a *Lupinus polyphyllus* (invasive neophytes)

APPENDIX C – EXPERIMENTAL INTERVENTIONS

The main part of experiments was done on soil dump (site B). The landfill/deposit is approx. five years old and substantially overgrown by invasive and expansive species. The experiments were followings: repeated mowing (twice per season), turf disturbance by digging, covering by black foil, covering by felt with foil, mulching, burning, application of herbicide and overlaying by stones. One more set of experimental plots were founded on the clearing of the former forest between central and west quarry where the mining will expand soon (site A). Here, the forest was cut ten years ago, now the site is dominated by invasive and expansive species. On this site we tested treatments: one mowing, application of herbicide and burning. Prior the experiments, the plots (except the control variant) were mowed.

A plain deposit west from the western quarry is in early succession stage and the majority of the soil surface is uncovered. At this site, stabilization sowings of grasses and herbs were tested expecting they grow the soil and prevent dispersion of undesirable species on this site. Prior the experiments, the plots (except the control variant) were dug.

Description and analysis of each treatment

Repeated mowing twice per season

Advantages (+)
- Relatively quick
- Simple, cheap
- Environment-friendly
- Undemanding on equipment
- Prevents seed production

Disadvantages (–)
- Non-selective
- Undesirable species are not removed sufficiently quickly

In the scale of years, the treatment would be perhaps considerably effective. This method reaches the best ratio price/performance and thus is suitable for large-scale application.

Turf disturbance by digging

Advantages (+)
- Simple
- Environment-friendly
- Cheap
- Undemanding on equipment
- Reducing clonal species (*Calamagrostis*, *Cirsium*)

Disadvantages (–)
- Arduous, slow
- Disturbance of vegetation cover – way for new invasions?

For usage on a larger area, manual digging could be substituted by ploughing and crumbling of the soil or by a lighter mechanization. The disturbance pushes the succession to the state of several years ago. On one hand, this may be a threat, on the other, it could be employed in management of overgrown sites with dense stands. Uncovering of the soil surface allows undesirable species to grow, thus it would be convenient to combine this treatment with other one stabilizing the soil, e. g. sowing or mulching.

Covering by foil

The covering was tested in two variants – covering by black textile foil and by felt with foil (oriented upwards)

Advantages (+)
- Both variants reduce biomass significantly, i. e. including undesirable species
- Prevention of dispersal of seeds of undesirable species

Disadvantages (–)
- Non-selective
- Slow
- Need of anchoring
- Price of the foil

Below the black textile (partly water-permeable) foil, there were drier conditions and thus the coverage of herb layer. By contrast, the felt with foil buffered the humidity and the soil did not get totally dry. The limitation of herb layer was rather due to the insufficient light.

Mulching

Mulching is a transfer of hay from source (species-rich) site and its spreading on a destination site.

Advantages (+)

Disadvantages (–)

- Transfer of seeds of desirable species
- Mulch reduces evaporation
- Prevents growing of ruderal species
- Prevents erosion

- Slow
- Arduous
- Need of source locality

The method can be partially mechanized to make the work more effitient. Mulching can be considered a perspective method for restoration of species-rich grasslands (the best for finishing of site reclamation, rather than for large-scale stabilization of soil deposits).

Burning

Burning is a traditional mode of landscape management. Treatment was performed in summer period when the turfs were sufficiently dry.

Advantages (+)
- Biomass removal
- Elimination of seeds of undesirable species

Disadvantages (–)
- Slow
- Need of supervision
- Non-selective
- Unfriendly to invertebrates

After two months, the effect of treatment was negligible. Burning is perhaps low-effective method for removing invasive and expansive species. However, in large-scale usage, the heat could be higher and sufficient for removing undesirable species and their seeds in soil. Nevertheless, such employing would require a fireman assistance to prevent spreading of fire out of the range.

Application of herbicide

For treatment, total herbicide based on glyphosate (Roundup Klasik) was used in concentration 4%.

Advantages (+)
- Quick carrying out
- Quick effect

Disadvantages (–)
- Non-selective
- Unfriendly to animals

This method is effective, however some species may be/become resistant, sprout subsequently and overgrow the cleared area. For removing of competitive grasses, more environment-friendly monocot-selective herbicide can be used. Considering the reduction of herb layer coverage, a sowing or mulching can be carried out for stabilization (with some delay). Being aware that application of a herbicide is a strong method with negative impacts, a large-scale usage is inapt. Yet it still has a place in a fighting against beginning of invasions and expansions.

Overlaying by stones

The area was overlaid by quarried stones in layer 10–20 cm thick.

Advantages (+)
- Environment-friendly
- Undemanding on equipment
- Reduces biomass production

Disadvantages (–)
- Slow
- Arduous
- Less effective
- Source of stones necessary

Overlaying by stones does not leave any bare soil and makes the surface more extreme. We observed lower germination of ruderal species. However, the stone layer overgrown by *Tussilago*, *Calamagrostis* and *Lupinus* also grew through. For stronger effect, thicker stone layer would be better. However, it would not be a cheap method for large-scale usage as the stones are a commodity that can be sold rather than waste it for site remediation that can be done other ways.

Sowings

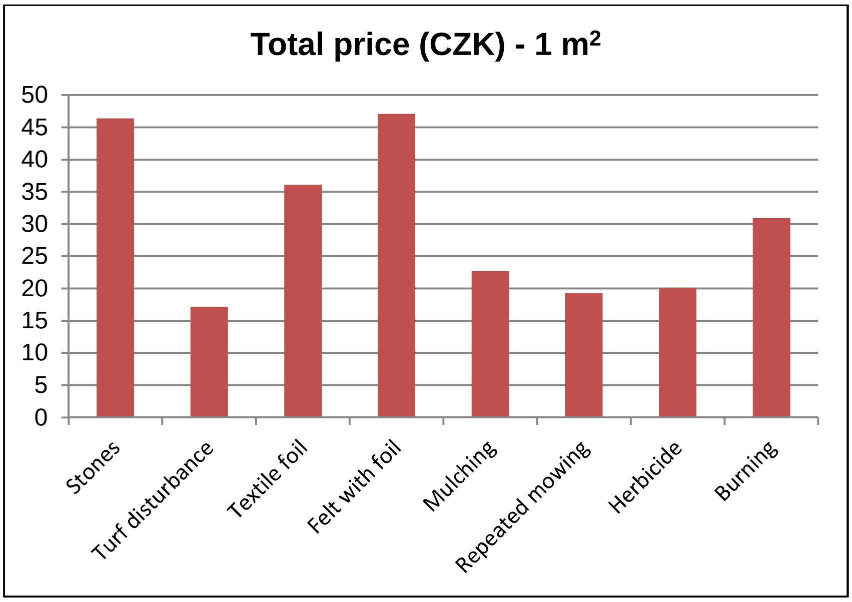
Sowing of three mixtures (for composition see a diagram below) was carried out at spring. Nevertheless, germination rate was low due to the dry spring, only legumes germinated well (*Anthyllis vulneraria* a *Trifolium incarnatum*). Thus, the effectiveness of the mixtures cannot be compared. The drought cased that even invasive or expansive species did not grow, so the experiment was not thwarted. We plan to observe the germination of rest of the species in the experimental sowing also next year to determine the impact on the plots.

Comparison of the treatments

The lowest price is in a simple soil disturbation, nevertheless it is necessary to keep in mind that this treatment should be combined with sowing or mulching which makes it substantially more expensive.

Repeated mowing follows. It it's a stand-alone method which used to be employed for centuries and it is a suitable for large-scale usage. Mulching can be also considered keenly-priced. Other treatments are due to higher final price usable rather for experimental, small-scale or spot usage.

Treatment	Stones	Turf disturbance	Textile foil	Felt with foil	Mulching	Repeated mowing	Herbicide	Burning
Working hours (1 person)	1.5	1.0	1.0	1.0	1.0	1.0	1.5	2.0
Number of workers	2.0	2.0	1.0	1.0	2.0	2.0	1.0	1.0
Hourly wage (CZK)	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0
Material used	stones (1 t)	spade	canvas (16 m^2)	canvas (16 m^2)	transport (10 km)	fuel (1l)	RoundUp (0.3l)	Burner
Price (work)	375.0	250.0	125.0	125.0	250.0	250.0	187.5	250.0
Price (material)	300.0	0.0	400.0	560.0	80.0	30.0	105.0	200.0
Overheads (20 % - transport, arrangement)	67.5	25.0	52.5	68.5	33.0	28.0	29.3	45.0
Total price (CZK) - 16 m^2	742.5	275.0	577.5	753.5	363.0	308.0	321.8	495.0
Total price (€) - 16 m^2	27.5	10.2	21.4	27.9	13.4	11.4	11.9	18.3
Total price (CZK) - 1 m^2	**46.4**	**17.2**	**36.1**	**47.1**	**22.7**	**19.3**	**20.1**	**30.9**
Total price (€) - 1 m^2	1.7	0.6	1.3	1.7	0.8	0.7	0.7	1.1



Conclusions

All the treatments led to decrease in herb layer coverage, namely *Calamagrostis* (see attachment A). To be able to evaluate the impact of tested treatments, it is, however, necessary to continue with the experiments in next years. For common management of sites "contaminated" by undesirable species, repeated mowing seems to be the most effective method. According to the experience from similar localities in the surroundings, mulching seems to be very promising (we do not have our own results from the plot yet, the impact of treatment is very slow). From the perspective of *Calamagrostis* reduction, good results were brought by soil disturbing by digging and in next years, we plan to combine it with sowing or mulching. Despite the low price, application of herbicide is due its negative impacts inconvenient for large-scale usage. Nevertheless, it is suitable for fighting against beginning of invasions and expansions.

Diagram of experimental plots – site A

Herbicide	Burning
Mowing	**CONTROL**

↑ **E**
→ **S**

Diagram of experimental plots – site B

Stones

Rhinanthus sowing

TEMPORARY DUMP OF SOIL

CONTROL
Turf disturbance
Black textile foil
Felt with foil
Mulching
II. mowing
Herbicide

↑ **N**
→ **E**

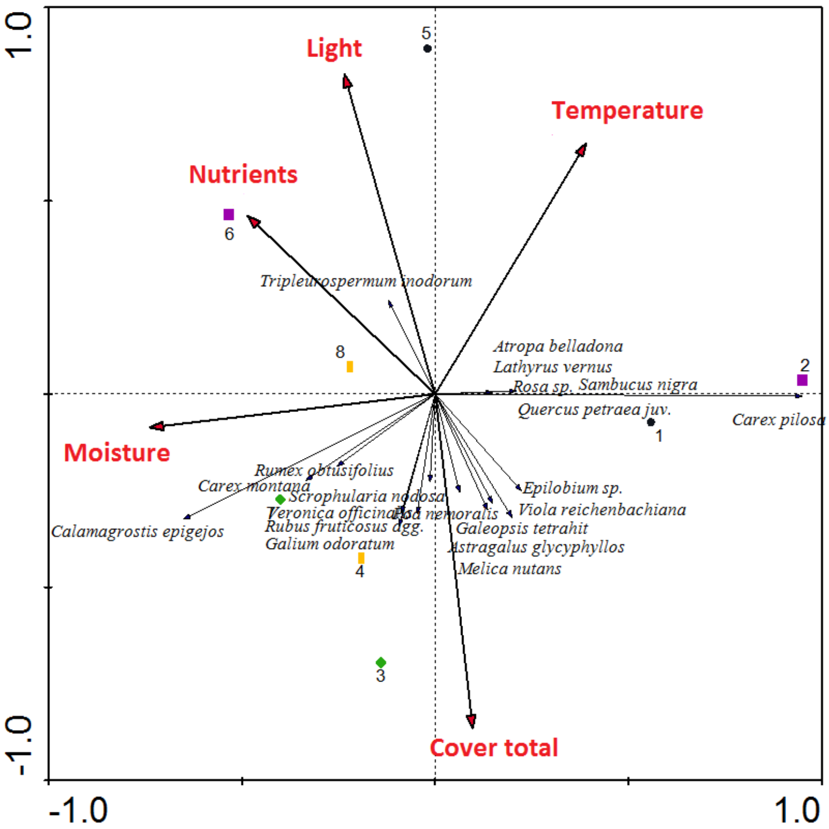
Burning

Experimental sowing

Mix I	**Mix II**	**Mix III**	
Festuca rupicola 48 %	*Festuca rubra* 60 %	*Anthyllis vulneraria* 43 %	**CONTROL**
Lolium multiflorum 25 %	*Plantago media* 5 %	*Plantago media* 5 %	
Anthyllis vulneraria 27 %	*T. incarnatum* 35 %	*Festuca rupicola* 52 %	

↑ **W**
→ **N**

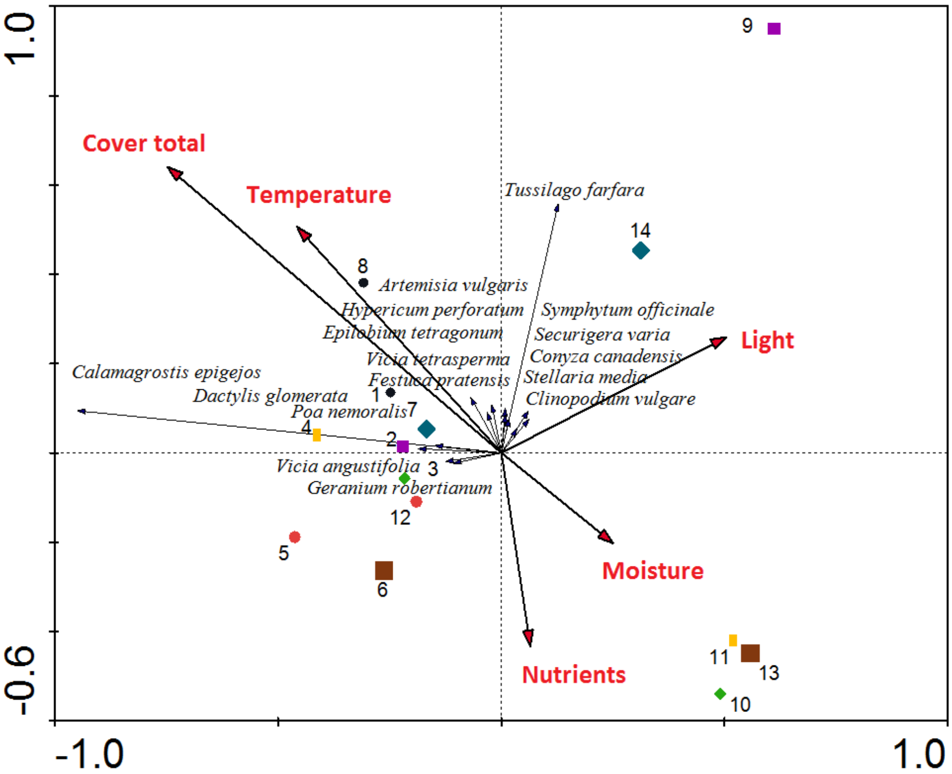
Ordination diagram of the unconstrained PCA analysis (Principal Component analysis) – experiments on the glade (plot A)



The length of the gradient acquired after the DCA analysis (Detrended Correspondence Analysis) was shorter than 3 SD and that is why we used a linear method. The data were square root transformed and on the diagram there are displayed only species with the highest fit. All environmental variables were displayed passively – cover total (estimated during the field sampling) and Ellenberg indicator values (EIH) for light, temperature, nutrients and moisture (non-weighted average for the relevés from the values of each species; values were calculated in the programme Juice). Same colours were used for the doubles of the same plots before and after the experimental interventions (black – herbicide, purple – burning, green – control and yellow – mowing). The cumulative percentage of the explained variance for the first axis was 25.7% and together with the second 47.1% (a strong part of the variance was also explained by the third and fourth axiss – together 65.4% and 76.2%). Then variability related to the environmental variables of the first axis explained 29.1%, together with second 52.2% and third 71%.

This ordination analysis which should show main gradients in the distribution of the studied plots and its species did not exactly explain what we expected. Relevés are not very similar, even if we compare the same control plots. Plots from the beginning of the experiment and control are displayed on the right and down left part of the diagram; there were common higher cover of the herb layer (moss layer was negligible) and partly also moisture, together with the biggest cover of our problematic species *Calamagrostis epigejos*. Forest survivors (e.g. *Carex pilosa* and *Lathyrus vernus*) almost disappeared after the interventions. It seems that nutrients demanding species prevailed even after the interventions as were burning and mowing (6, 8). In this faze the most effective was herbicide (5). There is not clear pattern in vegetation structure and its reaction on the experiments and it is obvious that more years for plot studying are needed.

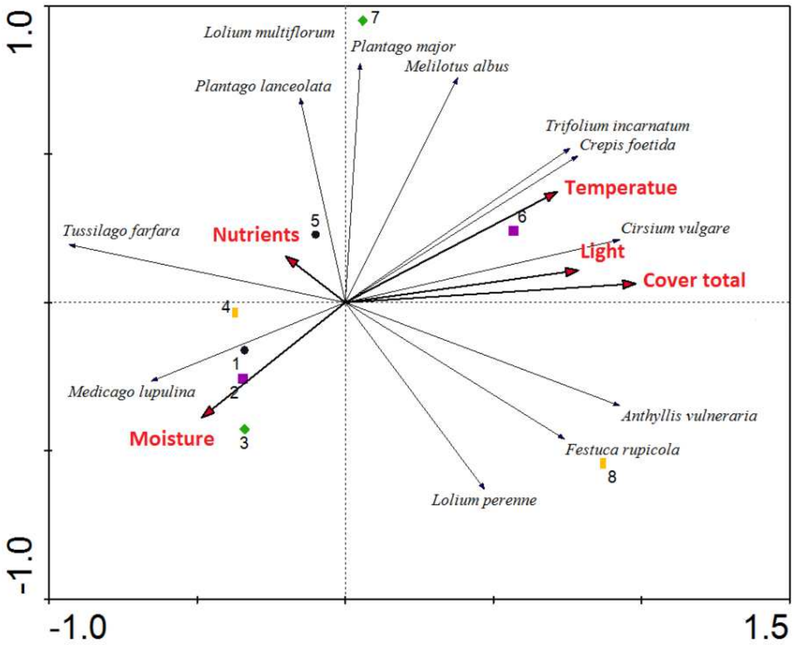
Ordination diagram of the unconstrained PCA analysis (Principal Component analysis) – experiments on the periodical soil heap (plot B)



The length of the gradient acquired after the DCA analysis (Detrended Correspondence Analysis) was shorter than 3 SD and that is why we used a linear method. The data were square root transformed and on the diagram there are displayed only species with the highest fit. All environmental variables were passively displayed – cover total (estimated during the field sampling) and Ellenberg indicator values (EIH) for light, temperature, nutrients and moisture (non-weighted average for the relevés from the values of each species; values were calculated in the programme Juice). Same colours were used for the doubles of the same plots before and after the experimental interventions (black – control, purple – digging, green – covering by geotextile, yellow – covering by textile with foil on the top, red – double mowing, brown – herbicide, blue – gravel). The cumulative percentage of the explained variance for the first axis was 39.3% and together with the second 55.5%; variation related to the environmental variables of the first axis explained 56.9%, together with second 76.6%. Then it does not rise too much.

This analysis is same, indirect, and it should show us and underline only the main relevés × species distribution patterns before and after the interventions. On the diagram we can see expected higher similarity in the same relevés taken before the experiments and both control plots (left diagram side), where *Calamagrostis epigejos* dominated. Nutrients and light demanders (according the passively used EIH values) prevailed on the plots where we used geotextile, textile with foil on its top (water evaporation was blocked) and surprisingly also after the herbicide application. On the other hand, the light demanding species were supported by the digging and gravel covering. But *Tussilago farfara* started to dominate there on the both plots. Temperature seems to be correlated with the total cover but this could be only ephemeral effect. Again, this will be clearer after several repetitions.

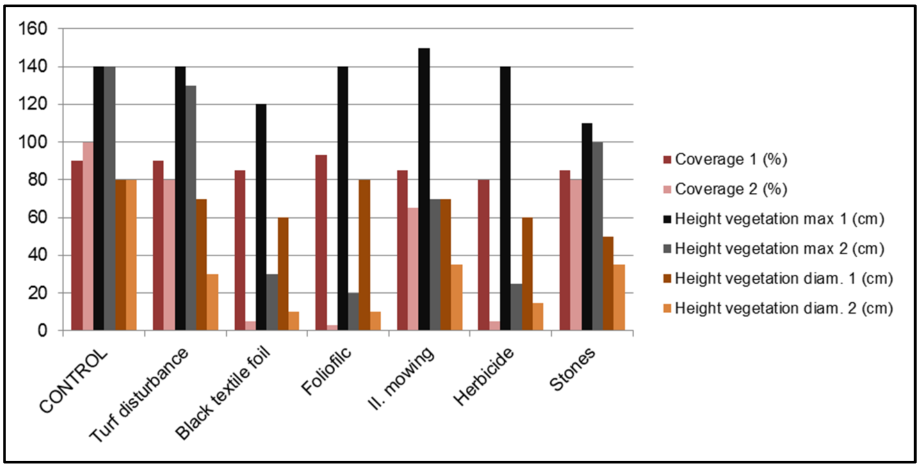
Ordination diagram of the unconstrained PCA analysis (Principal Component analysis) – sowing experiments



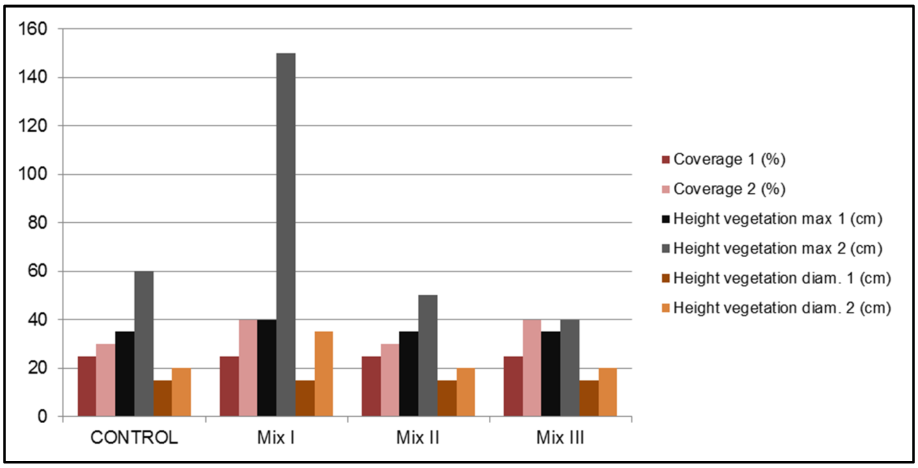
The length of the gradient acquired after the DCA analysis (Detrended Correspondence Analysis) was shorter than 3 SD and that is why we used a linear method. The data were square root transformed and on the diagram there are displayed only species with the highest fit. All environmental variables were passively displayed – cover total (estimated during the field sampling) and Ellenberg indicator values (EIH) for light, temperature, nutrients and moisture (non-weighted average for the relevés from the values of each species; values were calculated in the programme Juice). Same colours were used for the doubles of the same plots before and after the sowing (black – control, purple – mix 3, green – mix 2, yellow – mix 1). The cumulative percentage of the explained variance for the first axis was 41.6% and together with the second 59.7%; variation related to the environmental variables of the first axis explained 46.1%, together with second 62.7%.

Ordination divided the relevés like that those from the beginning are according the expectation clustered (*Tussilago farfara* dominated everywhere). Dissimilarity is higher between the relevés sampled after the digging and sowing. If we look on the environmental values, the temperature, light and total cover rise on the right side of diagram. There are displayed our experimental species (*Trifolium incarnatum*, *Anthyllis vulneraria* and *Festuca rupicola*) and more thermophilous ruderal species (*Crepis foetida* subsp. *rhoeadifolia* and *Cirsium vulgare*). Total cover was raised due to progress in a vegetation season but also thanks to the sowing (it was around 5–10%). Nutrients seem to be not too much important (soil is poor) and moisture distinctly rise to the left diagram side, close to the firstly sampled relevés where *Tussilago farfara* and *Medicago lupulina* dominated. It is possible that our experimental plants partly drained the water and this fact could figure like a barrier for some competitively strong moisture demanding species.

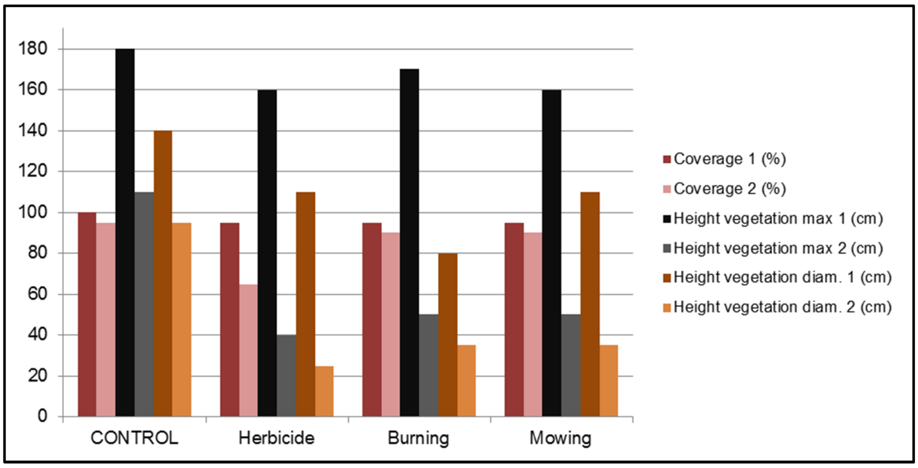
Analysis of coverage after experiments



Terrace on a dump



Sowing



Experiments on the area which will be quarried

Photodocumentation

Terrace on a dump

CONTROL – 10. 5. 2016

CONTROL – 1. 9. 2016

Turf disturbance – 10. 5. 2016

Turf disturbance – May 2016

Turf disturbance – July 2016

Turf disturbance – 1. 9. 2016

Black textile foil – 10. 5. 2016

Black textile foil and Felt with foil


Black textile foil – 1. 9. 2016


Felt with foil – 10. 5. 2016


Felt with foil – 1. 9. 2016


Herbicide – 10. 5. 2016


Herbicide – June 2016


Herbicide – 1. 9. 2016


Stone – 10. 5. 2016


Stone – May 2016


Stone – May 2016


Stone – 1. 9. 2016


Mulching


Burning


Mowing

Sowing

Default status – 10. 5. 2016

Preparation of plots – May 2016

CONTROL – 1. 9. 2016

Mix I (*Festuca rupicola, Lolium multiflorum, Anthyllis vulneraria*) – 1. 9. 2016

Mix II (*Festuca rubra, Plantago media, Trifolium incarnatum*) – 1. 9. 2016

Mix III (*Anthyllis vulneraria, Plantago media, Festuca rupicola*) – 1. 9. 2016

Experiments on the area which will be quarried


CONTROL – 29. 6. 2016


CONTROL – 14. 9. 2016


Herbicide – 29. 6. 2016


Herbicide – 14. 9. 2016


Burning – 29. 6. 2016


Burning – 14. 9. 2016


Mowing – 29. 6. 2016


Mowing – 14. 9. 2016

APPENDIX D – PROPOSALS FOR IMPROVING BIODIVERSITY

*The study clarifies the **possibilities** and summarizes our suggestions for general measures to be taken in the **area of interest A**. It does not only deal with one part of the reclamation process, but considers it in a broader space-time continuum. We expect the measures to last for at least 15–30 years.*

The basic phases of the process are:

- Mining preparation
- The course and end of mining
- Restoration

Further interventions that are a part of the process:

- Stabilization and remediation of temporary soil dumps
- Follow-up care with biotopes
- Control and elimination of invasive/expansive plant species

1. Biomonitoring

At the beginning, one must keep detailed track of vegetation and the plant and animal species (biologically valuable or potentially problematic) that can be found in the area of the quarry and its immediate surroundings. As part of this, a few goals that we would like to achieve during restoration, will be set. Monitoring should then be carried out both during the mining and in the years after its end.

2. Preparation before vegetation removal works

If the area designated for mining still has any woody plants, felling needs to be done. It is important that the intervention be timed well so that the area does not lay bare for an unnecessary long time. The felling should be done gradually based on the overburden. The areas that have already been deforested and where undesirable species have expanded already, measures leading to their elimination are suitable. The most efficient measure is mowing, including raking and the removal of the mowed biomass. Some species (*Rubus fruticosus* agg., *Sambucus ebulus*) cannot be dealt with by mowing only. This is where we can use chemical substances. However, they should never be applied to large areas, only dot spraying up to 1 m^2 should be done. The chemical method should always be the last resort, for it is not selective and the area might contain important or even protected species, which would then get destroyed as well.

3. Grassing over/Mulching

If there is the danger that an area would remain without a woody cover for a longer period of time, it is a good solution to temporarily change it to a grass cover. A bare area is susceptible to attacks from undesirable species, which may even spread from there. For the process of grassing over, we designed our own mixture, the „*Starting cocktail*“. The mixture contains almost 90% grasses. We base this on the experience that grasses need quite a lot of water which they drain from their surroundings and limit other, often undesirable, species. Grasses can cover the area very fast, which will then become unavailable to many species. We cannot also forget their anti-erosion function. We chose the species and representation based on the experiment and prices. The mixture is affordable (6.7 CZK/m^2), the species should grow fast and prevent undesirable species from entering.

Overview of species in Starting cocktail mixture, their volume and price

Plant species	Volume [%]	Volume in 1 kg [kg]	Price for 1 kg [CZK/kg]	Mixture price (w/o VAT) [CZK/mixture]
Festuca rubra	43,0 %	0,4	92,0 CZK	39,6 CZK
Lolium multiflorum	32,0 %	0,3	44,0 CZK	14,1 CZK
Festuca rupicola	14,3 %	0,1	1027,0 CZK	146,9 CZK
Anthyllis vulneraria	10,0 %	0,1	280,0 CZK	28,0 CZK
Plantago media	0,7 %	0,0	5850,0	41,0 CZK
Total	**100,0 %**	**1,0**		**269,5 CZK**

The second option of preparation is mulching with a material made up of grass-herb vegetation without undesirable species. Thus the sowing of locally significant and protected species is also under way. Mulch can hold humidity, which means it created ideal conditions for sprouting (in an usually scorched quarry). A certain alternative would also be to use the chopped down woody plants for stump shaping, for example *Salix caprea*, *Populus tremula*, *Carpinus betulus*. In this case, it is more suitable to leave the area without any interventions and have some woody plants grow on it.

4. Overbuden and soil deposition

Before overburden itself and before its removal, it is important that the soil is biologically stabilized – in our case that is without a seed bank of invasive and expansive plants. It is optimal to carry out overburdening in phases. When depositing the soil, it is necessary to place/"bury" the top part of the overburden into the lower part along with the undesirable species and that is including their roots and rhizomes so that they cannot grow through to the top.

5. Stabilization and remediation of temporary soil dumps

In permanent overburden dumps, reclamation suitable for nature that would stabilize the soil dump in the long run should be done within approximately the next two years. Even though temporary soil dumps do not last, even they need to be biologically stabilized (carry out a „temporary reclamation"). The ultimate aim is not to create a lasting culture like a forest. A suitable method of stabilization is grassing over by using the *Starting cocktail* mixture. The soil dump can be mulched over with hay or covered with a 40–50 cm of unusable gravel. Soil dumps that have not been stabilized need to be remedied first. The best method is to mow with a brush cutter, which also eliminates the shorter woody plants (juveniles and shrubs). It is key to remove the mowed biomass. Should any resistant plants appear, herbicide dot spraying can be applied. When it comes to invasive woody plants (e.g. *Robinia pseudacacia, Populus* ×*canadensis*), mechanical removal and a subsequent application of a herbicide on the stump is more suitable. An accompanying tool for remediation is to sow the semiparasitic *Rhinanthus* in areas where *Calamagrostis epigejos* grows. The precondition for this is to prepare the area by mowing, thorough digging and disrupting the turf. The temporary soil dumps need to be mowed continuously. We suggest mulching the mowed mass for the first two years. In the following years, it is important to rake and transport they hay. The reasons for digging is the lower amount of nutrients. Another possible tool for maintenance is a one-time pasture. Controlling the invasive and expansive plants is an absolute necessity.

6. Mining itself

The process of mining is important, above all the direction and the advancement as a follow-up to the spreading of soil. In this case we propose one direction of mining - that is from the western to the central quarry. In terms of time saving and soil movement, we consider it optimal if the mining is followed by spreading of the soil right away. We count on the fact that the area will be covered with stabilized soil from the overburdens. We estimate that such spreading would last up to a few years. We suggest that individual parts be spread gradually in stages and then restored. This is how we achieve a certain space-time diversity in new areas.

7. Terrain modelling

Our proposal is based on a partial restoration of the original terrain. The aim is the creation of two main slopes (oriented to the southwest and southeast). A small saddle (in image visualization number❶) will arise on the top and it will be made up of a platform with a slight tilt from the north towards the south. The slopes will not be monolithic. It will be a complex of a few slopes with various orientations. To stabilize the soil, the slopes will be equipped with elements connected with the nature (artificial erosion rills❷, benches, hollows, micro-terraces❸). The areas will be covered with various fractions of stones – from gravel all the way to large boulders❹. In small parts, it is suitable to preserve some of the uncovered quarry walls❺.

8. Biological reclamation

The aim of reclamation is to create a fine-grained mosaic of biotopes (from steppe❻ through forest-steppe❼ all the way to forest communities❽) through restoration that are familiar to the nature. We would like to allow the most space possible for succession. However, we count on the fact that the brought soil will be stabilized and will already contain reserves of seeds of suitable species. Therefore we suggest that the only 20% of the area will be reserved for the support of succession (planting of woody plants, mulching and additional sowing). Since both northern and southern parts will turn into a forest cover, we suggest that the slope edges be directed towards the forest. The closer to the centre of the slope, the more deforested station there should be. The base of the soil dump will be made up of a bio-corridor❾ which will connect the forest covers.

9. Stabilization of forest cover

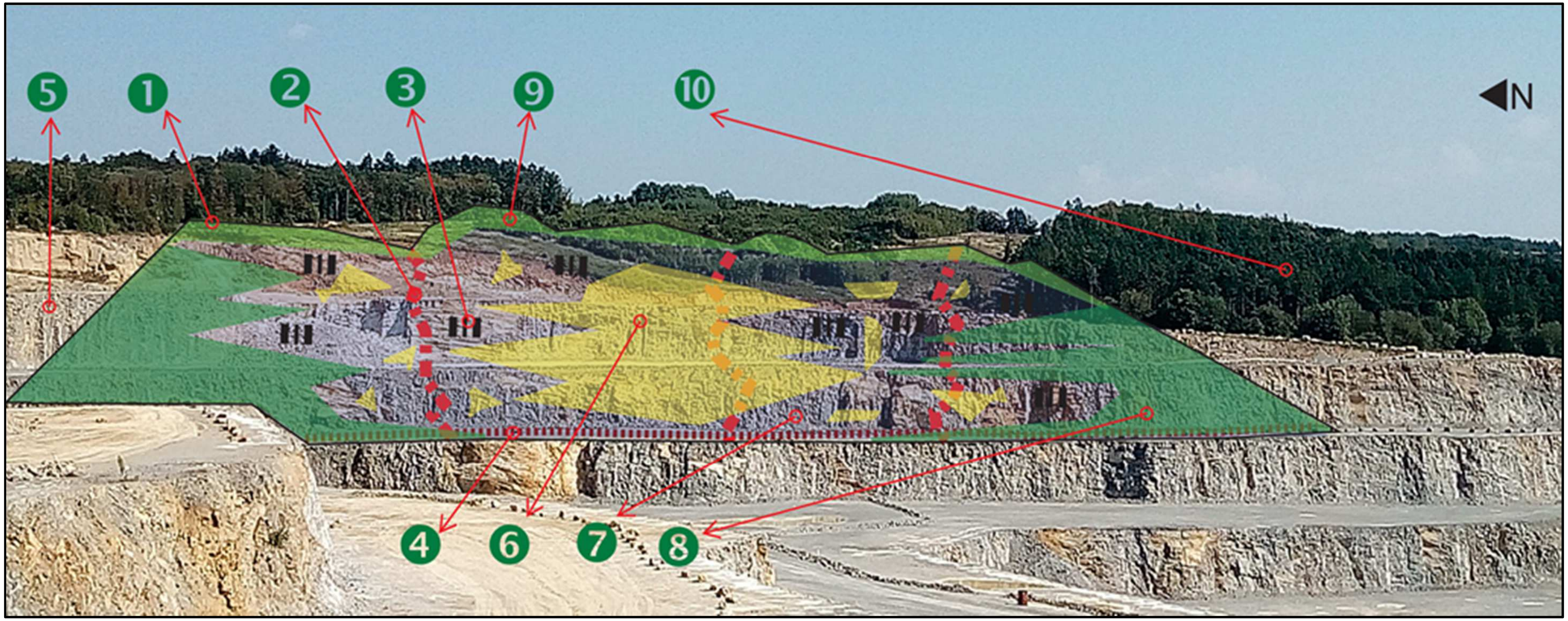
Because of the excavation of the area above the forest cover, the water regime will probably be influenced, especially in parts with conifers (spruce, larch, pine). The natural oak-hornbeam part is more stable, even in the parts directed towards the central quarry. This is why it will be necessary to change the economic target of the cover and change it into deciduous cover under the selective economy. Specifically, we propose that woody plants that are better at withstanding dryness⓾ be supported. Through the gradual removal of conifers, new space for juvenile deciduous trees in the undergrowth (oaks, lindens, willows, aspens, checker trees). As an addition, planting lindens, oaks, field maples, cherry trees and checker trees in advance will be suitable.

10. Taking care of restored areas

Taking care of restored areas and their surroundings will be done in the form of environmentalist management. The deforested areas will have to be mowed mosaically. To preserve the open spaces, disruption of the turf will have to be carried out. Pastures are also a suitable alternative. Forest covers should be maintained as middle-height forest – coppicing with reserved trees as a traditional woodland management that can on top of all provide firewood (= modern biomass heating). A necessary part is the continuous control over undesirable plants.

Visualization of area before mining

Visualization of modelling and biological part



❶ The top part will geomorphologically varied and it will be slanted slightly to the south.
❷ Vertical stabilization will be using artificial erosion furrows.
❸ The slopes will be supplemented by small terraces ("micro-terraces").
❹ The lower part of the slope will form stones.
❺ Selected rock walls remain intact.
❻ The middle part and the other part will be scattered steppe (yellow).
❼ Steppe will roam freely in the forest steppe communities (purple).
❽ Margins slopes are forests (dark green).
❾ On top of depositions will be bio-corridor, which will connect the two forests (light green).
❿ Forest cover in the southern part will stabilize and hardwoods will be supported.

APPENDIX E – SEMINAR EXPERIMENT IN BIODIVERSITY MANAGEMENT

The seminar called Experiment in Biodiversity Management: Innovative Approaches in Ecological Restoration was organized in Mokrá-Horákov in the South of Moravia on 14 September 2016. The main aim of the meeting was to share experiences about the close-to-nature recultivation of a limestone quarry located nearby. Almost three dozens of visitors consisted mostly of students of the Gardening Colledge in Rajhrad, South Moravia. But there were also some local conservationists and stakeholders present in place.

The first part of the seminar consisted of presentations led mainly by the members of the preparation team of the project of the same name which took part in the Quarry Life Award competition. After the opening speech given by Karel Lorka, the director of the company Ceskomoravsky sterk, Kamila Botkova who is a specialist in biodiversity appeared on stage. The name of her presentation was “Biodiversity in the main role” and she briefly introduced the competition Quarry Life Award and the main reasons, why close-to-nature recultivation is preferable to the classic technical recultivation. The second person to take the floor was the organizator of the seminar Vilem Jurek who is a specialist in recultivation at The Faculty of Forestry at Mendel University in Brno (MENDELU). He explained the basis of the innovative approach of recultivation which is used in the quarry Mokra as a part of a project in his presentation called “Why unconventional approaches to biodiversity conservation?” The key innovation lies in a key management of the vegetation na skryvce right before its extraction and its placement on a dumping ground in order to prevent reed grass and oat grass from further spreading. The third presenter was Veronika Kalnikova from The Faculty of Science at Masaryk University in Brno (MU), who briefly characterized the main invasive and expansive species of plants in the

area of the Mokra quarry. The last part of the first session was devoted to the presen-tation given by Pavel Vesely from The Faculty of Science at MU, who introduced some spe-cific experiments conducted on research pads at the Mokra quarry.

After the break, Hana Cihlarova from The Faculty of Forestry at MENDELU continued with her presentation “Reed grass versus oat grass”, in which she described the soil characteristics of the spontaneously renovated areas of the Mokra quarry and clarified which of these two types of grass is more suitable for this type of soil. Then Pavel Vesely took the floor again to explain the audience which types of stabilization of cover on research pads situated on quarry´s (temporary) dumping grounds. The morning program was concluded with the presentation of Vilem Jurek who introduced some ways of effective preparation of terrain before mining and how this influences the recultivation of the Mokra quarry.

The afternoon was devoted to the field excursion right in the Mokra quarry. The presenters gave a tour to those interested and showed them some specific research pads, where they experiment with different types of management - burning, sprinkling with herbicide, mowing, mulching with hay, covering by gravel or fabric of different characteristics. Next, they took the participants to the dumping grounds where various types of plants are sowed to stabilize the cover. As a final part of the afternoon programme, they all moved to the Eastern part of the quarry where they could have a look at some fine examples of old close-to-nature recultivations.

APPENDIX F – NOT ONLY PLANTS…

Our study has been focused mainly on the plant species. But animals are also important part of the quarries biodiversity. So we present here few photos with interesting discoveries from the animal kingdom.

Lycaena phlaeas

Apatura iris

Vanessa cardui

Bufo viridis

Little roe deer (*Capreolus capreolus*)

Camera trap registered interesting photos. Two cameras were situated in the forest in the southern part of area A for three months.

Vulpes vulpes

Capreolus capreolus

Capreolus capreolus

Lepus europaeus

Capreolus capreolus

Sus scrofa